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RESEARCH ARTICLE

Turtles in trouble. Conservation ecology and priorities for Australian freshwater turtles

Kristen Petrov[1] | **Sarah Sutcliffe**[2] | **Helen Truscott**[2] | **Cat Kutay**[2] | **Carla C. Eisemberg**[2] | **Ricky J. Spencer**[1] | **Ivan Lawler**[3] | **Deborah S. Bower**[4] | **James U. Van Dyke**[5] | **Arthur Georges**[6]

[1]School of Science, Western Sydney University, Richmond, New South Wales, Australia

[2]Research Institute for the Environment and Livelihoods, Charles Darwin University, Darwin, Northwest Territories, Australia

[3]Department of Climate Change, Energy, the Environment and Water, Canberra, Australian Capital Territory, Australia

[4]Department of Zoology, School of Environmental and Rural Science, University of New England, Armidale, New South Wales, Australia

[5]Centre for Freshwater Ecosystems, School of Agriculture, Biomedicine and Environment, La Trobe University, Wodonga, Victoria, Australia

[6]Institute for Applied Ecology, University of Canberra, Canberra, Australian Capital Territory, Australia

Correspondence
Arthur Georges, Institute for Applied Ecology, University of Canberra, Canberra, ACT 2601, Australia.
Email: georges@aerg.canberra.edu.au

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Abstract

The Australian freshwater turtle fauna is dominated by species in the family Chelidae. The extant fauna comprises a series of distinct lineages, each of considerable antiquity, relicts of a more extensive and perhaps diverse fauna that existed when wetter climes prevailed. Several phylogenetically distinctive species are restricted to single, often small, drainage basins, which presents challenges for their conservation. Specific threats include water resource development, which alters the magnitude, frequency, and timing of flows and converts lentic to lotic habitat via dams and weirs, fragmentation of habitat, sedimentation, nutrification, and a reduction in the frequency and extent of floodplain flooding. Drainage of wetlands and altered land use are of particular concern for some species that are now very restricted in range and critically endangered. The introduced European red fox is a devastatingly efficient predator of turtle nests and can have a major impact on recruitment. In the north, species such as the northern snake-necked turtle are heavily depredated by feral pigs. Other invasive animals and aquatic weeds dramatically alter freshwater habitats, with consequential impacts on freshwater turtles. Novel pathogens such as viruses have brought at least one species to the brink of extinction. Species that routinely migrate across land are impacted by structural simplification of habitat, reduction in availability of terrestrial refugia, fencing (including conservation fencing), and in some areas, by high levels of road mortality. We report on the listing process and challenges for listing freshwater turtles under the Australian Environment Protection and Biodiversity Conservation Act, summarize the state of knowledge relevant to listing decisions, identify the key threatening processes impacting turtles, and identify key knowledge gaps that impede the setting of priorities. We also focus on how to best incorporate First Nations Knowledge into decisions on listing and discuss opportunities to engage Indigenous communities in on-ground work to achieve conservation outcomes.

KEYWORDS
Chelidae, indigenous knowledge, listing, threatened species

INTRODUCTION

Australia is an island continent. Isolation over most of the Cenozoic has allowed the Australian biota to progress down unique evolutionary trajectories, leading to high endemicity. Australian freshwater turtles are no exception. All but one species belong to the family Chelidae otherwise, found only in New Guinea, East Timor, the Island of Roti, and South America. Chelids are unknown outside their present range even as fossils (Gaffney, 1979, 1981; Pritchard & Trebbau, 1984), so they are clearly of Gondwanan origin. The living chelid turtles of the Australasian region and South America appear to be reciprocally monophyletic (Georges et al., 1999; Seddon et al., 1997), with the Western Swamp turtle being the most basal lineage of the Australian radiation (Zhang et al., 2017). The pig-nose turtle, *Carettochelys insculpta*, is also restricted to Australia and New Guinea (Georges & Wombey, 1993), but the family to which it belongs (Carettochelyidae) was once widely distributed across the northern hemisphere (Joyce, 2014). *Carettochelys insculpta* has long been a resident of the Australasian region, represented by fossils from the upper Miocene of southern New Guinea (Glaessner, 1942) and from the upper Miocene/lower Pliocene of southern Australia (Rule et al., 2022).

Several factors have shaped the freshwater turtle fauna of the Australasian region. Australia is not only an island continent of long-standing isolation but also a relatively stable intraplate continental region. The interior of Australia has been largely devoid of major mountain building for the last 200 Myr, with most uplift restricted to the eastern margin (Blewett et al., 2012). This relative stability extends to Australia's rivers and associated drainage basins, their spatial and physical relationships are affected by relatively recent volcanism and basaltic extrusions, cyclic sea level change, and climatic variation in rainfall in what is a landscape of exceptionally low relief. Most of Australia avoided the physical rigours of the last ice ages, with glaciers limited to the south-eastern highlands. Instead, the Pleistocene and Holocene ice age impacts were primarily cycles of aridity linked to the interglacial cycles (Blewett et al., 2012), overlaid on a trend of progressively increasing aridity. This progressive aridity, beginning in the late to mid Miocene (12–5 Mya) and more recently over the past 15 000 years, is thought to have exacted a toll on freshwater turtle biodiversity in Australia, as evidenced by the diverse fossil record and the more widespread distributions across the continent (Gaffney et al., 1989; Rule et al., 2022). The current fauna comprises a series of distinct lineages, each of considerable antiquity, relicts of a more extensive and perhaps diverse fauna that existed when wetter climes prevailed (Georges, 1994). Those represented by monotypic genera include (a) the western swamp turtle, *Pseudemydura umbrina*, now restricted to a few localities near Perth in Western Australia; (b) the Fitzroy River turtle or white-eyed river diver, *Rheodytes leukops*, restricted to the Fitzroy-Dawson drainage of central coastal Queensland; (c) the Mary River turtle, *Elusor macrurus*, restricted to the Mary River drainage of south coastal Queensland; and (d) *Carettochelys insculpta*, restricted in Australia to a few of the larger rivers of the Northern Territory, though widespread and abundant in southern New Guinea. Thus, half of the genera are monotypic and highly distinctive; their relationships and affinities remain unclear.

The remaining elements of the Australian freshwater turtle fauna include a relatively recent radiation of species in the genus *Emydura*, which occupy a range of rivers, waterholes, impoundments, and permanent wetlands across south-eastern, eastern, central, and northern Australia. The southern *Emydura* epitomize the dynamic interaction of climate and the exceptionally low relief of the Australian landscape, with several lineages evolving along trajectories towards speciation but held back by episodic rainfall that opens avenues for dispersal (so-called portals) and episodic geneflow on a range of timescales from contemporary to Pleistocene (Georges, Gruber, et al., 2018). The northern species and subspecies of

Emydura subglobosa provide an excellent example of how turtle diversity in Australia has been influenced by the series of interglacial sea level changes that have established and obliterated Lake Carpentaria, which at times supported an extensive system of freshwaters embedded in a terrestrial tropical savannah to connect southern New Guinea with northern Australia. An early incursion appears to have established the Worrells turtle *Emydura subglobosa worrelli*, in the rivers draining into the now Gulf of Carpentaria, and a more recent incursion has a small population of the red-bellied turtle *Emydura subglobosa subglobosa*, in the Jardine River system at the tip of Cape York.

The genus *Elseya* in Australia comprises a series of riverine species in two major clades (Georges & Adams, 1992). Species of the subgenus *Pelocomastes* occupy eastern Australia (the white-throated snapping turtle *Elseya albagula* and the Irwins snapping turtle *E. irwini*) and the rivers draining into the Gulf of Carpentaria (the Gulf snapping turtle *Elseya lavarackorum*). The subgenus *Elseya* comprises a species complex currently referred to as the northern snapping turtle *Elseya dentata*, and the yellow-bellied snapping turtle, *Elseya flaviventralis* in the rivers draining Arnhem Land. The genus *Myuchelys*, the species of which were once included in *Elseya* but were not particularly closely related to them, comprise the widespread species complex *Myuchelys latisternum* (common sawshell turtle), and three species with restricted distributions in the Bellinger River (the Bellinger River helmeted turtle *M. georgesi*), the Manning-Barnard drainage (the Manning River turtle *M. purvisi*), and the headwaters of the northern basin of the Murray-Darling drainage (the western sawshell turtle *M. bellii*), respectively.

Finally, the Australian turtle fauna is perhaps best known for species that have developed distinctively long necks, the *Chelodina*, which comprise three major clades. The subgenus *Chelodina* (long-neck turtles) includes three species occupying eastern and south-eastern Australia (the eastern long-neck turtle *Chelodina longicollis*), northern Australia (the northern long-neck turtle *Chelodina canni*), and western Australia (the western long-neck turtle *Chelodina steindachneri*). These have moderately long necks and are carnivorous foragers. The second major clade, subgenus *Chelydera* (snake-neck turtles), occupies south-eastern Australia (the broadshell turtle *Chelodina expansa*) and northern Australia (the northern snake-neck turtle *Chelodina rugosa* and the sandstone snake-neck turtle *C. burrungandjii*). Kuchling's snake-neck turtle, *Chelodina kuchlingi*, is extremely rare, known only from the Ord River drainage of northern Australia (Kuchling, 2020), and possibly extinct. These species have exceptionally long necks and are carnivorous ambush predators. The third clade is monotypic (the oblong turtle *Chelodina oblonga*, subgenus *Macrochelodina*), one of two species endemic to the southwest corner of Western Australia (the other being *Pseudemydura umbrina*).

Australian freshwaters are particularly imperilled by a combination of low and unpredictable precipitation, potentially exacerbated by climate change, and aggressive water resource development that pushes rivers and wetlands beyond their capacity to deliver environmental services and maintain biodiversity (Georges & Cottingham, 2002). Our freshwater turtles are also imperilled by these changes to their habitats – by reduced water availability for wetlands, altered magnitude, frequency, and timing of flows, and in water quality – compounded by the often-restricted ranges of a highly catchment endemic, relictual freshwater turtle fauna. For these reasons, our freshwater turtle fauna is unfortunately overrepresented in the threatened species list under the Australian *Environment Protection and Biodiversity Act 1999* (hereafter EPBC Act), a situation characteristic of turtle faunas globally (Stanford et al., 2020). The turtles are in trouble.

In this paper, we address the topic of conservation and management of Australia's uniquely distinctive freshwater turtle fauna. The work arises in part from the recent Species Expert Assessment Program (SEAP) conducted by the Australian National Government in the context of the EPBC Act 1999 (https://www.legislation.gov.au/Details/C2021C00182). We address the complexities that arose during this process, including the paucity of knowledge for many species that constrained assessment of their status and subsequent listing, relisting, or delisting, the taxonomic impediment and confusion arising from the plethora of new names erected with inadequate taxonomic support, and the challenges with effectively incorporating the knowledge of First Nations People. We draw upon the current draft Conservation Advice documents for species proposed to be listed or relisted, other earlier relevant documents (Cogger et al., 1993), and additional literature on the biological attributes of the species (that is, not restricted to the EPBC listing criteria) to provide a comprehensive account for all species of Australian freshwater turtle.

THE LISTING PROCESS

Assessments of species for listing under the EPBC Act are undertaken by the Threatened Species Scientific Committee established by the Australian Government to make recommendations to the relevant minister for a decision. In making their assessments, they use indicative thresholds that closely align with those established by the International Union for Conservation of Nature (IUCN) criteria for assessing a species for inclusion on the IUCN Red List (IUCN Species Survival Commission, 2012). On completing the assessment, the committee makes its recommendation in the form of a Listing Assessment, which outlines the eligibility for listing, and an associated Conservation Advice document identifying immediate conservation priorities, placed in the context of available scientific information.

Under agreements with the States on a Common Assessment Method (CAM, https://www.dcceew.gov.au/environment/biodiversity/threatened/cam, Accessed 19th May 2023), species are assessed at the national scale using common assessment criteria. The States or Territories typically take the lead on species endemic to their jurisdiction. In the case of species whose distributions overlap multiple jurisdictions, the Australian government, or by agreement a State or Territory, will take the lead on preparing the draft listing assessment and conservation advice for consideration by the Threatened Species Scientific Committee. The Australian Government may assist this process by letting contracts for species assessment plans and the preparation of Conservation Advice documents, as with the recent SEAPs, in response to the 2019–20 bushfires (https://www.dcceew.gov.au/environment/biodiversity/threatened/seap, Accessed 19th May 2023). The resultant draft documents are also passed to the respective States and Territories for input before going to the Threatened Species Scientific Committee. There is a public comment process to capture any additional perspectives that may have been missed during the processes outlined above. If a species has been nominated for inclusion on the list via the relevant scientific committees of the states or territories but is found to be data deficient, it cannot be added to the threatened list under the EPBC Act. There is also a process for delisting species, which requires that the proponent demonstrate that the species is no longer eligible under any of the five criteria. Data deficiency against those criteria is not considered sufficient justification to warrant delisting.

The criteria for listing under the EPBC Act are provided in the EPBC Regulations (EPBC, 2000). Although broadly similar, there are some differences in the criteria for listing species under the EPBC Act and the IUCN Red List. The EPBC Regulations 2000 limit the Threatened Species Scientific Committee in its ability to fully align with IUCN criteria. The five criteria are verbally equivalent to the IUCN criteria, but quantitative thresholds are provided only for Criterion 5 (inconveniently, IUCN labels criteria by letters, EPBC by numbers). Given this similarity, in practice, the IUCN quantitative thresholds and guidelines are now extensively used to apply the EPBC criteria. Thus, those provided by the IUCN guidelines for Criterion A are used against EPBC Criterion 1, B against 2 and so on. Importantly, IUCN Criterion D2, used to identify small or restricted populations, is not currently available for EPBC listing.

In application then, the central difference between the EPBC and IUCN listing criteria lies in the requirement for documented evidence against the criteria. The interpretation of the data against those criteria is very similar. The emphasis on weight of evidence is stronger than for the IUCN Red Listing because the determinations under the EPBC Act have regulatory effect and are subject to legal challenge. Authoritative expert opinion can contribute to Conservation Assessments provided that opinion is supported by evidence and interpretation. The weight of opinion in the absence of evidence cannot be easily incorporated, and expert elicitation that is of value in other contexts (Martin et al., 2012) is rarely used.

TAXONOMIC IMPEDIMENTS

A first step in the listing process for any taxonomic group is to identify the species that are to be considered for listing. Under Section 528 of the EPBC Act, species and subspecies are species for the purpose of the Act, so both taxonomic levels can be listed. Section 517 of the EPBC Act allows that the Minister may, by legislative instrument, determine that a distinct population of biological entities is a species for the purposes of this Act. This aspect of the policy is applied very sparingly (http://www.environment.gov.au/biodiversity/threatened/species/pubs/197-rationale-part-range-listing.pdf), Accessed 24th May 2023. The concept of Evolutionarily Significant Unit (ESU, e.g. Moritz, 1994) is not formally recognized in the legislation. Despite widespread use in scientific circles and being broadly equivalent to subspecies, ESUs cannot automatically be assessed.

The Threatened Species Scientific Committee turns to the Australian Faunal Directory (AFD, https://biodiversity.org.au/afd/, Accessed 19th May 2023) for a list of valid taxonomic taxa, valid in the biological sense, and their associated valid binomial names (valid in the sense determined by the International Union for Zoological Nomenclature, ICZN). Taxonomy is subject to continual change as new biodiversity and new insights come to hand, so changes can be requested of the AFD during the formulation of conservation advice.

The taxonomy of Australian frogs and reptiles, and especially turtles, is subject to taxonomic churn arising from the proliferation of works published outside the normal channels of scientific discourse and norms of practice (Kaiser et al., 2013). A large volume of works is published in journals for which the authors of articles and the editor are the same, are privately circulated, or are published in journals produced by a non-scientific society without adequate editorial expertise and dedicated to the works of one author and associated colleagues (Wüster et al., 2021). While the names are arguably erected in accordance with the ICZN Code, the associated taxa are often erected without defensible scientific evidence or adequate diagnosis (see Thomson et al., 2023). Taxonomy matters. Early taxonomic uncertainty over the taxon *Chelodina kuchlingi*, since confirmed as a distinct species by some painstaking mitochondrial sequence studies of museum holotypes (Kehlmaier et al., 2019), led to the species being omitted from environmental assessments for the Ord River stage 2 development in northern Australia (Kinhill Pty Ltd, 2000), an unfortunate lost opportunity to address the data deficiencies and its conservation needs.

The first step in the Freshwater Turtle SEAP described in this paper was to determine which species have contemporary support and which are shadows established outside the mainstream scientific literature for which the evidence for their existence would not stand up to challenge by those organizations impacted by the provisions of the EPBC Act. This process has been since simplified by the establishment of an Official List of Species by the Australian Society of Herpetologists (ASH, 2022). Through this instrument, the Society has scientific oversight of the species of Australian reptile and amphibian for which defensible scientific evidence for their existence has been published. Unfortunately, this list was not available at the time of the 2022 freshwater turtle SEAP; however, the decisions we made on the pool of species with scientifically defensible diagnoses and descriptions (Table 1) concur with the ASH Official List of Species (ASH, 2022). Refer to the fully annotated official list for justification of the decisions made.

OTHER KNOWLEDGE GAPS FOR LISTING

The two main impediments to action on the listings were poor estimates of population size and other demographic parameters and the availability of point distributional data. While Population Viability Analyses (PVAs) were successful in predicting future population decline for some species (i.e. *Myuchelys georgesi*), in most cases the data in support of the PVAs were insufficient to generate defensible input to relevant selection criteria. Again, this was largely a result of poor contemporary population estimates that provided a baseline for modelling population growth, decline, and the probability of extinction. The PVA models also relied upon estimates of mortality across ages (i.e. egg, hatchling, juvenile, and adult) both in the context of threats (i.e. predation by European red foxes, *Vulpes vulpes*) and no threats. Given the similarities in the life-history traits of freshwater turtles (Congdon et al., 2018), mortality rates for well-studied species (i.e. *Myuchelys georgesi*) could be standardized across species; however, this compromised the accuracy of the PVA models to the point where the uncertainty in the modelling was unacceptable to the Threatened Species Scientific Committee in formulating their advice to the Minister. Research to obtain the necessary data for generating reliable predictions from PVAs is considered a high priority for species suspected of experiencing declines (Table 1).

Accurate and up-to-date point data, that is, geographic distributions as indicators for either extent of occurrence and/or area of occupancy, are very important for listing assessment. Declines or low population sizes in a portion of the range of a species need to be moderated by knowledge of the status across the species range. Baited remote underwater video surveillance (Coleman et al., 2023, this issue) and eDNA detection in natural waterways (Eiler et al., 2018; Raemy & Ursenbacher, 2018) are welcome advances to expand our knowledge of the distribution of freshwater turtles. While point data was available for each freshwater turtle species assessed, there was one instance (*Chelodina oblonga*, WA) where the point data and subsequent estimates of area of occupancy and extent of occurrence did not reflect the full extent of the species range. Surveys of *C. oblonga* in Western Australia have largely been confined to the Perth urban area, with survey efforts and data on population status and trends outside of this

TABLE 1 Species of Australian freshwater turtles and information relevant to assessing their conservation value and needs.

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Carettochelys insculpta** (pig-nose turtle)	Restricted to a few large drainages in the NT; large populations in southern New Guinea. Not considered rare because of substantial populations in New Guinea.	Highly distinctive phylogenetically. The sole surviving member of its family, once widespread in the northern hemisphere.	Obligate riverine species. Large size, palatability, ease of capture, and stereotyped nesting make this species attractive for exploitation by indigenous peoples. Preference for continuous year-long flows (spring-fed systems). Temperature dependent sex determination. Omnivore.	Habitat degradation and trampling of nesting banks. Water resource development. Climate change and its impact on population sex ratios.	Some Australian populations live in remote areas, including Kakadu National Park. Substantial extralimital populations in southern New Guinea.	Impacts of water resource development on habitat and connectivity. Effective monitoring of population trends in areas subject to altered land management practices.	Protection of riverine and riparian ecosystems from the impact of feral herbivores and stock throughout the species range and/or land clearing in buffer zones, particularly in the Daly River drainage. Manage the impact of trampling of nesting banks and feral pig predation on nests. Manage water resource development to avoid, as a high priority, cease-to-flow conditions in the Daly River during the northern dry season.	Monitor trends in sex ratios over time in the context of projections for climate change. Collect baseline data on population densities, movements, and habitat use in both wet and dry seasons.
Chelodina burrungandjii (sandstone snake-neck turtle)	Restricted to rain fed streams and billabongs of the sandstone plateaus of northern Australia. Not considered rare.	Not particularly phylogenetically distinctive. Member of the diverse clade of snake-necked turtles distributed across northern and eastern Australia and southern New Guinea.	Ambush predators are reliant on the high visibility of prey.	No current threats.	Located in remote and difficult to access regions of northern Australia. Levels of indigenous harvest are low.	Assessment of population numbers to serve as a baseline for future monitoring.	None required.	Poorly known. Basic research on its biology and life history would be an investment in the future.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Chelodina canni** (northern long-neck turtle)	Low abundances across an extensive range in northern Australia. Rarely encountered, but not considered rare.	Not particularly phylogenetically distinctive. Member of a diverse clade of long-necked turtles distributed across Australia, southern New Guinea, Timor, and Roti.	Ephemeral water specialists, uplands, and lowlands extending into semi-arid regions. Relies upon extensive overland movements and terrestrial aestivation (scale 5 yr) to cope with the unpredictability of the availability of ephemeral free standing waters. Obligate carnivore, forager.	Habitat simplification arising from overstocking and the consequent loss of potential terrestrial refugial opportunities. Altered surface flows in a landscape of exceptionally low relief impact patterns of drawdown and filling of ephemeral wetlands. Degradation of wetlands. Unseasonal fires.	Proliferation of water storages (farm dams and open storages) and other infrastructure (bores) improves water availability in the northern dry season.	Fill knowledge gaps in distribution as it relates to habitat attributes, estimate abundances, document nesting habitat, and seasonality of nesting in the context of the availability of standing water in the northern dry season. Identify dry season refugia.	Monitor water resource development where impacts are on dry season availability of free standing water in open woodland habitats. Protection of important wetlands and associated vegetation in dryland systems. Monitor frequency of road mortality as a potential future threat.	A better ecological understanding is required of how this species copes with the unpredictability of the cycles of wet and dry in the dryland systems of our north (e.g. Newcastle Waters). Habitat attributes that support high abundances are currently unknown. Triggers and conditions required for opportunistic nesting.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Chelodina expansa (broad-shell [snake-neck] turtle)	Widespread in south eastern Queensland and the MDB. Can be locally abundant. Not considered rare.	Not particularly phylogenetically distinctive. Member of the diverse clade of snake-necked turtles distributed across northern and eastern Australia and southern New Guinea.	Ambush predator reliant on high visibility of prey. Specializes on larger invertebrate and vertebrate prey. Exceptionally long incubation period for nests. Females often travel long distances (>500 m) overland to nest.	Movements along drainage lines are restricted in some areas by impoundments. Instream habitat simplification via channel modifications and disengaging. Altered food availability and accessibility arising from sedimentation and turbidification.	May have benefitted from the proliferation of carp, particularly in the MDB.	Undertake surveys to establish patterns of distribution and abundance across its range, and identify critical habitat for the species. Assess diets in areas of high abundance (e.g. Wentworth, NSW) and investigate reliance on European carp.	Resnagging. Riparian vegetation restoration. Water quality improvement, particularly in relation to sedimentation and turbidification. Continue to support community-led organizations and programmes such as Turtles Australia. Management of high road mortality areas identified on TurtleSAT or the Atlas of Living Australia.	This species is poorly studied and would benefit from a better understanding of the habitat requirements for instream survival and the attributes of habitat required for success in its autumn and winter nesting and protracted incubation periods. Improved knowledge of the impact of weirs and flow regulation.
Chelodina kuchlingi (Kuchling snake-neck turtle)	Population size is extremely low; distribution is extremely restricted. Extremely rare.	Not particularly phylogenetically distinctive. Member of the diverse clade of snake-necked turtles distributed across northern and eastern Australia and southern New Guinea.	Intrinsic vulnerabilities are not known.	Hybridization with *C. rugosa* following large-scale modification of its floodplain habitat through river damming and irrigation agriculture was identified as a potential cause of its decline.	Not applicable	Better characterize the diagnostic morphological characters of the species in comparison with *C. rugosa* and *C. burrungandjii* using modern non-destructive technologies.	Surveys to locate natural populations, assess their abundance, and determine the species range. Consider establishing a captive breeding insurance colony.	Undertake genetic assessment using nuclear markers to better assess the species distinctiveness and the impact of hybridization and introgression.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Chelodina longicollis** (eastern long-neck turtle)	Moderate to high abundances across an extensive range in south-eastern Australia. Not considered rare.	Not particularly phylogenetically distinctive. Member of a diverse clade of long-necked turtles distributed across Australia, southern New Guinea, Timor, and Roti.	Ephemeral water specialist. Relies upon extensive overland movements and terrestrial aestivation (annual) to cope with the seasonal availability of ephemeral free standing waters. Requires access to permanent water during extended droughts. Obligate carnivore, forager.	Habitat simplification arises from land clearing for agriculture, overstocking, urbanization, and other land use changes with the consequent loss of potential terrestrial refugial opportunities. Altered flow regimes, particularly in regards to flow magnitude and the extent of floodplain inundation. Wetland reclamation and/or degradation. Fine mesh fencing for rabbit control and/or conservation fencing impedes normal dispersal and is a cause of mortality. Road accidents are a very significant cause of adult mortality. Fox predation on nests. Unseasonal fires.	Proliferation of water storages (farm dams and open storages) and other infrastructure (bores, irrigation channels) improves water availability and annual refugia.	Quantification of the impact of road mortality on population viability and persistence; research on the efficacy of road underpasses. Quantification of the impact of fencing on population movements and carrying capacity; research on underwater passages. Relationship between wetland attributes and suitability for high population abundances and recruitment. Investigate opportunities for habitat enhancement in the built environment.	Implement connectivity corridors, under-road passages, underwater passages, and the identification and protection of drought refugia. Increase public awareness of turtles crossing roads. Mitigate fox impacts by establishing nesting areas on islands, whether constructed or natural. Wetland rehabilitation. Management of environmental flows to promote floodplain wetting. Continue to support community-led organizations and programmes such as Turtles Australia and Turtle Rescues New South Wales. Management of high road mortality areas identified on TurtleSAT or the Atlas of Living Australia.	One of the better studied species. More work is needed to refine the ecological understanding of how this species copes with the unpredictability of the cycles of drought in temperate Australia and the role of artificial impoundments and storages. Understanding the relationship between nesting success and the distribution and abundance of predators, including the introduced fox. Ecological and genetic studies to capture variability in traits and life history attributes across its range.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Chelodina steindachneri (western long-neck turtle)	Widespread in semi-arid and arid northern and north central WA. Low abundances throughout its range. Not considered rare.	Not particularly phylogenetically distinctive. Member of a diverse clade of long-necked turtles distributed across Australia, southern New Guinea, Timor and Roti.	Ephemeral water specialist, arid and semiarid regions. Relies upon extensive overland movements during wetter periods, terrestrial aestivation (scale 5 yr) and permanent and semipermanent standing water to cope with unpredictability in the availability of ephemeral free standing waters. Obligate carnivore, forager.	Habitat requirements poorly known. Hybridizes with *Chelodina oblonga* where the two come into contact, possibly because of human assisted dispersal (e.g. Chapman River, WA).	Occupies standing water associated with bores in pastoral properties, in addition to its natural wetlands.	Fill knowledge gaps in distribution as it relates to habitat attributes, estimate abundances, document nesting habitat and seasonality of nesting in the context of availability of standing water. Identify dry season refugia and aestivation sites.	None were identified in the broad context. Undertake a study of the hybridization of *Chelodina steindachneri* and *C. oblonga* to chart the likely trajectory arising from genetic exchange.	A better ecological understanding is required of how this species copes with the unpredictability of the cycles of wet and dry in dryland systems on a temporal scale of decades. Habitat attributes that support high abundances are currently unknown. Spring nester, but triggers and conditions required for opportunistic nesting and conditions conducive to reproductive success require attention.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Chelodina rugosa (northern snake-neck turtle)	Moderate to high abundances across an extensive range in northern Australia east of the Ord River WA and southern New Guinea. Not considered rare.	Not particularly phylogenetically distinctive. Member of the diverse clade of snake-necked turtles distributed across northern and eastern Australia and southern New Guinea.	Occupies principally seasonally inundated coastal and lowland wetlands and *Melaleuca* swamps. Seasonally aestivates in the substrate of ephemeral wetlands. Ambush predator.	Principal threats are degradation of floodplain wetlands from modification for pastoralism and exotic plant invasions, both of which alter the composition of available foods. Also impacted by a combination of feral pig foraging, trampling by feral buffalo in wetlands important for seasonal aestivation, and saline incursion. Highly valued food by indigenous communities and intermittently subject to high local levels of harvest.	Rapid growth to maturity in comparison with other freshwater turtle species. Shows density-dependent responses to reductions in local abundances. The range extends into protected areas such as Kakadu National Park. Extralimital in New Guinea.	Experimental work on the efficacy in exclusion fencing of important wetlands is a high priority. This should be directed at assessing the benefits of the composition and availability of food species and the benefits of turtle survivorship improvement of turtles during aestivation.	Wetland protection follows tactical research to identify the best approaches for excluding feral pigs and buffalo. Negotiation with landowners on the fencing of a portion of wetlands of particularly high value for turtles, commensurate with their production goals. Manage saline incursions and mitigate the causes.	Work with indigenous communities to co-manage this species and its habitat, and in particular, explore opportunities for wildlife utilization for food and pets. Monitor the quality of wild-caught turtles as food for indigenous communities. Increasing the value of the species will increase incentives to manage the species also conservation.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Chelodina oblonga** (oblong turtle)	Moderate to high abundances across its range in south-western WA. Not considered rare.	Highly distinctive phylogenetically. Represents a monotypic clade of long-necked turtles (subgenus *Macrochelodina*).	Relies upon overland movement for dispersal and, in the case of females, nesting. Prefers permanent and semi-permanent lakes, swamps, and rivers with complex vegetation. Terrestrial aestivation (annual) to cope with the seasonal availability of ephemeral free standing waters. Omnivore.	Predation of eggs and adults by red foxes and feral pigs. Increased frequency and intensity of droughts and periods of drying with climate change. The draining and infilling of wetland habitat in urban areas owing to urban development, as well as the loss of fringing vegetation around wetlands. Road mortality.	The proliferation of urban lakes and wetlands provides additional habitat for this species.	Quantify the impact of foxes and feral pigs on nests and adults. Quantify the impact of drought on habitat availability and develop predictive models for the likely impacts of climate change. Evaluate measures for increasing recruitment, such as nest site protection. Evaluate mitigation strategies for reducing road mortalities, such as eco-passages and artificial nesting locations.	Control of foxes and feral pigs, particularly around identified nesting sites. Connectivity corridors, under-road passages, and underwater passages increase public awareness of turtles crossing roads. Restore fringing vegetation around wetlands. Identify and protect drought refugia. Continue to support community-led organization and programmes such as Saving Our Snake-necked Turtle.	Monitor population size throughout the species range, with a focus on population size and demographics. Surveys of subpopulations outside the Perth metropolitan area are required to determine population size and trajectory. Investigate the potential impact of hybridization with *C. steindachneri*.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Elseya albagula** (white-throated snapping turtle)	Moderate abundances in suitable riverine habitat across multiple drainages in eastern central Queensland. Not considered rare.	Not particularly phylogenetically distinctive. Member of a clade (subgenus *Pelocomastes*) of three species riverine snapping turtles in eastern, north-eastern and northern Queensland.	Occupies permanent water, with bank overhangs and submerged structures. Bimodal breather and can respire aquatically, suggesting reliance on clear, flowing water. Primarily herbivorous.	Predation of eggs by foxes and feral pigs. An increase in the frequency and intensity of drought coupled with water extraction increases cease-to-flow events and the availability of refugial pools. Impoundments that obstruct turtle movement and reduce riffle-pool-riffle environments. Clearing of riparian vegetation.	No mitigation of threats was identified.	Quantify the impact of nest predation and establish effective methods for controlling nest predators. Quantify rates of subadult and adult mortality arising from impoundments.	Regional fox and feral pig control and protection of nesting sites through mesh wire and fencing. Implement strategies and programmes for the rejuvenation of aquatic macrophytes. Protect riparian vegetation. Liaise with water management authorities to create triggers around cease-to-flow actions in the event of drought.	Monitor population trends, with a focus on survivorship in each age class. Collect baseline data on movement and habitat use.
Elseya dentata (northern snapping turtle [species complex]	Moderate to high abundances where it is found, typically in lowland reaches and escarpment plunge pools in northern Australia. Not considered rare.	Not particularly phylogenetically distinctive. A species complex has yet to be well defined taxonomically. A member of a clade (subgenus *Elseya*) of snapping turtle species distributed across northern Australia west of the Gulf of Carpentaria.	No intrinsic vulnerabilities were identified. Omnivorous with tendencies towards herbivory as adults.	No specific threats was identified.	No mitigation of threats was identified.	Collect data to bring PVA to an acceptable level of accuracy to inform conservation planning. Undertake taxonomic research to resolve the species complex.	No specific management interventions were identified.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Elseya flaviventralis (yellow-bellied snapping turtle)	Moderate to high abundances where it is found, typically in lowland reaches and escarpment plunge pools of the Arnhem Land plateau in northern Australia. Not considered rare.	Not particularly phylogenetically distinctive. A member of a clade (subgenus *Elseya*) of snapping turtle species distributed across northern Australia west of the Gulf of Carpentaria and in New Guinea.	No intrinsic vulnerabilities were identified. Omnivorous with tendencies towards herbivory as adults.	No specific threats was identified.	Remote areas in which this species is found moderate the level of threat from altered land use practices.	Collect data to bring PVA to an acceptable level of accuracy to inform conservation planning.	No specific management interventions were identified.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.
*Elseya irwini** (Irwin snapping turtle)	Moderate abundances in suitable riverine habitat across multiple drainages in north-eastern Queensland. Not considered rare.	Not particularly phylogenetically distinctive. Member of a clade (subgenus *Pelocomastes*) of three species of riverine snapping turtles in eastern, north-eastern, and northern Queensland. Substantial genetic structure within the species.	Preference for habitat with clear, deep, slow-moving pools with alternating riffle sections. The species is a bimodal breather and can respire aquatically. Omnivorous with tendencies towards herbivory as adults, with reliance on intact riparian vegetation.	Susceptibility to novel diseases. Habitat modification through the construction of dams and weirs and the impacts of off stream land use change. Predation of eggs by feral pigs.	No mitigation of threats was identified.	Quantify the extent of feral pig predation. Determine the impact of flooding and drought on priority nesting sites and hatchling survival. Quantify the impact of increased suspended sediment levels on hatchling and juvenile growth, survival, and diving physiology.	Implement control of feral pigs and protection of identified nesting sites. Riparian restoration, including the restriction of stock from waterbodies. Rejuvenate aquatic macrophytes. Liaise with water management authorities to create triggers around cease-to-flow actions in the event of a drought. Limit sediment input to rivers.	Monitor population change throughout the species range. Collect baseline data on population densities, nesting areas, and survival. Undertake population genetics studies to determine the level of substructuring across drainage basins and to define significant distinct lineages that warrant independent management attention.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Elseya lavarackorum** (gulf snapping turtle)	Locally abundant in suitable riverine habitat across multiple drainages discharging into the Gulf of Carpentaria. Once considered highly restricted and rare. Not now considered rare.	Not particularly phylogenetically distinctive. Member of a clade (subgenus *Pelocomastes*) of three species of riverine snapping turtles in eastern, north-eastern, and northern Queensland and the NT. Substantial genetic structure within the species.	Preference for deep waterholes with rocky escarpments in spring-fed rivers. Primarily herbivorous, with a reliance on intact riparian vegetation.	Predation of eggs by feral pigs. Water extraction. Loss of intact riparian vegetation. Increase in the frequency and intensity of bushfires with climate change.	No mitigation of threats was identified.	Quantify the impact of feral pigs on nests and adults. Quantify the impact of nest damage from cattle, horses, and donkeys. Monitor impacts of fire on riparian vegetation.	Control the impact of feral pigs, cattle, horses, and donkeys at high priority nest sites through fencing, culling of pest species, and nest protection. Implement riparian restoration strategies. Develop flow trigger points for water extraction that maintain critical flows.	Monitor population change through ongoing surveys throughout the species range, with particular focus on population size and demographics.
*Elusor macrurus** (Mary River turtle)	Locally abundant within a single drainage. Rare.	A phylogenetically distinctive relictual lineage whose affinities are uncertain.	Restricted to permanent waters in a single drainage of coastal Queensland. The species is a bimodal breather and can respire aquatically, suggesting that riffle and flowing water are part of its critical habitat. Omnivorous tending to herbivory as adults.	Water resource development that alters flow regimes; nesting banks invaded by vegetation in the absence of clearing floods. Impoundments reduce availability and accessibility of stream riffles and associated oxygenated water. Sedimentation and turbidification impact cloacal breathing. Predation of eggs and adults by foxes. Livestock trampling of nests.	No mitigation of threats identified.	Identify areas of optimal and suboptimal habitat. Quantify the rates and causes of in-stream mortality of immature turtles. Establish accurate ageing techniques to estimate age at maturity.	Maintain stream flow and high quality in-river habitat between impoundments. Improve water quality through the revegetation of riparian habitats. Monitor water extraction and environmental flows during drought avoid cease-to-flow conditions and to ensure the availability of water. Continue to support community-led organizations and programmes such as the Mary River Co-ordinating Committee and landcare groups.	Collect baseline data on the distribution and abundance of the species in major tributaries and monitor population change. Monitor nesting beaches and quantify critical nesting habitat. Consider developing an ex-situ head-starting programme.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Emydura macquarii emmottii (Cooper Creek turtle)	Locally abundant and widespread in the Cooper Creek drainage. Not considered rare.	A lineage of the southern *Emydura* species complex that is sufficiently distinctive to warrant subspecies status.	Occupies permanent water in a dryland river system. Highly dependent on flows to maintain waterholes and on flooding for boom periods (floodplain inundation) to offset bust periods (instream flows only).	Water resource development that alters flow regimes in a distributory system of exceedingly low relief. Illegal netting.	No mitigation of threats was identified.	Identify waterholes that have served as long-term refugia. Study population structure in relation to flows to be better able to predict the consequences of altered flow patterns.	Pay particular attention to maintaining critical habitat attributes of value to the turtles in refugial waterholes. Factor turtles into conservation planning for the Cooper Creek drainage as an umbrella or indicator species. Closely monitor the impacts of new developments in the catchment.	Collect baseline data on the distribution and abundance of the subspecies in the major systems of the Cooper Creek and Diamontina drainages. Resolve the species status of the taxon, in the context of gene flow in contact zones. Restricted or leading to widespread introgression?
*Emydura macquarii gunabarra** (Hunter river turtle)	Locally abundant within a single drainage of coastal NSW (Hunter River). Not considered rare.	A lineage of the southern Emydura species complex that is sufficiently distinctive to warrant subspecies status. Appears to have arisen from a historical incursion across the Great Dividing Range from the MDB, with subsequent low level gene flow from other populations in coastal NSW rivers.	Inhabits small, permanent, deep waterholes. Omnivorous.	Susceptibility to novel diseases. Predation of eggs and adults by foxes. An increase in the intensity and frequency of fires, with increased turbidity owing to ash and silt being washed into streams. Loss of deep, permanent waterholes due to drought and water extraction. Loss of riparian vegetation as a result of land clearing and overgrazing by domestic stock.	No mitigation of threats was identified.	Quantify the extent of fox predation in the Hunter River catchment. Quantify the impact of mining activities on habitat quality and turtle populations.	Develop water sharing plans for the Hunter River catchment as a means of addressing the possible adverse impacts of water extraction. Create refugia for turtles during droughts. Consider establishing captive insurance colonies.	Collect baseline data on turtle movements, habitat use, and sources of adult mortality. Monitor population change. Monitor turtles for novel diseases.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Emydura macquarii krefftii (Krefft river turtle)	Locally abundant and widespread in east coastal Qld. Not considered rare.	A lineage of the southern *Emydura* species complex that is sufficiently distinctive to warrant subspecies status. Subspecies ill defined, and lacks consensus.	Inhabits small permanent water. Omnivorous.	No particular threats was identified.	No mitigation of threats was identified.	None identified.	Pay particular attention to maintaining critical habitat attributes as part of general programmes to monitor riverine health.	Better clarify the sub-species status of the taxon and resolve the three prevailing views.
*Emydura macquarii macquarii** (Murray river turtle)	Locally abundant and widespread within a single, but large drainage, the MDB. Not considered rare.	A lineage of the southern Emydura species complex that is restricted to the MDB.	Reliance on the permanent waterbodies. Omnivorous, scavenger.	Predation of eggs and adults by foxes. Increase in atmospheric temperatures and the intensity of drought conditions, both impacting the permanency of waterbodies; exacerbated by water extraction. Increased turbidity and loss of aquatic macrophytes owing to invasive carp, affecting food availability. Salinisation.	Can achieve high abundance in large impoundments and weirs.	Evaluate measures for reducing fox predation on adults. Investigate the value of artificial waterbodies for the persistence of the species.	Monitor water extraction and provide environmental flows during droughts to ensure water availability. Implement riparian restoration projects at locations where salinization is high. Manage the impact of foxes through predator control around nesting beaches and nest protection as a means of population supplementation. Continue to support community-led organizations and programmes such as Turtles Australia.	Collect data on population densities and monitor population change overtime. Improved knowledge of the impact of weirs and flow regulation. Collate and analyse historical data on the active removal of the species when regarded as a pest.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Emydura macquarii nigra (Fraser Island short-neck turtle)	Locally abundant and widespread on Fraser Island and the adjacent coast in eastern coastal Queensland. Not considered rare.	A lineage of the southern *Emydura* species complex that is restricted to Fraser Island and the adjacent Cooloola peninsula.	Reliance on the permanent waters of dune lakes. Omnivorous, scavenger.	Nutrification of the oligotrophic dune lakes the species inhabits.	Reduced vehicular access to many dune lakes following altered tourist management.	Ongoing monitoring of water quality in dune lakes in the context of visitation.	Maintain control over sources of nutrient enrichment in dune lakes that can be accessed by visitors.	Strategic research on the biology and life history of the subspecies. Genetic assessment of the substructuring of the isolated populations in the dune lakes with a view to formulating a strategy for maintaining genetic diversity in the long term.
*Emydura subglobosa sublgobosa** (red-bellied turtle)	Population size is low; distribution is restricted to the tip of Cape York (Jardine River). Rare in Australia, but abundant and widely distributed in southern New Guinea.	Distinctive in an Australian context but a recent incursion from New Guinea, where it is abundant and widespread.	Preference for off-river shallow, semi-permanent billabongs.	Habitat destruction by feral herbivores and predation by feral pigs. An increase in the frequency and intensity of droughts with climate change which would reduce the availability of dry season refugia. An increase in the frequency and intensity of fires. Poaching for the pet trade.	Extensive populations in southern New Guinea.	Quantify the extent of feral pig predation and rates of hatchling and juvenile recruitment. Quantify the diet and foraging ecology.	Regional feral pig control and protection of key wetlands and nesting locations through exclusion fencing. Manage the availability of dry-season refugia waterholes during periods of drought and consider translocating turtles from drying waterholes to permanent waterbodies.	Monitor population change throughout the species range in Australia with a focus on population size and demographics. Survey the southernmost distribution to clarify the species distribution. Collect baseline data on movement and habitat use in both wet and dry seasons.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Emydura subglobosa worrelli (diamond-head turtle)	Widespread in the north (NT and Qld), locally abundant. Not considered rare.	Not particularly phylogenetically, distinctive. A member of a recent radiation (genus *Emydura*). Pleistocene incursion to Australia from New Guinea.	No intrinsic vulnerabilities were identified. Requires permanent water. Omnivorous with tendencies towards herbivory as adults.	No specific threats was identified.	Occupies permanent billabongs on and off channel in remote areas, particularly those of the plateau country and associated escarpment. Remote distribution mitigates many potential impacts.	None identified.	No specific management interventions were identified.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.
Emydura tanybaraga (northern yellowface turtle)	Widespread in the north (NT and Qld), locally abundant. Not considered rare.	Not particularly phylogenetically, distinctive. A member of a recent radiation (genus *Emydura*).	No intrinsic vulnerabilities were identified. Requires permanent water. Omnivorous with tendencies towards herbivory as adults.	Alteration of floodplain dynamics and persistence of lowland billabongs. Saline intrusion. Exotic weeds, feral buffalo, and feral pig impact on wetland quality.	No mitigation of threats was identified.	None identified.	No specific management interventions were identified beyond wetland management.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.
Emydura victoriae (northern redface turtle)	Widespread in the north (WA and NT), locally abundant. Not considered rare.	Not particularly phylogenetically distinctive. A member of a recent radiation (genus *Emydura*).	No intrinsic vulnerabilities were identified. Requires permanent water. Omnivorous with tendencies towards herbivory as adults.	No specific threats was identified.	Occupies permanent billabongs on and off channel in remote areas, particularly but not restricted to those of the plateau country and associated escarpment. Remote distribution mitigates many potential impacts.	None identified.	No specific management interventions were identified.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Myuchelys latisternum (common sawshell turtle) [species complex]	Widespread in the east (Qld, NSW) and north (Qld and NT), locally abundant. Not considered rare.	A species complex. Not particularly phylogenetically, distinctive. A member of a clade (genus *Myuchelys*) of four species of helmeted turtles, its closest relative *M. bellii*.	No intrinsic vulnerabilities were identified. Carnivorous.	No specific threats was identified.	Thrives in highly modified habitats, such as irrigation channels in cane fields. Can feed on cane toads with impunity.	Undertake taxonomic research to resolve the species complex.	No specific management interventions were identified.	Fundamental research into the biology of this poorly studied species, particularly on nesting biology.
*Myuchelys purvisi** (Manning River helmeted turtle)	Locally abundant but restricted to a single small drainage (Manning-Barnard) of coastal NSW. Rare.	A phylogenetically distinctive relictual lineage basal to the *Myuchelys* radiation.	Restricted to permanent waters in a single small drainage of coastal NSW. The species is a bimodal breather and can respire aquatically, suggesting reliance on riffle habitat and clear flowing waters. Omnivore.	Predation of eggs and adults by foxes. An increase in the intensity and frequency of fires, with increased turbidity owing to ash and silt being washed into streams. Loss of deep, permanent waterholes due to drought conditions and water extraction. Likely susceptible to novel disease as is *M. georgesi*. Potential hybridization and introgression with *Emydura*.	No mitigation of threats was identified. Feeds on components of stock faeces that fall into the water.	Quantify feral pig and fox predation rates. Assess the genetic diversity of the species and test for the presence of hybrids with *Emydura*. Quantify the impact of cattle erosion and trampling on nesting beaches.	Implement protection of riparian habitats, including removal of weed species and protection of stream banks from cattle erosion. Manage the impact of water extraction and create cease-to-flow triggers and actions in the event of a drought. Establish captive insurance breeding colonies and consider supplementing populations should dramatic declines occur. Continue to support community-led organization and programmes such as the Manning River Turtle Group.	Collect baseline data on population densities and trends, and monitor population change. Regularly assess the abundance of Macquarie River turtles in the Manning-Barnard drainage.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Myuchelys georgesi** (Bellinger River helmeted turtle)	Once locally abundant but restricted to a single small drainage (Bellinger catchment) of coastal NSW. The population was recently decimated by a viral epidemic. Now extremely rare.	Phylogenetically distinctive. Part of a deep clade within *Myuchelys*, together with *M. bellii* and *M. latisternum*.	Restricted permanent waters in a single small drainage in coastal NSW. The species is a bimodal breather and can respire aquatically, suggesting reliance on riffle habitat and clear, flowing waters. Highly susceptible to disease, most recently the Bellinger River Virus. Omnivore.	Disease, particularly the Bellinger River Virus, has decimated the adult population. Predation of eggs and adults by foxes. Degradation of the riparian zone due to land clearing for agriculture and increased intensity and frequency of flood events owing to climate change. Hybridization with invasive *Emydura*.	No mitigation of threats was identified.	Determine the origin, mode of transmission of Bellinger River Virus and the susceptibility of the species and life-history stages. Quantification of competition for food between the species and *Emydura*. Quantification of the impact of nest predation and identification of nesting areas for management.	Establish and maintain captive breeding colonies as a source of population supplementation. Selective breeding for resistance to the virus is highly indicated using animals that have been exposed to and survived the virus. Continue to implement riparian restoration strategies, including the removal of weed species and protection of the stream banks from cattle. Manage the impact of hybridization through the removal and euthanasia of F1 hybrids. Mitigate the impact of foxes through nest protection. Continue to support community-led organizations and programmes such as Ozgreen and Landcare.	Monitor the progress of population recovery and assess the age and sex structure of the wild population to identify future disease outbreaks. Monitor mature females to determine if breeding is successful. Stratify monitoring to include the Kalang River sub-catchment.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Myuchelys bellii** (western sawshell turtle)	Locally abundant but isolated to three headwater tributaries of the MDB (Namoi, Gwydir, and Border Rivers); highly structured genetically. Rare.	Phylogenetically distinctive. Part of a deep clade within *Myuchelys*, together with *M. georgesi* and *M. latisternum*.	Restricted to permanent waters in a very restricted distribution. The species is a bimodal breather and can respire aquatically, suggesting that riffle and flowing water are part of its critical habitat. Omnivore.	Predation of nests and adult turtles by foxes. Increase in the frequency and intensity of drought events, reducing the availability of deep water habitat. Channel modification for flood mitigation. Likely susceptible to novel diseases, as is *M. georgesi*. Habitat degradation is owing to water extraction and bank erosion from livestock. Potential hybridization with invasive *Emydura*.	No mitigation of threats was identified.	Undertake population genetics studies to determine the level of substructuring across drainage basins and to define significant distinct lineages that warrant independent management attention.	Continue to implement riparian restoration strategies, including the removal of weed species and protection of the stream bank from cattle. Liaise with water management authorities to create triggers around cease-to-flow actions in the event of a drought. Continue fencing and nest protection to mitigate against fox predation. Consider the establishment of captive breeding insurance colonies, ensuring that the captives are representative of the genetic composition of the wild populations.	Collect baseline data on population densities and trends, and monitor population change. Support and enhance existing programmes targeted at monitoring nesting beaches and protecting nests. Monitor the range expansion and abundance of *Emydura* to within the range of M. bellii.

(Continues)

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
Pseudemydura umbrina (western swamp turtle)	Population size extremely low; distribution is extremely restricted. Extremely rare.	Extremely phylogenetically distinctive, representing the basal lineage for the Australian Chelidae.	Occupies summer dry, and winter wet ephemeral waters. Low fecundity. Carnivorous.	Critically low numbers introduce a risk of progressive erosion of genetic diversity and the ability to respond to environmental change. Fire during the aestivation period. Predation of by native species (e.g. bandicoots). Fox predation in areas not subject to fox exclusion. Road mortality.	No mitigation of threats was identified.	Continual monitoring of population abundance and demography. Undertake further research into the feasibility of translocations to areas outside the current range.	Active management and protection of the wetlands of Ellen Brook, Twin Swamps, and Mogumber Nature Reserves and other wetlands with the potential for re-establishment, including predator exclusion and predator control within fenced areas. Maintain a captive breeding insurance colony and use it as a source for supplementation and potential translocation. Implement translocations.	Conduct fundamental research on best practice for maintaining the genetic diversity of the captive colonies and for the selection of individuals for release into existing populations and to establish new populations. Modelling to identify areas for translocation with characteristics broader than those currently occupied.

TABLE 1 (Continued)

Species	Rarity	Distinctiveness	Intrinsic vulnerability	Recent, current, and future threats	Mitigation and offsets	Priorities for tactical research (immediate relevance)	Priorities for management intervention	Priorities for strategic research (long-term relevance)
*Rheodytes leukops** (Fitzroy River turtle)	Locally abundant within a single drainage (Fitzroy-Dawson, Qld). Rare in the sense of being geographically restricted, but locally abundant. Rare.	A phylogenetically distinctive relictual lineage whose affinities are uncertain.	Restricted to permanent waters in a single drainage of coastal Queensland. The species is a bimodal breather and can respire aquatically, suggesting that riffles and flowing water are part of its critical habitat. Specialized omnivorous diet.	Predation of nests by foxes and feral pigs. Construction of impoundments and loss of nesting habitats. Increased sedimentation owing to agriculture and mining practices. Loss of riparian vegetation and increased sedimentation as a consequence of bushfires associated with climate change. Changes to flow regimes due to drought events and water extraction. Trampling of nests by domestic species.	No mitigation of threats was identified.	Quantify the extent to which invasive species and native species are contributing to high nest predation. Determine how water quality affects hatchling and juvenile growth and survival. Quantify the range-wide impacts of drought and flood events.	Implement measures to control feral pigs, feral cats, and foxes and protect nesting beaches. Implement strategies for increasing recruitment in areas where nesting habitat has been lost. Preserve the remaining unregulated river and creek systems from future river infrastructure. Liaise with water management authorities to create triggers around cease-to-flow actions in the event of drought. Maintain stream flow and high quality in-river habitat between impoundments.	Collect baseline data on population densities and trends, and monitor population change.

Note: Taxonomy follows that of the Official List of Species of the Australian Society of Herpetologists (2022). Species in the preliminary list considered by the Freshwater Turtle SEAP are marked with an asterisk. Common names are not widely agreed upon but serve to give an indication of which species is referred to by the scientific name for a non-specialist audience. Recommendations for listing are not included because the listing process (consultation with the states, public consultation, and recommendation of the Threatened Species Scientific Committee) is yet to conclude. Collection of data to bring Population Viability Analyses and other modelling of demographic trends to an acceptable level of accuracy to inform conservation planning is recommended as a priority for tactical research for all species (only *Pseudemydura umbrina* and *Myuchelys georgesi* have adequate data). The priority of working with Indigenous land management groups, conservation groups, or communities and building community awareness is also a priority for management action for all species.

Abbreviations: MDB, Murray-Darling Basin; NG, New Guinea; NSW, New South Wales; NT, Northern Territory; Qld, Queensland; SA, South Australia; Vic, Victoria; WA, Western Australia.

region being inadequate to support its listing. In this instance, the species was not proposed for listing due to insufficient data.

SPECIES SELECTED FOR ASSESSMENT

A preliminary assessment was undertaken to identify species that were considered unlikely to progress to listing either because they were data deficient or because they were considered to be widespread, abundant, and unlikely to be subject to substantive population declines. They were not considered further. Of these, 12 were considered data deficient, with no available evidence likely to have bearing on the listing. Four of these were subspecies of the southern *Emydura* species complex (*Emydura macquarii*) (Georges, Gruber, et al., 2018), seven were species confined to the poorly studied tropical north (the northern redface turtle *Emydura victoriae*, the northern yellowface turtle *E. tanybaraga*, *E. subglobosa worrelli*, *Elseya dentata*, *Elseya flaviventralis*, *Chelodina rugosa*, and *C. burrungandjii*) and one is widespread and abundant in northern and eastern Australia but otherwise data deficient (*Myuchelys latisternum*, likely to be a species complex, Cann, 1998). *Chelodina expansa*, widespread in south-eastern Australia and considered stable and not rare, was also excluded from further consideration. *Pseudemydura umbrina* and *Chelodina kuchlingi* were subject to concurrent assessment by Western Australia and were removed from consideration to avoid duplication of effort.

The species eliminated from consideration because of data deficiency, and those for which a need for fundamental research on their biology is identified in Table 1, highlights the priority for additional research on the biology, natural history, and ecology of these species, and in particular, the need for baseline data on population densities and trends.

Following the preliminary assessment, 15 species (or subspecies) were selected for the preparation of Conservation Advice documents (Table 1) in consultation with respective experts, including those within Indigenous communities – *Carettochelys insculpta*, *Chelodina canni*, *C. oblonga*, *C. longicollis*, *Elseya albagula*, *E. irwini*, *E. lavarackorum*, *Elusor macrurus*, the Hunter River turtle *Emydura macquarii gunabarra*, the Murray River turtle *E. m. macquarii*, *E. subglobosa subglobosa*, *Myuchelys bellii*, *M. georgesi*, *M. purvisi*, *and Rheodytes leukops*. These Conservation Advice documents are to be considered by the respective States and Territories to consider and review under the Common Assessment Agreement, made available for open public comment, and passed to the national Threatened Species Scientific Committee, which will decide which species will be recommended for listing or relisting under the EPBC Act. This is a protracted process likely to continue into 2024. Conservation Advice documents can be found on the Species Profile and Threats Database maintained by the Australian Department of Climate Change, Energy, the Environment and Water (http://www.environment.gov.au/cgi-bin/sprat/public/sprat.pl, Accessed 24th May 2023).

KEY THREATENING PROCESSES

Globally, the most impactful threats to freshwater turtles arise from habitat loss, degradation, and fragmentation; exploitation for meat, medicinal products, and the pet trade (Ceballos & Fitzgerald, 2004; Gong et al., 2017; Lyons et al., 2013; Nijman & Shepherd, 2022; Sigouin et al., 2017); predation (Thompson, 1983; Van Dyke et al., 2019); and, in some cases, competition by invasive species (Figure 1, Cadi & Joly, 2004; Taniguchi et al., 2017);

FIGURE 1 An eastern long-neck Turtle, *Chelodina longicollis* (Right), and a red-eared slider, *Trachemys scripta elegans* (Left) basking on a log in an urban wetland in Sydney. Invasive turtle species, like the red-eared slider, are not wide-spread in Australia but have the potential become so and to compete for resources and habitat with native species of freshwater turtle.
Photo: Citizen Scientist via the TurtleSAT app.

and disease (Zhang et al., 2018). Overlaid on these pressures is the alteration of environments predicted by climate change (Stanford et al., 2020). Despite Australia's low human population size, Australian freshwater turtles are not quarantined from the impacts that apply globally. We just have a different combination of impacts where they differ in their respective magnitudes. Arguably, because of our rigid controls over wildlife exploitation and trade generally, the current harvest of freshwater turtles for consumption and export is of much lower concern in Australia than elsewhere (Alacs & Georges, 2008) and so is not considered a key threatening process.

Habitat loss and degradation

Because of Australia's peculiar climatic attributes (exceptionally low precipitation, unpredictability), water resource development, which alters the magnitude, frequency, and timing of flows, is of major concern (Bunn & Arthington, 2002; Deeth & Coleman, 2022; Georges, Webster, et al., 2002). Conversion of lotic to lentic habitat via dams and weirs (Bárcenas-García et al., 2022; Limpus et al., 2009) restricts turtle movement (Bower et al., 2012), eliminates riffle and riparian habitat important for some species (Bodie, 2001; Tucker et al., 2001), alters food availability (Tucker et al., 2012), favours lentic turtle species over other riverine species via ecosystem displacement (but see Clark et al., 2018), alters water temperature profiles downstream (Bae et al., 2014), and moderates flow events and floodplain inundation (Sparks, 1995). These impacts are exacerbated by land use change in catchments, which increases sedimentation, alters substratum characteristics, increases turbidity, results in eutrophication of what were formerly oligotrophic streams, and degrades or fragments riparian vegetation with attendant impacts on freshwater biota, including turtles. A range of invasive aquatic species, including carp, redfin, water hyacinth, and pale yellow water lily, have spread across Australian freshwater systems, disrupting food webs (Dugdale et al., 2013; Koehn, 2004). Land reclamation of ephemeral wetlands is an increasing concern (Burbidge & Kuchling, 2014; Cann, 1978, p. 23; Gabites & Spencer, 2023). Salt water intrusion in coastal regions (Agha et al., 2018) and those inland waters affected by salinization reduce habitat availability and introduce novel interactions between turtles and marine species (figure 11.4 of Roe & Georges, 2009). Mining and petrochemical extraction (e.g. VDM Consulting, 2012) can be of concern if assessments of impact on water availability, instream structural attributes (e.g. from sand mining, Flakus, 2002), and other requirements of freshwater turtles are not adequately considered at the planning stages (but see Freeman et al., 2014). Hydraulic fracturing for shale gas (Pepper et al., 2018) has the potential to contaminate ground or surface water relied on by freshwater turtles (Davis et al., 2021), such as the endangered *Elseya lavarackorum*, recently reported to occur in the Roper River, NT (Georges et al., 2021; Joseph-Ouni et al., 2022). Of particular concern to wetlands and other inland waters and the biota they support, including freshwater turtles, are the lasting and possibly permanent impacts of drought, exacerbated by climate change (Peterson et al., 2021).

Predation

A second area of concern for freshwater turtles in an Australian context is the introduction of exotic species, particularly predators. Turtles have an unusual life history among egg-laying vertebrates (and amniotes in general) in that the adults are long-lived yet highly fecund, often laying multiple clutches of eggs within a season. As such, they produce many more eggs than required to replace themselves and their partner in the absence of mortality among eggs, hatchlings, and juveniles, and so can sustain relatively high levels of mortality in these early life stages. Not so the adults (Heppell, 1998). Mortality of adults and the loss of reproductive potential that accompanies such mortality, if substantial, is of much greater concern than mortality of the juvenile life stages (Doak et al., 1994), as demonstrated by elasticity analyses and simulations – relatively small changes in adult survivorship have large proportional effects on population growth rate (Enneson & Litzgus, 2008). This needs to be considered when assessing the impact of threatening processes. Foxes are devastatingly efficient predators of turtle nests (Figure 2) and also kill or maim the adults if they are discovered while nesting. Fox predation is likely to cause low abundances of juvenile turtles in many wetlands (Spencer et al., 2017; Thompson, 1983), and field experiments have indicated that fox management can have positive effects on nest survivorship (Spencer & Thompson, 2005). However, quantitative estimates of consumption rates by native predators (Cann, 1998, pp. 30–33) in the absence of foxes are lacking, so it is not certain as to whether the impacts of fox predation greatly exceed what may have been the case before fox introduction (Chessman, 2021). Population models indicate that turtle populations demonstrate resilience against significantly high levels of nest predation, provided there is a certain degree of variability observed over a span of 5–10 years (Spencer, 2018). Regardless of the case, control of fox impacts on nesting success can be important for integrated management to accelerate the recovery of turtle populations reduced over time from other causes. Feral pigs, *Sus scrofa*, are also a source of predation, particularly in northern Australia (Fordham et al., 2008; Fordham, Georges, Corey, et al., 2006). While there are anecdotal accounts of instances of Indigenous harvest in excess of what is considered sustainable, there are no verified accounts, and the impact of pig predation is an order of magnitude

FIGURE 2 The introduced European red fox is a devastatingly efficient predator of turtle nests. Shown here is a fox that has depredated an artificial nest (chicken eggs) as part of a study of fox behaviour and impact (see also Terry et al., 2023, this issue). Photo: James Van Dyke, Wodonga.

greater than that of Indigenous harvest, moderated as it is by logistical and social constraints (Fordham, Georges, Corey, et al., 2006).

Disease

Emerging diseases are a relatively new consideration in wildlife conservation (Adamovicz et al., 2020), brought about by expanding human populations coming into greater contact with wildlife and the increased global travel by individuals and global trade in goods (Aguirre & Tabor, 2008). A notorious example is the human-assisted dispersal of the fungi *Batrachochytrium dendrobatidis* and *Batrachochytrium salamandrivorans*, which have devastated or exterminated numerous amphibian species around the world (Bower et al., 2017; Scheele et al., 2019). Australian species of freshwater turtle that are restricted to small drainages are particularly vulnerable (e.g. *Myuchelys georgesi*, Zhang et al., 2018; Chessman et al., 2020) because local extirpation translates to global extinction. Low population sizes sustained over long periods (i.e. bottlenecks) often lead to low genetic diversity and low potential to resist disease outbreaks. Vulnerability to disease may be exacerbated by environmental perturbations that compromise immunocompetence (French et al., 2008; Spencer et al., 2018).

Fire

Of all the threats faced by freshwater turtles, fire does not immediately spring to mind. However, wildfire in catchments can have profound effects on rates of sedimentation, nutrification, water quality, and other attributes of the riparian and instream environments important to freshwater turtles (Davies-Colley & Payne, 2023; Lovich et al., 2017). Those species that engage in substantial terrestrial activity (Santoro et al., 2020) may be directly impacted by unseasonal or intensity-enhanced fire (Harris et al., 2020), potentially aggravated by climate change. Nesting habitat (Markle et al., 2020) and riparian vegetation can also be severely impacted by fire, together with their value as a source of windfall fruits, flowers and insects for freshwater turtles. Increased fire frequency and intensity is often associated with drought, and the two synergize; a reduction of flows leads to a few isolated ponds serving as critical refugia, with their availability further reduced by infill from sedimentation caused by fire. Increasing fire frequency is a concern elsewhere if fires occur during dry periods when turtles are aestivating in leaf litter or other debris (Cann, 1998, p. 26; Roe & Bayles, 2021), but this has not yet been well documented in an Australian context.

Hybridization

Hybridization between even distantly related species of chelid turtle is remarkably common in the wild. In some cases, this is natural, as with the hybridization of *Chelodina burrungandjii* and *C. rugosa* in the escarpment country of Arnhem Land, of *C. canni* and *C. rugosa* in the rivers draining into the Gulf of Carpentaria, and of *C. canni* and *C. longicollis* in central coastal Queensland (Georges, Adams, et al., 2002; Georges, Webster, et al., 2002). In other cases, the hybridization follows human-assisted introductions, as with the hybridization of *Myuchelys georgesi* and *Emydura macquarii* in the Bellinger River (Georges, Spencer, et al., 2018) or *Chelodina oblonga* and *C. steindachneri* in the Chapman River of WA (Georges, 2019). Historical hybridization between *C. expansa* and *C. longicollis* in the Murray-Darling Basin (Hodges, 2016) has complicated eDNA surveys of sympatric populations as the two species share mtDNA genomes derived from *C. longicollis*. Consensus has not yet been achieved as to whether these hybridization events present a threat to the local endemic, potentially compromising its identity, or if substantial introgression is prevented by partial genomic incompatibility (Larson et al., 2013).

Other threats

Other threats to freshwater turtles include trampling of nests by feral herbivores or stock, incidental mortality from recreational fishing, roadkill, boat strikes, fencing (including conservation fencing, Ferronato et al., 2014), and illegal netting (Cann, 1998, Plate 3); these will be considered in more detail in the accounts against functional groups that follows.

SPECIES ASSESSMENTS

Table 1 is a compilation of intrinsic vulnerabilities, threatening factors, and proposed actions arising for species of Australian freshwater turtles. What follows is an integrated account of these factors organized against functional groups.

Riverine turtles

River turtles are large-bodied turtles that occupy both lentic and lotic environments (Moll & Moll, 2004). They require permanent waters and are flow dependent, with those occupying lentic environments perhaps more so than those that primarily occupy lotic environments. Several Australian species are bimodal breathers, complementing oxygen uptake via the lungs with uptake from buccopharyngeal or cloacal respiratory surfaces (Clark et al., 2008a, 2008b; Gordos et al., 2003; King & Heatwole, 1994; Legler & Georges, 1993). As a consequence, access to highly oxygenated water, such as that produced by water running off shallow beds of gravel and rock (riffles), is likely to be important, if not obligatory, to their persistence. Riffle habitat is impacted by the construction of dams and weirs. Loss of this critical habitat is likely to impact the riverine species of the Fitzroy River turtle *Rheodytes leukops*, the Mary River turtle *Elusor macrurus*, the white-throated snapping turtle *Elseya albagula*, *the* Irwin's snapping turtle *Elseya irwini*, and all species in the genus of helmeted turtles *Myuchelys* (Clark et al., 2009; Tucker et al., 2001). Another species that appears to depend on continuous flow is the pig-nosed turtle *Carettochelys insculpta* which, in Australia, occupies the dry-season spring-fed Daly River and preferentially aggregates in spring-fed reaches of systems that are primarily lotic in the dry season (e.g. Barramundie Creek in the South Alligator River) (Georges & Kennett, 1989). Demands for water for agriculture are highest in the dry season of the wet-dry tropics of northern Australia when river flows are at a minimum, which puts at risk riverine species such as the pig-nosed turtles should water resource development routinely lead to cease-to-flow conditions during the dry-season in the Daly River (Erskine et al., 2003; Georges, Webster, et al., 2002).

Perhaps the taxon most dependent on complex environmental flows is the Cooper Creek turtle, *Emydura macquarii emmottii*, which occupies the unregulated dryland river system in central Australia (Cann, 1998, pp. 146–151; Georges & Guarino, 2017). The Cooper Creek drainage in the Lake Eyre basin spans a landscape of exceptionally low relief to form an extensive distributary system of channels and waterholes that are principally fed by rainfall in the headwaters under the influence of the tropical monsoon. When Cooper Creek flows, waterholes, channels, and floodplains in the semiarid and arid regions are inundated before it discharges into one of the largest inland salt lakes in the world, Kati Thanda-Lake Eyre. These regions have a median annual rainfall of less than 200 mm/year (Kotwicki, 1986), and as such, they are a most unlikely area to find thriving populations of freshwater turtles. Long dry periods of low productivity ('busts') dominate but are punctuated by widespread floods, usually driven by rainfall high in the catchment ('boom' periods) (Puckridge et al., 2000). For the freshwater turtles, the boom comes in two forms. First, when the river runs, the turtles take advantage of foods carried into their waterholes with the floodwaters; they often concentrate around the inflows. These are 'mini-booms' (Bunn et al., 2006), occurring with greater frequency than major floods. Second, there are the major floods, which dramatically expand available habitat and access to new food sources, both during the floods and immediately after, as food species concentrate in the permanent waterholes as the floodwaters recede. So *Emydura macquarii emmottii* is critically dependent on flows – on the timing and frequency of river runs, on the frequency, extent, and duration of major floods, and on the pattern of floodplain inundation across the landscape, essential to the metapopulation dynamic of standing water that sustains the turtles (Georges & Guarino, 2017). One of the greatest threats to natural flow and flooding regimes in dryland distributary systems such as Cooper Creek is the diversion of flows. This water resource development in dryland rivers often decreases the frequency and duration of flow pulses, reducing floods and sometimes elevating base flows (Bunn et al., 2006). For *Emydura macquarii emmottii*, alteration of these flow attributes through water resource development and deliberate or inadvertent water diversion in a landscape of very low relief will be potentially catastrophic for the turtle populations (Georges & Guarino, 2017; Kingsford et al., 2006; Roe & Georges, 2009).

Riverine turtles that prefer lentic conditions can benefit from the changes arising from water resource development that have such an impact on those species that depend upon flowing waters. Species of the genus *Emydura* fall into this category, with large abundances reported in artificial impoundments (de Lathouder et al., 2009). However, all riverine species suffer impacts from degradation of riparian vegetation, reduction of instream structural complexity (Fielder et al., 2014), thermal changes arising from altered shading patterns and cold water release from storages (Whittington & Hillman, 1998), sedimentation that fills interstitial spaces in stream and river beds, nutrification, and increased turbidity, which affect the composition of food species, their availability, and their accessibility. A potentially important area of study is how the disruption of environments has impacted the food webs upon which turtles rely. Many are generalists, but their diets differ notably between even wetlands that are relatively near each other, with consequences for body condition (Petrov et al., 2018, 2020).

Riverine species typically nest in discrete areas such as sand or gravel beds or other open areas close to water. Unfortunately, feral herbivores such as donkeys *Equus asinus*, horses *Equus caballus*, and water buffalo *Bubalis bubalis* (and domestic stock) tend to access the water through well-defined, vegetation-free pathways (Cann, 1998, p. 30). Trampling of nests has been identified as a source of nest mortality for species including threatened *Carettochelys insculpta*, *Myuchelys georgesi*, and *Elseya lavarackorum* (Blamires et al., 2005; Georges & Wombey, 1993; Sattler, 1993).

Riverine species in regulated catchments require appropriate environmental water releases to maintain refugia and ensure the permanency of critical floodplain billabongs, to improve water quality (e.g. flush saline areas), and to reduce the impact of barriers to water flow and turtle movement created by regulating structures (e.g. dams). Environmental water releases, conservation fencing, and carp structures need evaluation as to impacts on freshwater turtles as they can hinder as well as help. For example, strategically timed releases of water can reduce flooding in traditional nesting areas during the nesting season (Espinoza et al., 2018). Carp exclusion screens should be designed so as not to exclude or inhibit large-bodied aquatic species such as turtles (Hillyard et al., 2010).

Ephemeral water specialists

Perhaps the species presenting the most complex scenarios for conservation are those that split their activity between aquatic and terrestrial habitats, the ephemeral water specialists. The eastern long-necked turtle *Chelodina longicollis* exploits ephemeral and semi-permanent waterholes, swamps, and rainpools when available, retreating to permanent waters or aestivating on land when such waters are not available (Chessman, 1983; Kennett & Georges, 1990; Roe & Georges, 2008a, 2008b). This species is an example of a widespread species that, although not yet endangered, is impacted by a diverse range of changes associated with land and water development. They have a marked propensity for overland travel, which they do in the warmer months in response to rain, and excellent navigational abilities (Graham et al., 1996). Terrestrial estivation of up to 480 days, without returning to water, has been observed (Roe & Georges, 2007), though energy stores ultimately limit survival out of water, where they cannot feed (Roe et al., 2008). Aestivation sites are typically located under the canopy in forested habitats where turtles bury themselves in leaf litter near woody structures such as shrubs and logs. These attributes make the species particularly vulnerable to land use practices (DCCEEW, 2023b). Altered flow regimes arising from water resource development dramatically reduce the timing and magnitude of floodplain inundation and so the availability of the ephemeral wetlands upon which the species depends. This is aggravated by wetland reclamation for agriculture, transport infrastructure, and urbanization (Gabites & Spencer, 2023), but is likely offset to some degree by the proliferation of farm dams in agricultural landscapes.

Structural habitat simplification that often accompanies urbanization and agricultural development reduces opportunity for aestivation – when this occurs, *Chelodina longicollis* tends to move more directly between permanent and ephemeral waters (Rees et al., 2009; Roe et al., 2011). Roads are a major cause of adult mortality in some areas (Figure 3, Santori et al., 2018) and have been attributed to differences in survivorship between populations in proximity to urbanization and those in nature reserves (Ferronato et al., 2016, 2017). Given that the regional carrying capacity of this species depends integrally on its ability to move across the landscape, impediments to this movement can have serious consequences. Fencing for pest control in agricultural areas and even conservation fencing (Ferronato et al., 2014) can be a substantial cause of direct mortality (dead turtles stacked against the fence in corners of paddocks were reported anecdotally after installation of rabbit-proof net fencing) but more insidiously, it can restrict turtle movements between permanent refugia and the ephemeral waters that are essential for population growth and maintenance of *Chelodina longicollis* (Kennett & Georges, 1995). Increasing fire frequency is a concern elsewhere where fires occur during dry periods when turtles are aestivating in leaf litter and other debris (Cann, 1998, p. 26; Roe & Bayles, 2021), but has not yet been well documented in an Australian context. There are

FIGURE 3 Road kill can be a substantial source of mortality for species that split activity between terrestrial and aquatic environments, as does the eastern long-necked turtle *Chelodina longicollis*. Much goes unreported when turtles wander off the road to later die, or when scavengers remove carcasses. Road underpasses, coupled with judicious placement of fencing, can reduce the impact in high-mortality areas.
Photos: John Roe and Martha Rees, Jervis Bay.

anecdotal reports of mortality from ingesting cane toad tadpoles (e.g. in Cooper Creek and Fraser Island), and the species may have been reduced in abundance where the two co-occur, but definitive evidence is lacking. Finally, fox predation on the nests and occasionally nesting females is substantial, though whether this is more substantial than would have arisen from predation by native predators is not certain (Chessman, 2021).

Although widespread and often locally abundant, the eastern long-necked turtle, *Chelodina longicollis* is particularly vulnerable to land use practices associated with agriculture, pastoralism, transport infrastructure, and urbanization. Priorities for conservation action include wetland restoration with a focus on enhancing production of instream foods such as macroinvertebrates, riparian restoration as a source of windfall foods, underpasses for hotspots of road mortality enhanced by guiding fencing, mitigation of fence mortality (Ferronato et al., 2014) and disruption of essential movements (Kennett & Georges, 1995) by introduction of underwater passages that allow movement of turtles but not pest species that are the direct target of the fencing, better management of ground cover and forested areas in proximity of wetlands (including fire) where this is commensurate with production goals and fox control and/or nest protection as a means of enhancing recruitment in areas where the turtles are in decline.

Other species with similar habits to *Chelodina longicollis* are the northern long-necked turtle *C. canni* and the western long-necked turtle *C. steindachneri*, though the context in which these habits come to bear on their conservation is quite different – *C. longicollis* occupies the east and southeast of Australia, which are subject to the most intensive land and water development, whereas *C. canni* and *C. steindachneri* occupy more remote regions. Neither *C. canni* nor *C. steindachneri* are well studied, and the frequency and duration of the droughts with which they need to contend are on longer timescales than for *C. longicollis*. For *C. canni*, simplification of habitat that accompanies high stocking rates in pastoral areas with consequential reduction in opportunities for terrestrial aestivation, widespread fires with intensities enhanced by exotic grasses (Rossiter et al., 2003), and altered surface flows in areas of exceptionally low relief (e.g. Sunday Creek and Newcastle Waters, NT) that impact refugial surface waters during the dry season when the species nests are all likely threats to the species persistence in parts of its range (DCCEEW, 2023a). These should govern priorities for on ground action. Feral pigs may also have some impact on the species via habitat destruction (Doupé et al., 2009) and predation on nests (Figure 1). The nests are scattered and difficult to locate, and the adult palatability is reduced by the pungent odour released when the animals are stressed (Kennett et al., 1992), so Indigenous harvest rates are low.

The northern snake-neck turtle, *Chelodina rugosa*, occupies the ephemeral waters of the extensive floodplains of rivers in the wet dry tropics (Kennett et al., 2014). It copes with the seasonal unpredictability of free-standing water by aestivating in the mud of the billabongs it occupies (Grigg et al., 1986; Kennett & Christian, 1994) and does not typically engage in long-distance migrations between ephemeral and permanent waters. The species copes with the unpredictable availability of dry nesting sites by nesting underwater at the edge of billabongs as they recede as the dry season progresses (Fordham, Georges, & Corey, 2006; Kennett et al., 1993). Both of these life history attributes make the species extraordinarily vulnerable to trampling by feral water buffalo and feral pig predation (Figure 4, Doupé et al., 2009; Fordham et al., 2008; Fordham, Georges, Corey, et al., 2006). Feral pigs are a major threat to the species across northern Australia (Freeman, 2010; Freeman et al., 2014). *Chelodina rugosa* is seasonally harvested by Indigenous communities in northern Australia and New Guinea (Fordham et al., 2004; Kennett et al., 2014),

FIGURE 4 Feral pigs have a devastating impact on wetlands in the tropical north of Australia. Shown here is damage to an area typically used by the northern snake-neck turtle *Chelodina rugosa* for nesting and aestivation during the dry season of the wet-dry tropics. Fencing sensitive wetlands is an option that requires evaluation through research and monitoring.
Photo: Damien Fordham, Arnhem Land.

but the offtake is considered to be an order of magnitude lower than losses from feral pig predation (Fordham et al., 2008). The species also exhibits a strong density-dependent response to population reduction (Fordham et al., 2009), has a low age at maturity, and is therefore considered quite resilient to population fluctuations. The species does not appear to have been severely impacted by the cane toad, with reports of it feeding on toads with impunity (Covacevich & Archer, 1975) or potentially causing deaths (Greenlees & Shine, 2011). Priorities for conservation action directed at this species include wetland protection (particularly from the impact of exotic plants and saline incursions in low lying areas) and restoration, using fencing to reduce the impact of feral water buffalo and pigs on sensitive wetlands (Figure 4). The value of the species to Indigenous communities can be enhanced by linking it to opportunities for commercial wildlife harvest (Figure 4, Fordham et al., 2007), a contemporary avenue for bringing younger people into closer contact with their lands and traditional owners. Small numbers of the species appear periodically in the global pet trade, presumably arising from the Merauke region of Indonesian New Guinea (Lyons et al., 2013), but the low-level trade is not considered to pose a threat to the species.

Closely related to the northern snake-neck turtle *Chelodina rugosa* is *Chelodina burrungandjii* (Thomson et al., 2000), which occupies streams and billabongs of the sandstone plateaus of Arnhem Land and the Kimberley and the associated escarpments (Thomson et al., 2011). Because of the remote regions it occupies, the species is data deficient, and it is difficult to make an assessment of its conservation needs. There is no evidence of it having been impacted by feral water buffalo, feral pigs, or the cane toad. The species may be subject to natural local hybridization and introgression with the lowland *Chelodina rugosa* in the Arnhem Land regions (Georges, Adams, et al., 2002; Georges, Webster, et al., 2002), but otherwise is considered secure. A third snake-necked turtle from the Ord River region of northern Australia, *Chelodina kuchlingi* (Kuchling, 2020), is considered poorly known, exceptionally rare, and possibly extinct.

Pseudemydura umbrina is Australia's rarest freshwater turtle and also an ephemeral water specialist restricted to isolated locations within the Swan River Coastal Plain of Western Australia (Burbidge & Kuchling, 2014). The species occupies ephemeral wetland swamps, where it spends the wet Austral winter and spring feeding, growing, and mating, and the dry summer and autumn aestivating under leaf litter or in natural cavities and tunnels below ground (Burbidge, 1981). Already faced with a short period in which to actively feed and accumulate resources, important for hatchling growth and survival (Mitchell et al., 2012) and adult reproduction (Kuchling & Bradshaw, 1993) any further contraction of the wet winter-spring period could be catastrophic for the local and therefore global persistence of this species.

Primary threats to the species leading to its current status include land clearing and habitat change associated with urbanization, agriculture, and land reclamation, predation by exotic and native animals, and wildfire (Burbidge & Kuchling, 2014). Evidence from the fossil record suggests that the species or closely related species occupied a much more extensive range (Gaffney et al., 1989) and appears to have been restricted to its current range in the south-west of Western Australia by progressive aridification of the Australian continent. There are growing concerns over the ability of the species to withstand contemporary climate change, with indications of further reductions in annual average rainfall, in addition to altered timing and duration of wetland inundation (Burbidge & Kuchling, 2014). The species appears to have been geographically marginalized by historical climate change, decimated by habitat loss and other new pressures brought to bear under human influence and on the brink of extinction precipitated by further climate change. Protection of the remaining sites occupied by the species is now critical, and the successful establishment of a breeding and insurance colony provides opportunity for population supplementation and translocation to new suitable sites (Mitchell et al., 2013).

A central question is how aggressive one should be in selecting new sites for the translocation and establishment of self-sustaining populations of *Pseudemydura umbrina*. A representative of the genus, possibly the same chronospecies (Gaffney et al., 1989), is in the mid-Miocene fossil record of Riversleigh (13.5 Mya), when the site was at the latitude of Rockhampton (Gaffney et al., 1989). Can the past inform our strategies for the translocation and establishment of this critically endangered species and extend our modelling beyond the restrictive habitat parameters drawn from those that have accompanied its decline to the brink of extinction (Archer et al., 2019; Dietl & Flessa, 2010; McDowell et al., 2023)?

Relictual lineages

Finally, those species that occupy single drainages or are highly restricted in distribution present particular issues for conservation. The challenges are greater because local extinction is global extinction, and so these species are more vulnerable to local catastrophes. A recent example is the decimation of the sole population of the Bellinger River helmeted turtle, *Myuchelys georgesi*, by a novel virus that entered the Bellinger River in 2015 (Chessman et al., 2020; Zhang et al., 2017). Other single drainage species – *Rheodytes leukops*, *Elusor macrurus*, *Myuchelys purvisi*, and Australian populations of *Emydura subglobosa subglobosa* (Schaffer et al., 2009) – may be similarly vulnerable to such events. Part of the concern for these species arises from the progressive erosion of genetic diversity that has occurred as a result of their highly restricted distributions and total population sizes. Low genetic diversity can render them less able to accommodate change, less able to spring back when pressures on abundance diminish, and less able to respond to management interventions. Australian populations of the pig-nosed turtle *Carettochelys insculpta* have exceptionally low genetic diversity compared with their New Guinea counterparts (Matt Young *in litt*. with DAWE 2022), a likely combined result of the founder effect and sustained bottlenecks in environments in Australia less well suited to supporting high population abundances.

FIRST NATIONS KNOWLEDGE

Indigenous peoples have much to contribute to policy formulation for threatened species management, recovery, and action plans arising from those policies and the implementation of those plans. Indigenous knowledge is deep, having been accumulated through observation and experimentation over many generations. The veracity of this knowledge has been continually tested through collaboration across countries and against its value to the subsistence economy and culture of First Nations people. Indigenous knowledge complements that which is generated by contemporary scientific approaches, and there are many cases where Indigenous knowledge has informed scientific investigations in unique and valuable ways. Globally, there appears to be a resurgence in the recognition and valuing of Indigenous knowledge in policy and debate (Howard et al., 2011; Gómez-Baggethun et al., 2013; IUCN, 2020: Mauro & Hardison, 2000). However, the progressive loss of localized knowledge continues (Aswani et al., 2018: Horstman & Wightman, 2001).

Recognition and use of Indigenous Ecological Knowledge in Australian conservation varies considerably by region influenced by patterns of colonization and hence the ability of First Nations to freely access their lands and reinforce their knowledge within the changing climate (Ens et al., 2021: Whitehead et al., 2003). Customary land management in some parts of central and northern Australia remains an unbroken practice (ASRAC, 2017; Ross et al., 2009; Yibarbuk et al., 2001), whereas in densely populated regions of south-eastern Australia and areas where people were unable to maintain connection to land, the use of such knowledge is limited in comparison (Ens et al., 2021), although stories of some enduring conditions and technology are retained. Traditional knowledge is sustained through continuous relationships between plants, animals, natural phenomena, landscapes, and timing of events that are useful to local peoples. When utility and relevance are lost, the knowledge transferred verbally from one generation to the next risks being diluted or even lost. Fostering opportunities for young people to interact with their elders and traditional owners of the land on their country (Figure 5) is one of the highest priorities for many Indigenous communities because this is central to maintaining their culture, including maintaining Indigenous ecological knowledge. Indigenous Protected Area programme of Australia (established 1997) and government-funded Indigenous Ranger programmes (starting as 'Working on Country' in 2007), have seen a rise in the wider acknowledgement and use of Indigenous ecological knowledge in Australian conservation (Ens et al., 2015). However, the use of Indigenous ecological knowledge beyond Aboriginal communities and into mainstream consciousness arguably remains limited and poorly integrated into contemporary conservation. This was acknowledged in Freshwater Turtle SEAP by an attempt to engage Australia's First Nations People in addressing the challenges of species assessment and the inclusion of Indigenous ecological knowledge in the species listing assessments and conservation advice.

FIGURE 5 Wildlife utilization is an under-explored avenue for small-scale commercialization by Indigenous communities and importantly, for engaging Indigenous youth in culturally meaningful activities that take them on to traditional lands and increase interaction with traditional owners. Shown here are preparations for the incubation of the eggs of the northern snake-neck turtle, *Chelodina rugosa*.
Photo: Arthur Georges, Maningrida.

At the commencement of the Freshwater Turtle SEAP, an engagement plan was prepared establishing guiding principles, including protection of cultural intellectual property, approval processes, ethical engagement, methods, and objectives. Indigenous land management groups and First Nation organizations were mapped to the ranges of all freshwater turtle species of interest. A search of all published and publicly available information of cultural significance was undertaken. Conservation Advice documents developed through the wider SEAP process incorporated cultural significance by first undertaking an initial mapping. Where published information was available, it was used. Where unpublished or no information was found, First Nations organizations were contacted directly, informed of the project, and asked for their involvement. Over 70 First Nation organizations were contacted. Workshops were organized in the Northern Territory and Queensland, where target species were clustered. However, engagement was obstructed by the COVID-19 Pandemic, and this limited in-person consultation to the Northern Territory. Feedback for the Northern Territory workshop was very positive and seen as an opportunity to advance conservation conversations and agenda on a larger scale. This was considered an important initiative, especially as the quality of and satisfaction with consultation was greatly reduced when not conducted in person. This was foreseeable given the known preferred engagement process by First Nations but unavoidable given the tight timelines of the project in the context of the Pandemic. Future projects need to operate on longer timescales and consider the most appropriate means for discussions with First Nations people on these important issues. All information obtained during consultations was drafted into written text and shared with contributors for further edits and approval. Our work should be seen as a tentative start to a process that will require much more substantial input over a longer period than the single year duration of our project.

Another important factor in this consultation is that the information sought by ecologists is often from a different framing than that in which knowledge is shared in the community; hence, it takes the community time to translate or interpret what is requested. Freshwater turtles are a significant part of Aboriginal culture, as part of dreamtime stories, art, cultural practice, and ceremony, and as customary food sources (Cann, 1998, pp. 43–45; Cann & Sadlier, 2017, pp. 1–12; Ferronato & Georges, 2023), associated with the ongoing significance and responsibilities for the preservation of freshwater turtles. What part of this knowledge is suitable or appropriate for sharing needs to be considered by participants. The challenges for effectively incorporating Indigenous ecological knowledge in contemporary systems were identified from all quarters; in feedback received from First Nations participants, researcher observations, and expert comments during and following engagement on freshwater turtles.

Notwithstanding this process, it is important to note that the significance of ecological communities, particular species, spiritual, and other cultural values is diverse and varied for the many Indigenous peoples that live in a particular area and care for their country. This account is not intended to be comprehensive or applicable to, or speak for, all Indigenous people. Such knowledge may be only held by Indigenous groups and individuals who are the custodians of this knowledge. As a result, the SEAP project generated recommendations for further integrating and recognizing Indigenous ecological knowledge in Australia in an inclusive and meaningful way for the benefit of Australia's biodiversity and its people.

Possibly the most poignant observation to emerge from a number of sources is the need to move from Indigenous engagement to a marriage. The term 'engagement' is often seen as a loaded term, derived from a somewhat one-sided perspective of mainstream western society reaching out to Indigenous communities to draw their knowledge into western policy frameworks and implementation. What many Indigenous communities expect is a more even-handed relationship, a 'marriage', where First Nations people work together with and as part of the broader Australian community to chart solutions for biodiversity management, including threatened species management. This both-way learning includes western ecologists understanding how knowledge is shared as much as the knowledge itself. Our Conservation Advice documents capture what we could in the time available to include a cultural perspective on each species – its traditional cultural and utilitarian value – from a First Nations perspective. The inclusion of a broad statement of cultural significance of the species under consideration in all Conservation Advice documents is welcome. However, the Indigenous communities we interacted with hope for more than this. They expect better mechanisms for incorporating Indigenous knowledge to complement that of western scientists in providing the foundation for decisions on listing. They would like to see greater clarity in the process by which Indigenous knowledge can be included in the evidence that supports the final listing, given that Indigenous knowledge is not typically published via scientific outlets yet provides a much deeper understanding of the ecological system in which these species reside, and the effect of any intervention into this system. Given a strong imperative from First Nations people to create opportunities for their young people to engage with elders and traditional owners on the country, there was strong support for an explicit requirement in Conservation Advice documents to include First Nations perspectives in the recommendations for action arising from the advice.

Effective engagement with First Nations people takes time and is built on trust, it needs to be conducted in ways commensurate with the decision-making processes of First Nations, and it typically requires multiple engagement opportunities and consultation with the country. It is not an exercise that can be rushed or that can be in any way superficial, it must have clearly defined outcomes and should be considered an ongoing process. Furthermore, the process of consultation has been led within a western framework of what to consider and what focus is to be used, which is often at odds with the Indigenous approach (Robinson, 2016). For instance, the discussion of one species would usually not be conducted within the Aboriginal community without considering related species, such as their opposite in moiety, as a way of maintaining balance in the environment (Bell, 2014). Also, an area of land would not be considered without acknowledging the paths or storylines that track through that country and link to other species and resources. Understanding such structures of Indigenous knowledge is required for appreciation of the way this knowledge maintains sustainable practice.

Engagement translates to marriage when First Nations people are given a voice in determining recommendations for actions in the Conservation Advice, but also when they are integrally involved in implementing recovery plans and action plans on the country. For Aboriginal people, another participant in this marriage is the country, and they are giving voice to that country (Robinson, 2016), or even some say re-creating country through their activities. Because implementation is often the responsibility of the States, this will require explicit attention during negotiations between the Australian government and the state governments, which involve First Nations in decision-making when working on the formulation and implementation of actions on the ground to improve the conservation of threatened species. This includes supporting the generation of new knowledge to bring data-deficient species to a point where well-supported listing decisions can be made and respecting that there may be disagreement over preservation methods. For instance, total bans on hunting may not be appropriate in the First Nations context, where hunting involves caring for the country and managing the environment for that species (Robinson, 2016). True progress can be claimed when First Nations people are consulted, respected, engaged, and empowered to lead on-ground actions on their traditional lands when the EPBC Act is invoked in response to development proposals. First Nations people should be integrally involved in bringing their knowledge to the table when the EPBC Act 1999 is triggered and in the on-ground investigative processes that follow such a trigger.

The attitudes of First Nation peoples towards consultative processes such as those outlined here vary considerably among Indigenous communities and groups. A primary determinant of this diversity is the degree of disenfranchisement. Much can be done to build trust and constituency in the processes of government where it involves engagement and consultation with First Nations people and, more importantly, control of the consultation methods and the context of the study. Engagement should involve all levels of decision-making in the EBPC processes. These recommendations highlight the challenges to be overcome if Indigenous ecological knowledge and cultural significance are to be recognized and integrated into Australian conservation agendas and systems, such as species assessments and resulting conservation advice and plans. The SEAP process undertaken in 2021 sought to collect broad statements of cultural significance, content for freshwater turtle species was gathered and submitted on 13 draft Conservation Advice documents. To effectively and meaningfully include First Nations knowledge in species listing under the EPBC Act, additional actions arising out of the above recommendations must be considered, including the contribution of Indigenous knowledge to evidence that affects or supports the final listing, explicit attention to actions to involve first Nations people in management and recovery actions on the ground, and involvement of First Nations people in bringing their knowledge to the forefront when the EPBC Act is triggered.

ROLE FOR CITIZEN SCIENCE

Citizen science has become an increasingly popular tool for engaging scientists with the public. Citizen science allows scientists to communicate their research in a more accessible way, whilst increasing their access to large quantities of data that may have been difficult or otherwise expensive to collect without the help of members of the public. Citizen science can play a crucial role in the conservation of freshwater turtles, in part because, among reptiles, turtles are viewed as unthreatening and thus with greater empathy. Dependable observations on population trends and the development of efficient conservation strategies, the establishment of foundational datasets, the rigorous assessment of data quality, the verification of observations through photographs, field visits, or independent surveys, as well as the adjustment for biases and uncertainties, are imperative prerequisites for harnessing the full potential of citizen science. Citizen science can also act as a STEM education tool, whereby participants learn experientially about their species of interest (Santori et al., 2021). This has been reflected in the uptake of citizen science programmes and mobile applications worldwide.

In 2018, the Urban Turtle Project (https://www.urbanturtleproject.org/, Accessed 9th May 2023) was initiated in Alabama, the United States, with the goal of building a long-term data set on the demography and ecology of turtle populations in urban waterways of Birmingham, Alabama, and increasing public awareness of the state's chelonian diversity (Coleman, 2020). In India, a citizen science initiative between the Indian Turtle Conservation Action Network and WCS/TSA India Turtle Conservation Program saw the launch of KURMA-Tracking, a mobile application used to educate the public on the ecological importance and threats to turtles and tortoises in India. KURMA also contributes to scientific data collection by recording turtle sightings, including illegal activities and rescues (Dutta et al., 2020). In Australia, TurtleSAT (https://TurtleSAT.org.au, Accessed 27th March 2023) was introduced in 2015 and allows the public and community groups to report turtle sightings, critical habitat for nesting, road mortality hotspots, and predation levels (Figure 6). This information can be used to map turtle distribution and relative abundance, identify areas of high conservation value, and inform management decisions.

TurtleSAT is part of the 1 Million Turtles community conservation Program (https://1millionturtles.com/, Accessed 27th March 2023). The 1 Million Turtles Community Conservation programmes have been instrumental in engaging citizens in turtle conservation and connecting them with nature in their local environments. One million Turtles is unique among Citizen Science programmes in that the programme facilitates the public and local community groups to take a hands-on approach to conservation by participating in activities such as nest monitoring, turtle rescues, habitat restoration and the construction of turtle islands for nesting. The programme also raises awareness about the importance of turtles in our ecosystem and the threats they face. By empowering citizens to take an active role in conservation, the programme changes attitudes towards science and

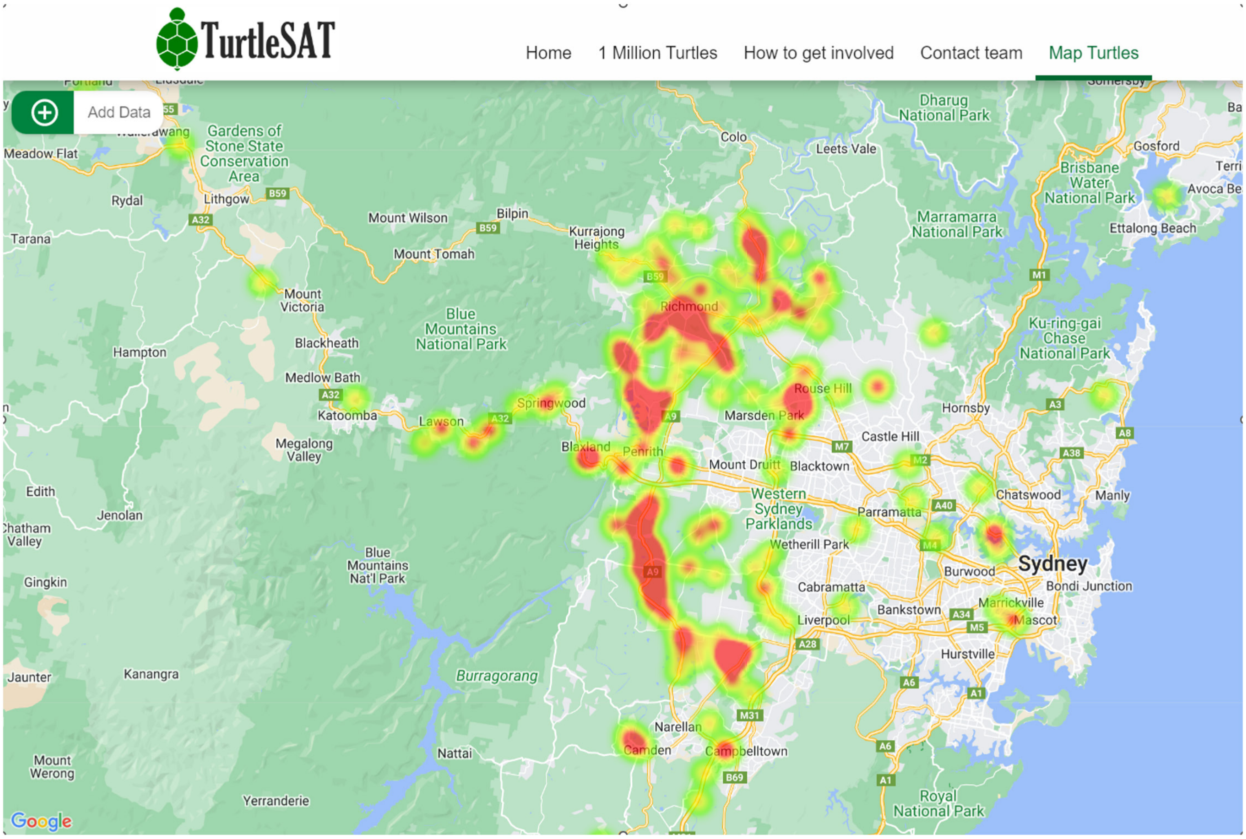

FIGURE 6 Real-time hotspots of turtle mortality are available as part of a suite of data visualization tools through the TurtleSAT citizen science reporting app.

technology and encourages more people to get involved in scientific research. It helps build constituency behind science.

CONCLUDING REMARKS

Turtles date back in the fossil record to the Late Triassic (Anquetin et al., 2017), which places them amongst the oldest lineages of reptiles. Their unique body plan and life history strategies have led to this success and permitted them to survive in diverse environments and to persist through substantial geological and climatic changes. Globally, turtles are now in trouble (Stanford et al., 2020), and Australia' turtles are no exception. However, the unique challenges presented by our climate, the stability of our landscape, and the fragility of our systems under continual assault from development mean that we have to craft our own solutions. We cannot simply import them from elsewhere. The same is true of managing the wetlands and waterways that provide habitat for turtles. Indeed, many of the threats faced by Australia's turtle fauna can be addressed by improved, appropriate management of our inland waterways and wetlands more generally. Habitat modification and degradation, altered flow regimes, invasion by exotic weeds, the impact of feral pests, and the uncertainty introduced by climate change affect all aquatic and semi-aquatic species and cannot be addressed solely by a specific focus on turtles. Given their popularity with the public, turtles may be effective charismatic species whose plight could be used to champion changes that will benefit aquatic ecosystems as a whole. The challenge is to bring the conservation needs of turtles and the refugia and habitats critical for their long term persistence to the table when the broader issues of conservation of wetlands and other inland waters or catchment-wide impacts of fire are discussed. Coupled with this is the need for better appreciation of the role freshwater turtles play in ecosystem dynamics (Lovich et al., 2018; Santori et al., 2020). In Australia, this challenge is primarily hampered by the view of much of the public, stoked by the media and the agricultural industry, that water is simply a resource for human activities and that the use of water to support endemic Australian ecosystems is wasteful (Davies, 2019). Countering this view is one of the great challenges faced by conservationists in Australia (Grafton et al., 2020).

Some species are well represented in protected areas such as national parks, but most of Australia's turtle biodiversity resides outside protected areas, in wetlands and waterways of rural lands, in areas dedicated to agricultural or industrial activity, or in urban landscapes. Their conservation relies on interfacing with the government, conservation agencies, indigenous communities, and pastoral and agricultural communities to achieve conservation actions and outcomes that are often achievable and commensurate with production goals. Irrigation storages are potential refugia for aquatic species, including turtles, in addition to being a way to provide water to agricultural landscapes. Conservation requires building constituency in the broader community in support of turtle conservation through education on the plight of freshwater turtles and the options available for their conservation management so that communities can engage with scientists to achieve the changes and outcomes required. Citizen science not only brings many hands to address the on-ground challenges of turtle conservation but also raises awareness and builds constituency behind the need for action by governments, by industry, and by local communities including Traditional Owners. Furthermore, citizen science provides an opportunity to give local citizens the skills, knowledge, and tools to drive their own conservation initiatives. They can then identify hotspots of turtle activity and work with local councils or land management agencies to protect those areas. As researchers, we can contribute to this process by providing scientific evidence and guidance, facilitating discussions between stakeholders in government and the public (both with whom we interface), and providing support for grant writing and scientific licencing applications.

Bringing Indigenous knowledge and perspectives to species conservation is important and needs to go beyond a token acknowledgement of the value of particular species to Indigenous culture and practices. Opportunities exist to work with Indigenous communities in setting priorities for the conservation of freshwater turtles and to engage Indigenous communities and youth in on-ground activities associated with management, research, monitoring, and remediation. Researchers should build lasting working relationships with First Nations communities in their areas of expertise to facilitate knowledge transfer in both directions and provide funded opportunities for First Nations People to prioritize their own conservation interests. This is done well in some cases, but much more can be done in the context of species conservation.

Species conservation requires commonality of purpose and agreement on priorities for action – a collaborative approach to data collection and use, and an agreed framework for minimal baseline data required to support decision-making. The common assessment method (CAM) and the SEAP process bring state and national governments together and is an important element of the equation, but more needs to be done to provides a framework for discussion of priorities for knowledge generation, setting of priorities, and action on the ground. The top priorities for conservation planning for freshwater turtles are to redress the knowledge gaps that prevent adequate modelling in support of PVA and other analyses and other criteria applied under the EPBC Act. There is a pressing need for research on the basic biology, natural history, and ecology of all species to better inform conservation management in what is a rapidly changing environment, particularly impacting on inland waters. Special attention needs to be given to the 12 species that were data deficient to the point that no determination of status under the EPBC Act was possible. This fundamental research, too, requires coordination across multiple agencies. We hope this paper will contribute to the planning processes for freshwater turtles.

AUTHOR CONTRIBUTIONS

Kristen Petrov: Conceptualization (equal); data curation (equal); investigation (equal); project administration (equal); writing – original draft (equal). **Sarah Sutcliffe:** Conceptualization (equal); data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); writing – original draft (equal). **Helen Truscott:** Data curation (equal); formal analysis (equal); investigation (equal); methodology (equal); writing – review and editing (equal). **Cat Kutay:** Validation (equal); writing – original draft (supporting). **Carla C. Eisemberg:** Conceptualization (equal); formal analysis (equal); investigation (equal); writing – original draft (equal). **Ricky J. Spencer:** Conceptualization (equal); funding acquisition (equal); investigation (equal); writing – original draft (equal). **Ivan Lawler:** Formal analysis (equal); methodology (equal); writing – original draft (equal). **Deborah S. Bower:** Conceptualization (equal); investigation (equal); writing – original draft (equal). **James Van Dyke:** Writing – original draft (equal). **Arthur Georges:** Conceptualization (lead); funding acquisition (lead); investigation (equal); project administration (lead); writing – original draft (equal).

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Author IL is employed by the Department of Climate Change, Energy, the Environment, and Water, the department that funded the SEAP project, which forms the basis of much of what is included in this paper. Author AG is a director of Biomatix Pty Ltd.

ORCID

James U. Van Dyke https://orcid.org/0000-0002-3933-111X
Arthur Georges https://orcid.org/0000-0003-2428-0361

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