Lintermans, M., Geyle, H.M. Beatty, S., Brown, C., Ebner, B., Freeman, R., Hammer, M.P., Humphreys, W.F., Kennard, M.J., Kern, P., Martin, K., Morgan, D., Raadik, T., Unmack, P.J., Wager, R., Woinarski, J.C.Z., and Garnett, S.T. (2020) Big trouble for little fish: identifying Australian freshwater fishes in imminent risk of extinction. *Pacific Conservation Biology,* Vol. 26, Iss. 4, 365-377.

DOI: https://doi.org/10.1071/PC19053

Big trouble for little fish: identifying Australian freshwater fishes in imminent risk of extinction

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Summary text

Australian freshwater fishes have typically been neglected in conservation planning, despite evidence of catastrophic declines. Here we use structured expert elicitation to identify the Australian freshwater fishes in imminent risk of extinction. All 22 taxa considered had moderate to high (> 40%) likelihoods of extinction in the next two decades. Using conservation progress metrics, we identify priority management needs for averting future extinctions.

Abstract

Globally, freshwater fishes are declining at an alarming rate. Despite much evidence of catastrophic declines, few Australian species are listed as threatened under national legislation. We aim to help redress this by identifying the Australian freshwater fishes that are in the most immediate risk of extinction. For 22 freshwater fishes (identified as highly threatened by experts), we used structured expert elicitation to estimate the probability of extinction in the next ~20 years, and to identify key threats and priority management needs. All but one of the 22 species are small (<150 mm total length), 12 have only been formally described in the last decade, with seven awaiting description. Over 90% of these species were assessed to have a >50% probability of extinction in the next ~20 years. Collectively, the

biggest factor contributing to the likelihood of extinction for the freshwater fishes considered is that they occur in small (distributions ≤44 km^2), geographically isolated populations, and are threatened by a mix of processes (particularly alien fishes and climate change). Nineteen of these species are unlisted on national legislation, so legislative drivers for recovery actions are largely absent. Research has provided strong direction on how to manage approximately 35% of known threats to the species considered, and of these, about 36% of threats have some management underway (although virtually none are at the stage where intervention is no longer required). Increased resourcing, management intervention and social attitudinal change is urgently needed to avert the impending extinction of Australia's most imperilled freshwater fishes.

Additional Keywords: alien species, anthropogenic mass extinction crisis, biodiversity conservation, climate change, Delphi, IDEA, introduced species, threatening processes

Running head: big trouble for little fish

Introduction

Global extinctions are occurring at an accelerating rate in response to a mix of human-driven threats (Johnson *et al.* 2017), and this is likely to continue to increase over time (Ceballos *et al.* 2015). Freshwater fishes are the largest vertebrate group (~17,750 species), and freshwater habitats are arguably the most imperilled globally (Dudgeon *et al.* 2006; Dudgeon 2011; Vorosmarty *et al.* 2010; Reid *et al.* 2019). Therefore, the conservation of freshwater fishes and their habitats should be of major concern in maintaining our biological inheritance.

Freshwater environments are imperilled for several reasons: (i) they are limited in extent—only ~3% of the water on earth is fresh and only ~0.29% of global freshwaters are liquid (i.e. not frozen in polar ice caps) and available for most fishes (i.e. not underground) (Gleick 1996); (ii) they are subject to escalating water extraction and regulation (domestic, agricultural, aquaculture, hydropower, industry and urban uses); (iii) the quality of freshwaters continues to decline as a result of anthropogenic use and alteration (e.g. habitat loss and water extraction). Freshwaters are the 'receiver' of sundry terrestrial perturbations and degradation (i.e. they are at the bottom of landscapes and so receive elevated levels of sediment and pollutants); (iv) river systems are linear with large edge to area ratios and so are extremely prone to fragmentation; (v) they are spatially isolated (limiting fauna movements between adjacent catchments), and often fragmented; and (vi) they are increasingly invaded and occupied by alien species (Dudgeon 2011; Reid *et al.* 2019)..

Each of these factors is contributing to the decline of freshwater fishes, which has been catastrophic in some parts of the world. For example, the Living Planet Index (LPI) shows a decline in monitored freshwater vertebrate populations (mostly fishes) of 84% between 1970 and 2014 (WWF 2016; WWF 2018). Likewise, in Australia, freshwater fishes have fared poorly, with many species suffering from catastrophic declines since the 1950s (Lintermans 2013a; Lintermans 2013b). This decline has been attributed to habitat loss, introduced species, alteration to natural flow regimes, fragmentation, water pollution and overexploitation (Duncan and Lockwood 2001; Dudgeon *et al.* 2006; Vorosmarty *et al.* 2010); threats which are unsurprisingly similar (with the exception of altered flow regimes) to those facing terrestrial environments. However, many additional threats to freshwater environments are emerging (e.g. climate change, expanding hydropower, infectious diseases), and so the need to ameliorate the dynamic pressures on freshwater environments is even more pressing (Reid *et al*. 2019).

Along with other signatories to the Convention on Biological Diversity, the Australian government has committed to avoiding further extinctions (United Nations 2015; Department of Environment and Energy 2016), a task that first requires identification of the species at most immediate risk. Typically, this is achieved using statutory threatened species lists, but such lists are reactive rather than proactive; i.e. they usually require considerable time to update, and so may not be the best way to prioritise urgent actions (Possingham *et al.* 2002; Wilcove and Master 2005). Furthermore, these lists are often not comprehensive or up-to-date. For example, in August 2019, the number of freshwater fishes listed under the Australian Government's *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), was 38, whereas the non-statutory national threatened species list of the Australian Society for Fish Biology (ASFB) contained 61 species (Lintermans 2017) out of the 315 freshwater fish species so far accepted as occurring in Australia. Not only are few of Australia's imperilled freshwater fish species listed under the EPBC Act, but the addition of fish species to that list has been especially slow since the mid-2000s. In particular, small-bodied species are often neglected, with larger species (usually targets for commercial, artisanal and recreational angling) capturing the most public attention (Reynolds *et al.* 2005; Ellis *et al.* 2013; Saddlier *et al.* 2013).

Imperilment can be recognised not only in the size and composition of official lists of threatened species, but also through mathematical models that estimate extinction risk based on life history parameters and population growth rates (e.g. Population Viability Analysis, PVA). However, this approach requires high quality data to achieve reliable outputs (Coulson *et al.* 2001), which are typically not available for threatened species (Martin *et al.* 2012). In this context, a useful alternative source of knowledge may come from experts (Hemming *et al.* 2018). Experts have acquired learning and experience that allows them to provide valuable insight into the behaviour of environmental systems (McBride *et al.* 2012). They are able to synthesize multiple risks and probabilities in ways that may be intractable for numerical models (Geyle *et al.* 2018) or within the administrative structures of government listing processes. Furthermore, the variation in experience and risk perception among experts allows for the development of multiple "mental models" from the same empirical data, where integrating the opinions of multiple experts may be seen as an exercise in model averaging (Symonds and Moussalli 2011).

Structured elicitation protocols have been developed in an attempt to counter some of the cognitive and motivational biases commonly encountered in expert elicitation (McBride *et al.* 2012). These approaches employ a formal, documented, and systematic procedure that encourages experts to cross-examine evidence, resolve unclear or ambiguous language and think about where their judgements may be at fault or superior to those of others (McBride *et al.* 2012; Hemming *et al.* 2018).

In this paper, we used structured expert elicitation to estimate extinction risk for Australia's most imperilled freshwater fishes, with the aim of improving prioritisation, resourcing, and direction of management for preventing future extinctions. Specifically, we aimed to:

i. Estimate the probability of extinction (in the wild) in ~20 years' time for the subset of Australian freshwater fishes identified to be at most immediate risk of extinction (by experts in freshwater fish ecology) using structured expert elicitation;

ii. Identify key threats, and our progress towards alleviating the impacts of those key threats using the conservation progress metrics developed by Garnett *et al*. (2018); and

iii. Identify ongoing policy and management needs for the prevention of future extinctions of Australia's most imperilled freshwater fishes.

Our approach follows estimates of imminent extinction risk among Australian birds and mammals (Geyle *et al.* 2018). Note that this assessment for freshwater fish preceded the 2019-20 wildfires in Australia, which are likely to have severely worsened the conservation outlook for many freshwater fish species.

Materials and methods

Initial selection – fishes at greatest risk of extinction

The ASFB Threatened Fishes Committee (TFC) contains science representatives from all Australian states and territories. It has maintained a non-statutory national threatened fish listing since 1985, and has assessed species against IUCN criteria since 1997 (Lintermans 2013b). For the current study, the ASFB TFC produced a list of freshwater fishes at high risk of imminent extinction (i.e. within the next ~20 years) based on expert review (undertaken by the TFC and external experts). From a total candidate list of ~90 freshwater fish taxa (either listed as threatened by the ASFB TFC (Lintermans 2017), or species recently recognised (but undescribed) and considered threatened as at early 2018), an initial shortlist of 37 taxa was assembled. Twenty experts (selected based on their experience and knowledge of freshwater fishes in particular regions) then scrutinised this shortlist to evaluate threats, recent population trajectories, and initial estimates of extinction risk, with the aim of identifying the taxa most likely to become extinct in ~20 years (assuming no changes to current management). After 12 weeks of detailed correspondence and information review, a final list of 22 taxa (including both described and undescribed species) from eight genera was produced for detailed assessment (Table 1). Notably, only three taxa in this list had been designated as threatened under the EPBC Act as of November 2019 (Table 1).

Structured expert elicitation

Fifteen of the 20 experts participated in a workshop to estimate freshwater fish extinction probabilities using structured expert elicitation (approach adapted from the Delphi and IDEA methods; see Burgman *et al.* 2011, McBride *et al.* 2012 and Hemming *et al.* 2018). Our elicitation procedure involved five main steps:

i. Prior to the workshop experts were provided with a summary of relevant information on each taxon based on published literature, unpublished reports and information provided by taxon specialists (including from some who did not attend the workshop). This information on biology, habitat requirements, population parameters, geographic range, historical and predicted rates of decline and threats was provided so that all experts had the same information available when making assessments about extinction risk for a given taxon. This information was also given greater context during a presentation to the workshop led by relevant taxon specialist(s).

ii. Following presentations on all of the taxa under consideration (with opportunity for workshop participants to seek clarification from the presenting experts), experts were asked to provide an initial estimate of the probability of extinction in the wild (within the next ~20 years) of each taxon (scaled from 0–100%), *assuming a continuation of current levels and characteristics of management*. Additionally, experts provided a level of confidence in each of their estimates (very low, ≤ 20%; low, 21–40%; moderate, 41–60%; high, 61–80%; or very high, ≥ 80%).

iii. Individual estimates of extinction probability were compiled, and then modelled using a linear mixed-effects model ('lme' in package 'nlme') in R 3.6.0 (R Core Team 2019), where estimates were logit-transformed prior to analysis. We controlled for individual experts consistently underestimating or overestimating likelihood of extinction by specifying their identity as random intercepts. We specified a variance structure in which the variance increased with the level of uncertainty associated with each estimate of likelihood of extinction. Confidence classes of 'very low', 'low', 'moderate', 'high' and 'very high' were converted to uncertainty scores of 90, 70, 50, 30 and 10% respectively. This model allowed us to predict the probability of extinction (with 95% confidence intervals) for each taxon. Predicted probabilities and confidence intervals were then displayed graphically, in order of predicted imperilment. Summary statistics (mean, median and range) were also provided, so experts could compare their estimates to those made by the rest of the group.

iv. A facilitator drew attention to major discrepancies between experts, triggering a general conversation about the interpretation and context of background information for each taxon. Each taxon specialist(s) was then given the opportunity to clarify information about the presented data, introduce further relevant information that may justify either a greater or lesser risk of imminent extinction, and cross-examine new information.

v. Experts then provided a second assessment of the probability of extinction (and the associated confidence in their estimate) for each taxon.

Testing for concordance among expert assessments

We measured the level of agreement among experts in the relative ranking of the most imperilled freshwater fishes using Kendall's Coefficient of Concordance (W) (Kendall and

Babington Smith 1939). This test allows for comparison of multiple outcomes (i.e. assessments made by multiple experts), whilst making no assumptions about the distribution of data. Average ranks were used to correct for the large number of tied values in the dataset.

Progress towards conservation – threat assessment and identification of management needs

We used the approach developed by Garnett *et al.* (2018) to assess progress in understanding and alleviating the impacts of the threats facing Australia's most imperilled freshwater fishes. This has five components: (i) identifying the threats affecting each species; (ii) assessing the timing, scope and severity of those threats (IUCN 2012) to identify which are having the greatest impact; (iii) assessing our level of understanding of how to manage each threat; (iv) assessing the effectiveness of management attempts aimed at alleviating threat impacts; and (v) assembling the data into metrics of progress for individual taxa or threats (e.g. current threat impact, research and management need, research and management achievement, see Supplementary Material S1 for more information). These metrics allow for ready comparison of large numbers of threatened taxa and threatening processes and may be aggregated to understand trends in conservation success for an individual taxon through time or for threats across multiple taxa and locations.

Results

Most imperilled fishes – taxon summaries

The current relevant knowledge on each of the 22 taxa under consideration (used to justify the expert assessment that they are at greatest risk of extinction in the next 20 years) is summarised in Supplementary Material S2. Each of the 22 fish taxa considered here is extremely range-restricted and endemic to a single Australian state, with a maximum current range (Area of Occupancy, AOO) of 44 km^2, an average AOO of ~18 km^2, with most (~68%)

having an AOO ≤16 km^2 (Table 1). The 22 taxa are widely scattered across Australia with the majority located in southern Australia (Fig. 1). Fourteen taxa are from the family Galaxiidae, with three rainbowfishes (Melanotaeniidae), and three percichthyids. All but one (*Gadopsis* sp., with body size of ~150-240mm) are small-bodied (adult size <150 mm total length).

Likelihood of extinction

Collation and analysis of expert opinion indicated that 20 of 22 fish taxa (i.e. >90%) are at high risk (probability of extinction >50%) of becoming extinct within the next ~20 years (Fig. 2). The taxa with highest estimated extinction risk are the Shaw galaxias (*Galaxias gunaikurnai*) and the West Gippsland galaxias (*G. longifundus*) (both with >80% likelihood). No taxon had a <40% likelihood of extinction. There was a reasonable and highly significant degree of conformity among experts in their assessments of extinction risk for most species ($W = 0.37$, $p = <0.001$).

Progress towards conservation – threat assessment and identification of management needs

Across the 22 taxa considered, there was a total of 152 threats identified covering 40 different categories (IUCN Threats Classification Scheme, Version 3.2, IUCN 2019), with an average of 6.9 threats per taxon. For ~35.5% of the threats affecting the 22 taxa, research has provided strong direction on what needs to be done to manage them. However, for the majority of threats, there is little or no understanding on how to manage them effectively (Fig. 3a). About 36% of the threats facing the most imperilled freshwater fishes have some management underway, but only one threat (deliberate disposal of industrial effluents, for the Barrow cave gudgeon *Milyeringa justitia*) is at the stage where solutions are being achieved without continued conservation intervention (Fig. 3b).

Current threat impact, research need, and management need was greatest for the Daintree rainbowfish *Cairnsichthys bitaeniatus* and Malanda rainbowfish *Melanotaenia* sp. (Table 2), in part because these taxa are affected by the most threats (12 and 11 respectively, Supplementary Material S3). The Malanda and Running River rainbowfish *Melanotaenia* sp. had higher research and management achievement scores than other taxa, suggesting that more progress has been made in alleviating at least some of their threats. For example, translocations have been undertaken to new creeks to minimise the chances of hybridization (Unmack *et al.* 2016; Moy *et al.* 2018). All of the galaxiids had similar and reasonably high scores for all metrics (Table 2), reflecting the similarities in threatening processes facing each taxon in this group (foremost alien trout intrusion/predation, followed by fire and drought, Supplementary Material S3).

Climate change had the greatest scores for current threat impact, research need and research achievement, likely because it affects all of the taxa under consideration and is generally considered to be of high consequence. Moreover, in almost every case there is some, if limited, understanding of the long-term potential effects of climate change. Alien species had the greatest scores for management need and management achievement, which was largely driven by the continued threat of alien trout invasion of galaxiid streams, and because collectively, the most progress has been made in attempting to control alien species (e.g. Raadik *et al.* 2015), or raising awareness about their impacts (although this has not necessarily been effective) (Fig. 4).

Within the broader climate change category (i.e. considering the threat categories at their most specific level, Table 3), an increase in the frequency or intensity of storms and floods scored highest, followed closely by drought (Table 3), with both threats affecting >80% of the taxa under consideration. Of the alien species known to affect the 22 taxa under consideration, alien trout (*Salmo trutta, Oncorhynchus mykiss*) posed the greatest threat, followed by eastern gambusia (*Gambusia holbrooki*) (Table 3). However, the biggest factor affecting the most imperilled freshwater fishes (with the highest collective score for current threat impact, research need and management need, Table 3), was that almost all of them have suffered range contractions, and now persist only as a few (or in some cases single) small, isolated populations. This means they are highly vulnerable to a single catastrophic event (e.g. alien trout invasion, fire, or extreme weather) which could rapidly lead to extinction. Research and management achievement was greatest for efforts to control the threat posed by trout, though we acknowledge that this management response often occurs without ongoing funding commitments, and is only one component of long-term effective trout management strategies. There was little or no achievement for management of climate change (Table 3). The raw data used for the threat assessment and worked calculations are available in Supplementary Material S3.

Discussion

Up-to-date assessments of conservation status and estimates of extinction risk are essential for targeting conservation management (Harris *et al.* 2012; Reece and Noss 2014). This is even more important for unlisted species that do not yet have the legislative drivers provided by statutory listing (Donlan 2015). At a time when the number of listed threatened taxa is rapidly growing, and funding currently available for recovery is insufficient to meet the management requirements across all threatened taxa (Gerber 2016; Allek *et al.* 2018), this study provides critical evidence that can help redress the substantial shortcomings in, and need for, the conservation of freshwater fishes in Australia.

Overall, experts were pessimistic about the status of the most imperilled freshwater fishes, with modelled probabilities of extinction, assuming current management, exceeding 40% for all of the taxa under consideration. Alarmingly, 20 taxa (i.e. ~91%) were predicted to be more likely to go extinct than to persist over the next ~20 years. This suggests that the total number of future extinctions may be markedly higher than the figures reported over the previous two decades. In Australia, far fewer freshwater fishes are known to have gone extinct than recorded for mammals, birds, reptiles, frogs, invertebrates or plants (Woinarski *et al.* 2019). In 2019 the first documented Australian freshwater fish extinction was identified (Kangaroo River Macquarie perch *Macquaria* sp.) (New South Wales Department of Primary Industries, unpublished data), while the Pedder galaxias *Galaxias pedderensis* is known to be extinct in the wild (Chilcott *et al.* 2013). There have also been many regional (localised catchment) extinctions (Lintermans 2013b; Morgan *et al.* 2014; Wedderburn and Whiterod 2019).

The 'underwater, out-of-sight' nature of freshwater fishes means there is highly like to have been undetected extinctions, particularly given the high level of cryptic diversity now known to be present in Australia's freshwater fauna (Adams *et al*. 2014, Raadik 2014). Australia has around 275 described freshwater fishes (a total growing rapidly in recent times). However, this figure is likely to be much larger based on an additional ~25% recognised but undescribed species, and a similar proportion of genetically-determined cryptic species (Hammer *et al.* 2013, 2018; Adams *et al*. 2014; Raadik 2014). Many of these undescribed species are likely to be of high conservation concern due to their typically small range sizes, likely array of threats, and general absence of targeted conservation management to mitigate potential threats. This suggests that an increase in the projected number of extinctions over the next two decades is plausible.

Although the relationship between geographic range and conservation status is not always straightforward, a small range does predispose species to a high extinction risk from stochastic events (Purvis *et al*. 2000; Larson and Olden 2010; Pritt and Frimpong 2010), and hence is a commonly applied criterion for assessing conservation status. All 22 taxa considered here have extremely small range sizes and are restricted to a single Australian state or territory. Furthermore, given that 20 of 22 taxa occur in linear habitats (one is a spring endemic, one is subterranean), mostly in small headwater streams (with an average width of 1–3 m), the actual area of occupied habitat in most cases is <1 km^2. All 22 taxa are non-migratory, and so the AOO reflects the true distribution for their entire lifespan, with limited capacity to move away from or around local threats. The precise distribution of the Barrow cave gudgeon is particularly problematic to ascertain or monitor, as it is only recorded from bore-holes (Larson *et al*. 2013). Although bore holes (accessing groundwater—most as anode protection bores) have been drilled on Barrow Island at more than 60 sites over several decades (Humphreys 2000), once capped there is no way to monitor range change or persistence for this taxon.

Another factor that is likely to contribute significantly to extinction risk is the small adult body size of 21 of the 22 species, with small body size in freshwater fish previously documented to be associated with higher extinction risk (Reynolds *et al.* 2005; Olden *et al.* 2007; Kopf *et al.* 2017). Small body size predisposes them to predation by alien species such as trout, which is reflected in the high score for current impact of invasive species. Trout predation on galaxiids is well documented as a driver of local extinction and range contraction (McDowall 2006; Chilcott *et al.* 2013). For the seven non-galaxiids considered in this study, competition/predation by other invasive species such as sooty grunter *Hephaestus* *fuliginosus*, redfin perch *Perca fluviatilis*, eastern gambusia and two species of tilapia (*Oreochromis mossambicus* and *Pelmatolapia mariae)* was identified as a threat, with these invasive fish also previously implicated in declines or predation of small-bodied freshwater fish (Pusey *et al.* 2004; Canonico *et al.* 2005; Pyke 2008; Wedderburn and Barnes 2016)**.**

A notable feature of our results is the generally higher risk of extinction predicted for the most at-risk freshwater fishes relative to a previous study conducted on Australian birds and mammals using the same methods (Geyle *et al.* 2018). The vast majority of freshwater fishes considered in this study (20) were predicted to have a likelihood of extinction >50% in the next 20 years. By comparison, 'only' nine birds and one mammal were predicted to have a likelihood of extinction >50% over the same time period (Geyle *et al.* 2018). This result may reflect, in part, differences in risk perception between the experts who assessed freshwater fishes compared with those who assessed birds and mammals. However, it is more likely that differences in extinction risk among taxonomic groups are real: the intrinsic vulnerability of freshwater fishes to extinction is high, which is congruent with the global pattern of extreme imperilment of freshwater ecosystems (Dudgeon *et al.* 2006; Vorosmarty *et al.* 2010). Most of the fishes considered have far smaller AOOs than most of the highly imperilled birds and mammals, have suffered far more rapid recent declines, have far fewer prospects for recovery or protection, and have received far less management investment. Uniquely, obligate aquatic organisms are also imperilled by the mostly linear and fragmented nature of the habitats they occupy and the loss of the medium they require to breathe and move (water), whereas the loss of air does not occur within terrestrial environments. Also, a common management response for terrestrial vertebrates is the exclusion of predators (e.g. Harley *et al.* 2018; Moseby *et al.* 2018). Predator exclusion is more difficult for fishes, especially where threats exist (or could be introduced) upstream (Lintermans *et al.* 2015). The chances that someone would introduce a feral predator to a mammal enclosure, or a captive bird population are extremely low. By contrast, alien trout and other harvested alien fish species (e.g. redfin perch, sooty grunter) are commonly introduced by members of the public and some agencies into streams (e.g. Lintermans *et al.* 1990; Lintermans 2004; Pusey *et al.* 2004), following which they will almost certainly consume any small native fish persisting there as they spread through the catchment.

As a group, galaxiids dominate the list of Australia's most imperilled freshwater fishes (14 of 22 taxa) with alien trout intrusion the major threat (Jackson *et al.* 2004; McDowall 2006), in addition to suffering from inappropriate fire regimes and climate-related threats. Many galaxiids do not thrive or readily breed in captivity, so their persistence relies on the availability of perennial trout-free streams. However, trout are particularly difficult to manage as they are now widespread in cool freshwater streams in south-eastern Australia, and trout-fishing is strongly supported by socially and politically powerful advocacy groups and state government fisheries agencies (Jackson *et al.* 2004; Hansen *et al.* 2019). On the basis of our assessment, the *status quo* management of trout will result in extinctions of native galaxiids. To avoid such loss, there needs to be improved public awareness of this concern, change in values in key sectors of society and management agencies, improvements in government policy, more targeted and effective management efforts, and better collaboration among those using freshwater ecosystems.

While collaborations with recreational anglers have increased and been essential to the recovery of species like the trout cod *Maccullochella macquariensis*, which is a target native species for anglers (Koehn *et al.* 2013; Lyon *et al.* 2018), there is less enthusiasm in that sector for non-target threatened fishes, though this is changing, and some public support is being given to galaxiids. Nevertheless, a trout introduction by an uninformed or unsympathetic angler could eliminate any of several known galaxiid species. Installation of trout barriers (where possible), and carefully considered translocations (of galaxiids) to establish new populations are keys to ensuring the long-term survival of Australia's threatened galaxiids (e.g. Ayres *et al*. 2012), but these steps are difficult to achieve in a predator-saturated landscape.

Nineteen of the 22 highly imperilled freshwater fishes identified here are not listed as threatened under the EPBC Act (as at May 2020), although all are likely to meet the eligibility criteria. Unlisted taxa are ineligible for the extremely limited national threatened species funding that is sporadically available, and do not have national recovery plans or associated recovery teams; elements that have been shown to improve recovery trajectories internationally (Taylor *et al.* 2005; Kerkvliet and Langpap 2007). Although formal listing does not guarantee that extinction will be prevented (Woinarski *et al.* 2017), there have been some success with EPBC-listed freshwater fish: without listing and recovery actions, there is little doubt that Pedder galaxias and barred galaxias *Galaxias fuscus* would have become extinct in the last few decades, while the Mary River cod *Maccullochella mariensis* would now be near extinction (Lintermans 2013b). The National Threatened Species Strategy (Department of Environment and Energy 2016) focuses solely on EPBC-listed taxa and currently does not contain any identified priority fish for recovery actions.

The assessments of the 22 species reported in this study were subsequently incorporated into a recent IUCN Red List assessment for Australian freshwater fishes, which identified 89 threatened taxa, with a further 16 identified as near threatened (excluding most currently undescribed taxa) (M. Lintermans, unpublished data). The IUCN Red List is recognised as a useful tool for establishing global conservation priorities (Rodrigues *et al.* 2006), however it is non-binding, has no statutory power in Australia and is not designed to distinguish species on a rapid trajectory towards extinction, from those with very small populations that may persist for long periods (Geyle *et al.* 2018; Dirzo *et al.* 2014). Consequently, while it has gone some way to raising awareness of the plight of the 22 species considered, it has had a limited role in galvanising policy and management actions to halt further extinctions.

Our results show that none of the most imperilled Australian freshwater fishes have had all threats reduced to a stage where they no longer need at least some form of ongoing management to persist, and that only one threat (affecting a single species) is at the stage where management is no longer required. The progress values reported here are lower than that reported for the 22 most imperilled Australian birds (identified in Geyle *et al.* 2018), suggesting that more is being done to secure the status of Australia's avifauna, compared with the most imperilled fishes (Garnett *et al.* 2018). For example, Garnett *et al.* (2018) estimated that research was providing strong direction on how to manage about 55% of the threats facing the most imperilled birds, and that about 56% of threats had some management underway (noting that these figures are likely to be conservative given more work has been done to secure some of the most imperilled birds in the time since 2018 when they were calculated). These values for imperilled birds are considerably higher than the comparable figures reported here for the most imperilled Australian freshwater fishes (i.e., ~35% and ~36% respectively).

Recommendations

This study predicts that over half of Australia's most imperilled freshwater fishes may become extinct in the next two decades without immediate and sustained remedial action. To reduce the risk of this happening a series of national management and policy responses are required:

i. Management action are required urgently, even for species not yet formally described, and should not wait for such description.
ii. Similarly, conservation actions should not be delayed until the taxa under consideration are formally listed as threatened under the EPBC Act. The listing process can take several years, and once listed there is no guarantee of Commonwealth funding (see point v).
iii. Nonetheless, there is also a pressing need for the highly imperilled but currently unlisted taxa to be listed formally as threatened under national and state/territory legislative processes, along with the preparation of recovery plans and establishment of recovery teams.
iv. A national freshwater fish action plan, like those available for threatened Australian birds, mammals and reptiles (Garnett *et al.* 2011; Woinarski *et al.* 2014; Chapple *et al.* 2019), is urgently needed. Such a plan will be critical to coordination of recovery efforts for nationally threatened freshwater fishes and coordinated national responses to their threats.
v. Any update of the national Threatened Species Strategy (TSS; Department of Environment and Energy 2016), due in 2021, must include fishes, as well as reptiles, frogs and invertebrates in addition to the 20 mammals, 20 birds and 30 plant taxa prioritised in the first version. If the TSS is not updated, the preparation (and resourcing of implementation) of a national freshwater fish action plan (see point iv above) becomes even more important. Prevention of future freshwater fish extinctions is a national priority. The 22 taxa assessed here are obvious priority candidates.

vi. Recognising that all fish species considered here are extremely range-restricted (each endemic to a single Australian state), and that conservation of Australian biodiversity is a shared responsibility between national and state/territory governments, there is also a need and opportunity for state governments to provide more leadership in the conservation management of imperilled fish species restricted to their jurisdictions.

vii. Climate change was assessed as the major threat overall, affecting all 22 species assessed. Projected changes in rainfall, runoff, air temperatures and the frequency of extreme events (drought, fire, flood) all have significant implications for freshwater fish. A national framework and funding to deal with these issues is urgently required.

viii. Alien fishes (both those introduced from overseas and translocated native species) were assessed here to be a major threat to 20 of 22 highly imperilled fishes. After being suggested almost 20 years ago (Koehn and MacKenzie 2004; Lintermans 2004) and under development since 2007, the national Freshwater Pest Fish Strategy, including for recreational and non-recreation species, needs to be completed and given the national status of a Threat Abatement Plan (TAP). Existing policy initiatives, such as the EPBC Act Key Threatening Process (KTP) on *Novel biota and their impact on biodiversity* (TSSC 2011) and the Australian Pest Animal Strategy (IPAC 2017), are effectively silent on priority alien fishes or priority actions to manage them. In the absence of a TAP for alien fishes, there is no national guidance on how this important threat should be addressed or coordinated, and hence little coherent or effective mitigation.

In conjunction with the national management and policy responses outlined above, urgent on-ground actions are required (sensu Lintermans 2013a). The probability of further extinctions of Australian freshwater fishes in the next two decades is extraordinarily and unacceptably high—only urgent action, enhanced policy, and increased community awareness will prevent this from happening.

Acknowledgments

We'd like to thank the Australian Society for Fish Biology Threatened Fishes Committee, along with Brad Pusey, Iain Ellis, and John Koehn for contributing to the preparation of the list of most imperilled freshwater fishes. This research (including data collation, analysis, and preparation of the manuscript), was funded by the Australian Government's National Environmental Science Program, through the Threatened Species Recovery Hub and the Northern Australia Environmental Resources Hub.

Conflicts of interest

The authors declare no conflicts of interest.

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Table 1. The common and scientific names, Area of occupancy (AOO), state of occurrence, year of description (year described) and the EPBC *Environment Protection and Biodiversity Conservation Act, 1999* (as at August 2019) and Australian Society for Fish Biology (ASFB, as assessed using IUCN Red List criteria) conservation status listings (Lintermans 2017) for the most imperilled Australian freshwater fishes (based on structured expert elicitation). Note that calculation of AOO is based on the IUCN method (using 2x2 km grid squares).

					Conservation Status	
Scientific name	Common name	AOO (km^2)	State	Year described	EPBC	ASFB
Galaxias aequipinnis	East Gippsland galaxias	12	VIC	2014	Not listed	Critically Endangered
Galaxias brevissimus	Short-tailed galaxias	16	NSW	2014	Not listed	Critically Endangered
Galaxias fontanus	Swan galaxias	15	TAS	1978	Endangered	Critically Endangered
Galaxias gunaikurnai	Shaw galaxias	4	VIC	2014	Not listed	Critically Endangered
Galaxias lanceolatus	Tapered galaxias	16	VIC	2014	Not listed	Critically Endangered
Galaxias longifundus	West Gippsland galaxias	12–16	VIC	2014	Not listed	Critically Endangered
Galaxias mcdowalli	McDowall's galaxias	8–28	VIC	2014	Not listed	Critically Endangered
Galaxias mungadhan	Dargo galaxias	16	VIC	2014	Not listed	Critically Endangered

Galaxias supremus	Kosciuszko galaxias	8	NSW	2014	Not listed	Critically Endangered
Galaxias tantangara	Stocky galaxias	4	NSW	2014	Not listed	Critically Endangered
Galaxias sp.	Hunter galaxias	44	NSW	Undescribed	Not listed	Not listed
Galaxias sp.	Moroka galaxias	4	VIC	Undescribed	Not listed	Not listed
Galaxias sp.	Morwell galaxias	20	VIC	Undescribed	Not listed	Not listed
Galaxias sp.	Yalmy galaxias	36	VIC	Undescribed	Not listed	Not listed
Cairnsichthys bitaeniatus	Daintree rainbowfish	12	QLD	2018	Not listed	Not listed
Melanotaenia sp.	Malanda rainbowfish	28	QLD	Undescribed	Not listed	Critically Endangered
Melanotaenia sp.	Running River rainbowfish	16	QLD	Undescribed	Not listed	Critically Endangered
Scaturiginichthys vermeilipinnis	Red-finned blue-eye	4	QLD	1991	Endangered	Critically Endangered
Gadopsis sp.	SW Victoria River blackfish	28	VIC	Undescribed	Not listed	Not listed
Guyu wujalwujalensis	Bloomfield River cod	12	QLD	2001	Not listed	Vulnerable
Nannoperca pygmaea	Little pygmy perch	40	WA	2013	Endangered	Critically Endangered
Milyeringa justitia	Barrow cave gudgeon	8	WA	2013	Not listed	Not listed

801

Table 2. The ^normalised scores of performance for threat impact, research and management needs and achievements for the most imperilled Australian freshwater fishes (based on structured expert elicitation). Grey shading indicates values ranking in the top 10 for each metric. See table footnote for explanation of scores.

			Need		Achievement	
Scientific name	Common name	Threat impact	Research	Management	Research	Management
Galaxias aequipinnis	East Gippsland galaxias	64.1	61.8	57.8	67.2	80.5
Galaxias brevissimus	Short-tailed galaxias	64.1	61.8	71.8	67.2	0.0
Galaxias fontanus	Swan galaxias	48.0	51.4	44.7	37.5	52.0
Galaxias gunaikurnai	Shaw galaxias	64.1	61.8	59.8	67.2	69.0
Galaxias lanceolatus	Tapered galaxias	64.1	61.8	57.8	67.2	80.5
Galaxias longifundus	West Gippsland galaxias	64.1	61.8	57.8	67.2	80.5
Galaxias mcdowalli	McDowall's galaxias	64.1	61.8	59.8	67.2	69.0
Galaxias mungadhan	Dargo galaxias	64.1	61.8	57.8	67.2	80.5
Galaxias supremus	Kosciuszko galaxias	68.1	65.5	74.2	71.8	11.5
Galaxias tantangara	Stocky galaxias	60.3	66.1	63.5	43.5	23.0
Galaxias sp.	Hunter galaxias	64.1	61.8	71.8	67.2	0.0
Galaxias sp.	Moroka galaxias	64.1	61.8	59.8	67.2	69.0
Galaxias sp.	Morwell galaxias	74.8	71.7	69.8	79.5	80.5
Galaxias sp.	Yalmy galaxias	64.1	61.8	59.8	67.2	69.0
Cairnsichthys bitaeniatus	Daintree rainbowfish	93.5	100.0	96.7	73.5	45.7

Melanotaenia sp.	Malanda rainbowfish	100.0	98.4	100.0	100.0	69.0
Melanotaenia sp.	Running River rainbowfish	40.6	36.6	28.1	48.9	100.0
Scaturiginichthys vermeilipinnis	Red-finned blue-eye	23.5	20.9	19.2	29.0	40.9
Gadopsis sp.	SW Victoria River blackfish	64.1	66.7	71.8	55.0	0.0
Guyu wujalwujalensis	Bloomfield River cod	53.4	62.1	59.4	29.6	1.9
Nannoperca pygmaea	Little pygmy perch	57.6	69.3	60.7	26.4	21.8
Milyeringa justitia	Barrow cave gudgeon	39.7	51.9	42.1	7.9	13.6

^Note that the results of the analysis are normalised so that the scores provided for each species are relative. For example, a score of 100 for research achievement does not mean that all of the threats facing the Malanda rainbowfish are well understood, but that collectively, we know more about the threats facing this rainbowfish than any other species under consideration.

Table 3. The list of threats that ranked in the top 10 (grey shading) for threat impact, research or management needs or achievements (based on scores ^normalised to 100) for the most imperilled Australian freshwater fishes (based on structured expert elicitation). The number of species affected by each threat is in parenthesis. See table footnote for explanation of scores.

		Need		Achievement	
Threat type	Threat impact	Research	Management	Research	Management
[#]Small, single or few isolated populations (21)	100	100	58.3	100	39.3
Increase in drought frequency, intensity (19)	79.1	95.4	24.1	90.6	0
Increase in storm, flooding frequency, intensity (18)	80.5	98.3	22.9	92.2	0
Increase in fire frequency, intensity (17)	76.3	92	23.2	76.5	29.4
Trout *Salmo trutta* & *Oncorhynchus mykiss* predation (15)	70.7	27.3	100	44	100.0
Soil erosion, sedimentation (12)	57.6	68.7	18.6	59.6	17.4
Feral pig *Sus scrofa* (3)	3.4	2.8	2.7	2.9	2.6
Eastern gambusia *Gambusia holbrooki* (3)	14.4	12.6	10.8	13.7	7.4
Tilapia *Oreochromis mossambicus* and *Pelmatolapia mariae* (3)	13.4	13.9	7.3	13.7	4.5
Eastern rainbowfish *Melanotaenia splendida* (2)	9.6	3.4	13.9	5.5	14.9
Sooty grunter *Hephaestus fuliginosus* (2)	8.6	9.3	4.2	9.1	2.2
Temperature extremes (2)	7.2	10.3	0	8.2	0
Secondary salinisation (1)	4	4.7	1.3	3	4.1
Deliberate disposal of industrial effluents (1)	0.9	0.9	0.6	0	2.9

^ Note that the results of this analysis are normalised so that the scores provided for each threat are relative. For example, a score of 100 for management achievement does not mean that we are managing alien trout effectively, or for all of the taxa impacted, but that collectively, we are doing a better job at managing trout (with respect to reducing its impact on the most imperilled freshwater fishes) than the other threats considered.

While not normally considered a threat per se, the overwhelming response from experts was that highly restricted range or population size was a dominant feature in considering research and management needs of most taxa.

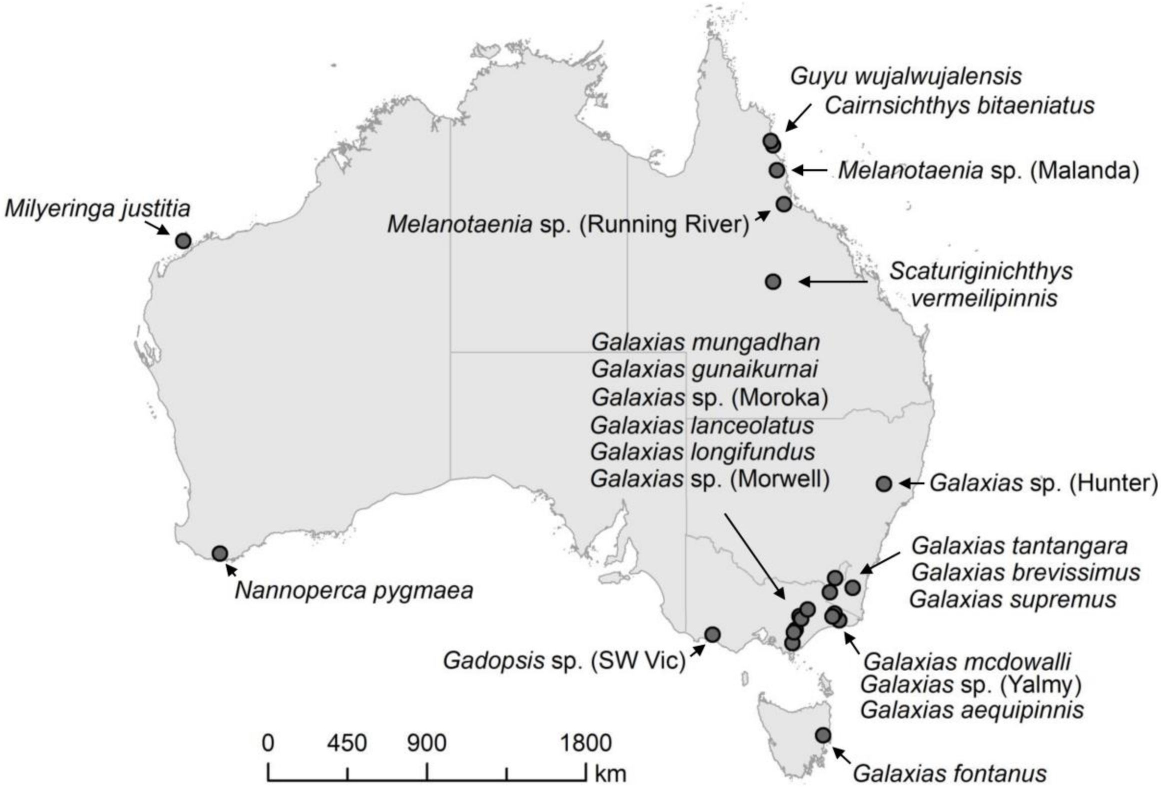

Figure 1. The approximate geographic locations of each of Australia's 22 most imperilled freshwater fishes. State and Territory boundaries are also shown.

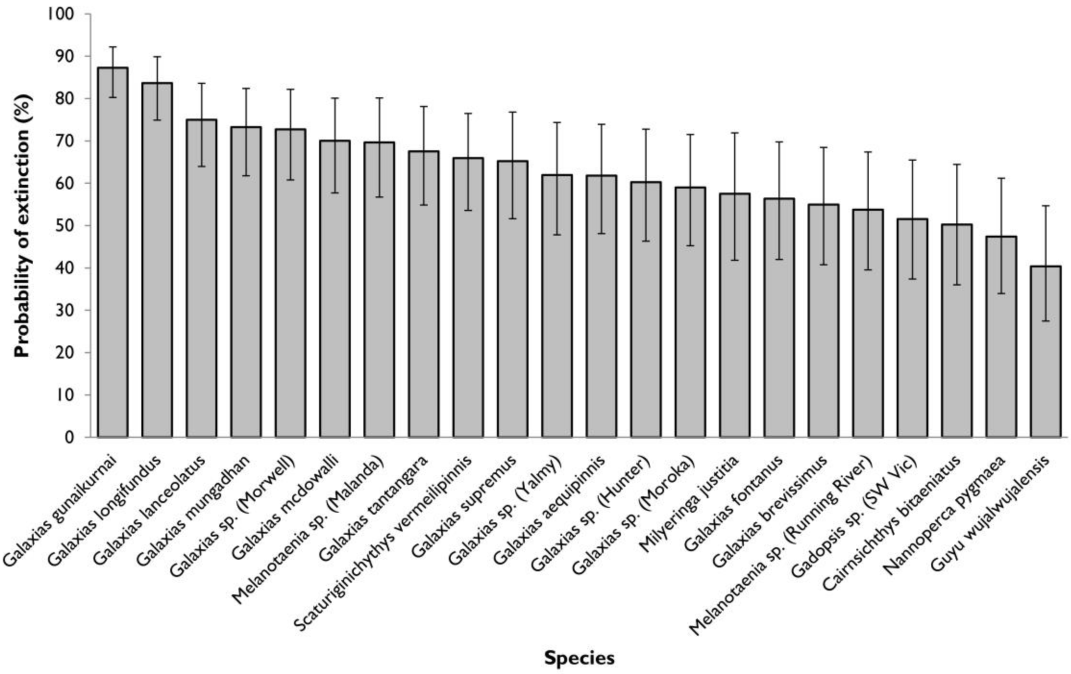

Figure 2. The predicted probability of extinction (%) in the next 20 years for the Australian freshwater fishes considered to be most imperilled. Predicted probabilities are based on structured expert elicitation (with 95% confidence intervals) and are presented in order of imperilment from left to right.

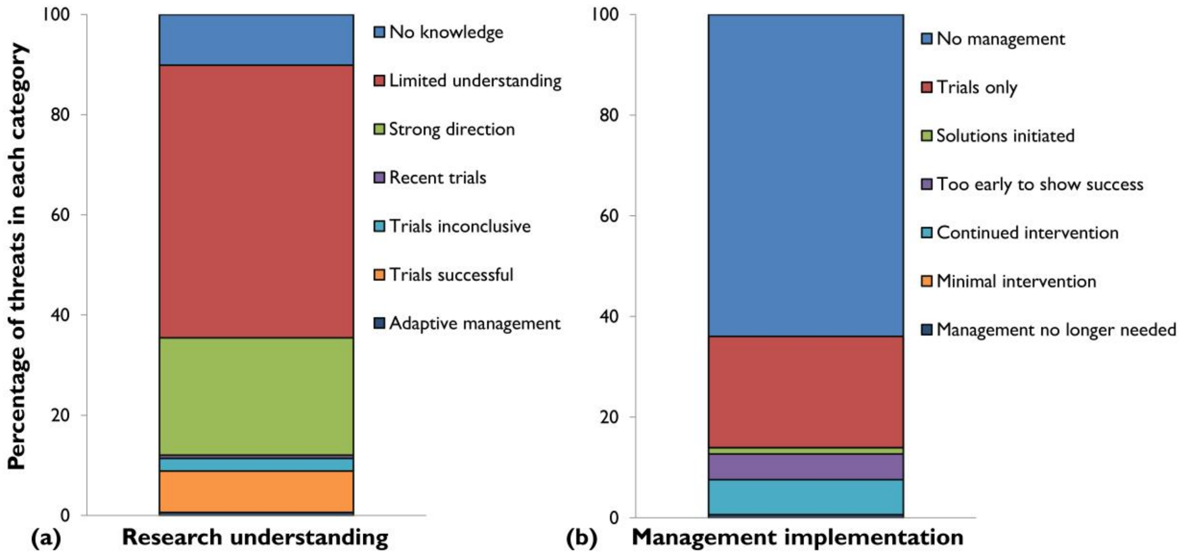

Figure 3. The level of progress in (a) understanding and (b) managing the threats to the 22 most imperilled freshwater fishes. This highlights that for most of the threats, understanding is limited, and management is either limited or currently not occurring.

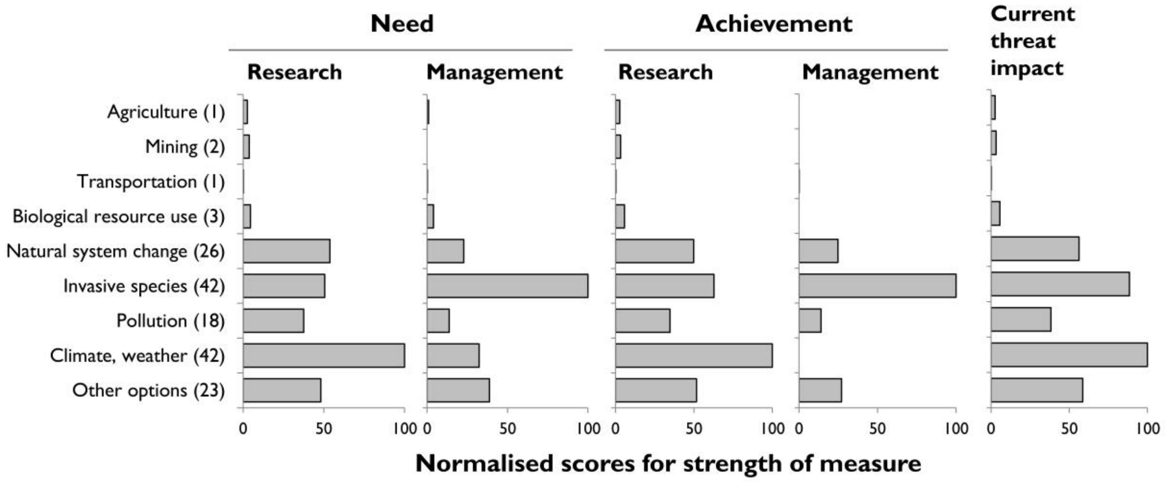

Figure 4. Normalised values for threat impact, research and management needs and achievements for the 12 major threat classes (IUCN 2019) affecting the 22 most imperilled freshwater fishes. The figure in parenthesis refers to the total number of individual threats facing the priority fishes within each category.

Supplementary material for

Big trouble for little fish: identifying Australian freshwater fishes in imminent risk of extinction

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Supplementary Material S1: progress towards conservation – threat assessment and identification of management needs using the methods outlined in Garnett *et al.* (2018).

Identifying threats affecting each species

Key threats were derived from relevant literature, listing advices (where applicable), and from species-specific experts based on unpublished information. All threats were categorised using the IUCN Red List threat classification scheme down to the most specific level possible.

Assessing the timing, scope and severity of threats (threat impact)

Following IUCN (2012), species-specific experts assessed the timing of each threat (i.e. ongoing, near future; may occur or return in the short-term, or distant future; may occur or return in the long-term); the extent or scope (i.e. the proportion of the total population affected); and the severity (i.e. the rate of population decline caused by the threat within its scope). The timing, scope and severity was then converted to a weighted threat impact score, which reflected the total population decline over ten years or three generations (whichever is longer), likely to be caused by the threat (i.e. the product of the scope and severity) weighted by timing (IUCN 2012; see Garnett *et al.* 2018 for greater detail). Scores were then readily translated into categories of threat impact, where negligible impact refers to population declines of < 2%, low impact refers to population declines of 2–10%, medium impact refers to population declines 11–50% and high impact refers to population declines > 50%.

Assessing progress in understanding (research need and achievement) and managing (management need and achievement) threats

For each threat affecting the focal taxa, species-specific experts assigned a category of progress for management understanding (which represents the current level of knowledge on how to manage the threat) and management implementation (which represents the extent to which each threat has been managed). We considered both research and management need as well as research and management achievement. For management understanding, there were seven mutually exclusive categories ranging from (i) no knowledge and no research (weighted against 1 for need and 0 for achievement) to (vii) research complete and being applied or ongoing research associated with adaptive management (weighted against 0 for need and 1 for achievement). For management implementation, there were another seven mutually exclusive categories ranging from (i) no management (weighted against 1 for need and 0 for achievement) to (vii) the threat no longer needs management (weighted against 0 for need and 1 for achievement; see Table S1.1).

Assembling data into metrics of progress for individual species and threats

For each threat facing the focal taxa, we calculated the research need and research achievement (i.e. our management understanding), and management need and management achievement (i.e. management implementation) as in Garnett *et al.* (2018). Each of the metric scores were weighted against threat impact, so that threats assessed as having a higher impact were afforded a greater weight, leading to greater scores for each of the need and achievement metrics. We took this approach because higher impact threats are likely to cause more devastating declines over time, and thus require more urgent attention. Conversely, it allows for greater recognition to be given when threats of higher impact are alleviated.

We also calculated the overall research and management needs and achievements for each species by summing the species-specific needs or achievements for a given threat, then dividing by the maximum possible score for each threat to provide a measure that could be compared between species. These scores also took into consideration the number of threats facing each species; for example, a species likely to be affected by 4 medium impact threats would have higher scores for all metrics compared with a species that is likely to be affected by 2 medium impact threats (assuming a similar level of management understanding and implementation).

All aggregated metric scores (i.e. collective scores for threats or species) were standardised to 100, and thus are relative to all other threats or species considered; e.g. a score of 100 for management achievement for a given threat does not necessarily mean that the threat no longer needs management (i.e. vii in Table S1), but rather suggests that, compared to all other threats considered, it is being managed the most effectively. For further information on how the metrics are derived see Garnett *et al.* (2018).

Dealing with uncertainty

In one case (the Barrow cave gudgeon *Milyeringa justitia*), there was insufficient knowledge to confidently assign threats to a severity class. We compared the overall metric scores for this species (i.e. considering all threats collectively), as well as for the individual threats affecting this species, using both the minimum severity category (i.e. causing negligible declines <1%) and the maximum severity category (i.e. causing declines 50–100%). Although the normalised scores for all metrics using the minimum and maximum values varied widely, this had only a minor impact on the rank of the Barrow cave gudgeon (where the greatest change was from 22^{nd} to 20^{th} for research need) and its threats (with only one additional threat by metric combination ranking in the top 10) with respect to the rest of the focal taxa and their threats (see Tables S1.2 and S1.3). Given we were interested in the collective impact of threats on our focal taxa (more specifically in identifying which threats require the most immediate action), we adopted a precautionary approach, and assigned the maximum category of severity for all threats affecting the Barrow cave gudgeon.

Table S1.1. Categories of progress for understanding threats and implementing management.

Category	Weighting	
Management understanding	**Need**	**Achievement**
i. No knowledge and no research	1.00	0.00
ii. Research being undertaken or completed but limited understanding on how to manage threat	0.83	0.17
iii. Research has provided strong direction on how to manage threat	0.67	0.33
iv. Solutions being trialled but work only initiated recently	0.50	0.50
v. Trial management under way but not yet clear evidence that it can deliver objectives	0.33	0.67
vi. Trial management is providing clear evidence that it can deliver objectives	0.17	0.83
vii. Research complete and being applied OR ongoing research associated with adaptive management of threat	0.00	1.00
Management implementation	**Need**	**Achievement**
i. No management	1.00	0.00
ii. Management limited to trials	0.83	0.17
iii. Work has been initiated to roll out solutions where threat applies across the species's range	0.67	0.33
iv. Solutions have been adopted but too early to demonstrate success	0.50	0.50

v. Solutions are enabling achievement but only with continued conservation intervention	0.33	0.67
vi. Good evidence available that solutions are enabling achievement with little or no conservation intervention	0.17	0.83
vii. The threat no longer needs management	0.00	1.00

Table S1.2. Comparison of the normalised scores (overall) and rank (in parenthesis, with respect to the rest of focal taxa) of the barrow cave gudgeon (*Milyeringa justitia*) for current threat impact (CTI), research need (RN), management need (MN), research achievement (RA) and management achievement (MA) assuming the minimum (min) category of severity (negligible declines <1%) and the maximum (max) category of severity (declines of 50–100%) for each threat affecting the species.

	CTI	**RN**	**MN**	**RA**	**MA**
Min	0.9 (22)	1.1 (22)	0.9 (22)	0.2 (22)	0.3 (20)
Max	42.5 (21)	51.9 (20)	42.1 (21)	7.9 (22)	13.6 (18)

Table S1.3. Comparison of the normalised scores and rank (in parenthesis, with respect to all threats affecting the focal taxa) of threats affecting the Barrow cave gudgeon (*Milyeringa justitia*) for current threat impact (CTI), research need (RN), management need (MN), research achievement (RA) and management achievement (MA) assuming the minimum (min) category of severity (negligible declines <1%) and the maximum (max) category of severity (declines of 50–100%).

Threat		**CTI**	**RN**	**MN**	**RA**	**MA**
Small, single or few isolated populations	**Min**	100 (1)	94.1 (3)	57 (2)	100 (1)	35.7 (2)
	Max	100 (1)	100 (1)	57 (2)	100 (1)	35.7 (2)
Acoustic shock	**Min**	0.1 (37)	0.1 (36)	0.0 (34)	0.1 (36)	0 (16)
	Max	3.8 (25)	5.4 (17)	0.0 (34)	4.3 (24)	0 (16)

Mining seepage	**Min**	0 (38)	0.1 (37)	0 (34)	0 (38)	0 (16)
	Max	1.8 (30)	2.6 (30)	0 (34)	2.1 (30)	0 (16)
Deliberate disposal of industrial effluents	**Min**	0 (40)	0 (40)	0 (33)	0 (40)	0.1 (15)
	Max	0.9 (34)	0.9 (34)	0.6 (26)	0 (40)	2.7 (9)
Electric fields	**Min**	0 (38)	0.1 (37)	0 (34)	0 (38)	0 (16)
	Max	1.8 (30)	2.6 (30)	0 (34)	2.1 (30)	0 (16)
Sea level rise	**Min**	1 (29)	1.1 (29)	0.3 (28)	1.1 (29)	0 (16)
	Max	5.0 (16)	5.9 (13)	1.6 (21)	5.7 (15)	0 (16)

Supplementary Material S2: The current relevant knowledge on each of the 22 focal taxa (used to justify the ASFB conclusion that these species are at greatest risk of extinction in the next 20 years).

East Gippsland galaxias *Galaxias aequipinnis*

A Victorian endemic (Raadik 2014), known only from the Arte River system – a tributary of the Goolengook River (part of the Bemm River catchment in coastal east Gippsland). The population is split by the presence of alien brown trout into two; a larger population in the Arte River and a small population in the Little Arte River (within close proximity to one another), above waterfalls with trout below. The population, currently ~9300 individuals, is estimated to have declined by 52% in the past 10 years. The major threats are (i) further invasion by alien trout which will almost certainly cause extinction if able to colonise the streams in which the last populations persist; (ii) sedimentation following severe storms and flooding from the many forestry tracks that cross the catchment (which also increase the risk of human-assisted trout invasion), timber harvesting operations and post-fire debris flow; (iii) toxic retardants used in fire suppression; (iv) drought (reducing water quality and availability) and (v) low genetic variability, which has impeded attempts at captive breeding. Trout invasion monitoring and trout removal is conducted when funds are available (Raadik 2019), and translocation to establish new populations has been limited by the lack of trout-free suitable locations in a predator saturated landscape.

Short-tail galaxias *Galaxias brevissimus*

A New South Wales endemic (Raadik 2014) that occurs in the upper Tuross River and Jibolaro Creek catchments. It persists in two small, isolated populations, each upstream of areas where alien trout occur. The population, currently ~7000 individuals, is estimated to have declined by > 50% in the past 10 years. The threats are the same as those facing the East Gippsland galaxias (excluding the threat of forestry, which does not occur in these catchments). Currently there is no active management.

Swan galaxias *Galaxias fontanus*

A Tasmanian endemic that occurs naturally in the headwaters of the Swan River above Hardings Falls and in four tributaries of the Macquarie River in eastern Tasmania. Presently, there are 19 populations; 10 natural and 9 translocated that have been established for conservation purposes. Of the ten natural populations; one is almost certainly extinct, with four under high levels of threat from climate impacts and invasive fishes. Of the nine translocated populations; three are presumed extinct, with three under high levels of threat from climate impacts and invasive fishes. Largely, only three 'safe' populations remain.

All habitats where healthy populations of this species persist are free of other fish (except *Anguilla australis*) and are protected from invasive fishes (e.g. brown trout, redfin perch and the climbing galaxias) by some sort of barrier (waterfall, marsh or variable flow) (Threatened Species Section 2006). This species is tolerant of elevated temperatures and low oxygen concentrations so is able to survive when streams become a series of isolated pools. Between 1992 and 2018 there has been a 56% percent decrease in the length of stream occupied (44.5 km down to 19.5 km).

The Swan galaxias is one of three focal taxa to be formally listed as threatened under the EPBC Act (as at November 2019), where it is listed as Endangered.

Shaw galaxias *Galaxias gunaikurnai*

Endemic to Victoria (Raadik 2014), the species has undergone a 99% population decline in the past 10 years, caused by alien trout predation. It now persists as a single very small population (~80 mature individuals) in a tributary of the Caledonia River, part of the Macalister River Catchment in the coastal Gippsland region. Threats and current management are the same as those for the East Gippsland galaxias (excluding the threat of forestry, which does not occur in these catchments). Artificial barriers have been erected to restrict the movement of alien brown trout and rainbow trout (*Oncorhynchus* mykiss) into the stream, but reinvasion could occur as a result of human-assisted trout invasion or drown-out of barriers during high flows.

Tapered galaxias *Galaxias lanceolatus*

Endemic to Victoria (Raadik 2014), the species is known only from the headwater reaches of Stoney Creek, a tributary of the Thomson River in West Gippsland. Having undergone a decline of >90% in the last 10 years, it now persists as a single, small population (~1200 mature individuals) in approximately 12 km of stream length, upstream of a waterfall with alien trout below. The threats and current management are the same as those for the East Gippsland galaxias.

West Gippsland galaxias *Galaxias longifundus*

A Victorian endemic (Raadik 2014), the species is known only from the headwaters of the east branch of Rintoul Creek, – a tributary of the La Trobe River. It persists as a single, small population (~100 mature individuals) in approximately 6 km of stream, upstream of a waterfall. In the past five years the adult population is estimated to have declined by 99% as a result of predation by alien trout. The major threats and current management are the same as for the East Gippsland galaxias.

McDowall's galaxias *Galaxias mcdowalli*

Endemic to Victoria (Raadik 2014), McDowall's galaxias in only known from the type locality in the headwaters of the Rodger River in the coastal East Gippsland region where it persists as a single population (~13,500 mature individuals) in approximately 10 km of steam, upstream of a waterfall with alien trout below. The threats and current management are the same as those for the East Gippsland galaxias (excluding the threat of forestry, which does not occur in these catchments). In particular, the catchment is crossed by a major track accessing a campsite, allowing easy stream access and increasing the risk of human-assisted trout invasion.

Dargo galaxias *Galaxias mungadhan*

A Victorian endemic (Raadik 2014), the species is known only from the headwaters of Lightbound Creek, a shallow and small (1 m wide) tributary of the Dargo River, in the coastal Gippsland region. Having declined by 90% in the past 10 years, it now persists as a single, small population (~1200 mature individuals), in approximately 3.7 km of stream, upstream of a waterfall with alien trout below. The threats and current management are the same as those for the East Gippsland galaxias.

Kosciuszko galaxias *Galaxias supremus*

A New South Wales endemic (Raadik 2014), this species occurs in the upper Snowy River on Mount Kosciuszko. The adult population is estimated to have declined by 50% in the last 10 years, and now persists as two, very small (~5000 mature individuals) isolated populations (with a total linear occurrence of ~3 km of stream) upstream of waterfalls with alien trout below. The populations are geographically very close; with their headwaters separated by only 300 m. The threats are the same as those facing the East Gippsland galaxias (excluding the threat of forestry, which does not occur in these catchments), but no management actions have been undertaken.

Stocky galaxias *Galaxias tantangara*

A New South Wales endemic (Raadik 2014), this species is only known from the type locality in the headwaters of Tantangara Creek in the upper Murrumbidgee River catchment (NSW FSC 2016; Allen and Lintermans 2018). It persists as a single small population, restricted to approximately 3 km of the small creek above a waterfall with alien trout below. The major threats to this species include (i) trout invasion (incursion likely to wipe out entire population) and (ii) extreme events (fire, flood and drought) and the impacts on stream and riparian habitats from over-abundant feral horses.

Yalmy galaxias *Galaxias* sp.

A recently identified, undescribed species in the *Galaxias olidus* complex (sensu Raadik, 2014). Allozyme genetic results confirm this population as a new species, with morphological analysis currently underway, to be be followed by its' formal description (T. Raadik, unpublished data). Endemic to Victorian, it is known from the Rodger River, Yalmy River and Serpentine Creek System, extending over approximately 35 km. It persists as a single, small population in a sand-infilled stream. The Yalmy Galaxias is a habitat specialist found among faster flow in cobble areas, much of which has been smothered by coarse sand. The population is estimated to have declined by ~64% over the past 10 years. The threats and current management are the same as those for the East Gippsland Galaxias, with the exception of habitat loss (through sedimentation impacts), which is the major threat to this species. Although alien trout are likely absent at present due to warmer water temperatures, there is a possibility of invasion (due to a lack of appropriate barriers) which could lead to rapid extinction of this species.

Morwell galaxias *Galaxias* sp.

A recently identified, undescribed new species in the *Galaxias olidus* complex (sensu Raadik, 2014). Allozyme genetic results confirm this population as a new species, with morphological analysis underway, to be followed by its' formal description (T. Raadik, unpublished data). A Victorian endemic, known from the headwaters of the Morwell River, east branch, in the Strzelecki Ranges. It persists as a single, small population upstream of a waterfall with alien trout below, but does extend to low-order headwater tributaries. Small isolated populations may exist in remote headwater reaches of nearby pockets of state forest. The population is estimated to have declined by ~56% in the past 10 years, which is attributed to a deterioration in the habitat quality (sedimentation). The threats and current management are the same as those facing the East Gippsland Galaxias.

Moroka galaxias *Galaxias* sp.

A recently identified, undescribed new species in the *Galaxias olidus* complex (sensu Raadik, 2014). Allozyme genetic results confirm this population as a new species, with morphological analysis underway, to be followed by its' formal description (Raadik, unpublished data). A Victorian endemic, it occurs in the headwater reaches of the Moroka River in about 2.6 km of stream. It persists as a single, small population upstream of a waterfall with alien trout below. The threats and current management are the same as those for the East Gippsland Galaxias (excluding the threat of forestry, which does not occur in these catchments).

Hunter galaxias *Galaxias* sp.

A recently identified, undescribed new species in the *Galaxias olidus* complex of species (sensu Raadik, 2014). Allozyme genetic results confirm this population as a new species, with morphological analysis underway, to be followed by its' formal description (Raadik, unpublished data). A New South Wales endemic, it persists as a series of small, isolated populations in a section of the Hunter River catchment. The threats and management actions are the same as those for the East Gippsland Galaxias (excluding the threat of forestry, which does not occur in these catchments). The impact of alien trout is currently mediated by low water levels and high water temperatures, though the threats from drought and fire are severe.

Daintree rainbowfish *Cairnsichthys bitaeniatus*

Endemic to Queensland, this species is only known from minor tributaries of Hutchinson and Cooper creeks, despite significant search effort in surrounding areas (Martin and Barclay 2013). It has a restricted range and is suspected to be undergoing a continuing decline in its Extent of Occurrence (EOO), Area of Occupancy (AOO) and number of subpopulations. It occurs in permanently flowing water in rainforest, which is likely a critical habitat requirement. The preferred microhabitat is braided, small pool-riffle sites within 1 km of the foot slopes of the Great Dividing Range where it congregates in moderate-high flow locations, particularly those that provide cover (i.e. small log jams and submerged root masses (Martin and Barclay 2013; Hammer *et al.* 2018). The main threats to this species are (i) habitat loss, particularly through destruction caused by feral Pigs (*Sus scrofa*), (ii) the loss of stream flow/drying due to extended drought, (iii) water extraction and (iv) climate change (Martin and Barclay 2013). Other recently identified threats include siltation due to ongoing major natural landslides in the catchment and potential invasion by alien fishes.

Malanda rainbowfish *Melanotaenia* sp.

First recognised as a genetically distinct species in the 1990s, limited taxonomic examination and increasing hybridisation hindered formal diagnosis and description. It is endemic to Queensland, currently known only from six natural and one translocated population in small upper tributaries of the North Johnstone River, southern Atherton Tablelands. Between the mid-2000s and 2016 a decline in range of approximately 70% was observed. Of the remaining fish, up to 50% were hybrids with Eastern Rainbowfish (*M. splendida*) that previously occurred lower in the system but have spread upstream over the last 20–30 years due to changing habitat conditions (associated with the clearance of riparian vegetation for dairy), climate change, and partly assisted by human translocation. The main threats include (i) drought, (ii) storms and flooding, (iii) habitat clearance and (iv) introduced fish species (Unmack *et al.* 2016).

Running River rainbowfish *Melanotaenia* sp.

First suspected to be a unique species in 1982, it is endemic to Queensland and restricted to a 13 km section of the Running River (upper Burdekin catchment) between two gorges. The lower gorge has prevented upstream invasion of the naturally occurring eastern rainbowfish (*M. splendida*), while the upper gorge has prevented range expansion of the Running River rainbowfish. Translocation of eastern rainbowfish upstream of the upper gorge has now allowed for downstream invasion of this species into the range of the Running River rainbowfish. Without intervention, the pure form of the Running River rainbowfish will be completely lost (though timing uncertain), as the major threat to this species is hybridisation (Unmack and Hammer 2015). Recent work has translocated Running River rainbowfish to two creeks (naturally lacking Rainbowfish) in the Running River system, though these populations are yet to establish, and it is too early to determine if they are evolutionarily viable.

South-west Victoria River blackfish *Gadopsis* sp.

A recently identified, undescribed new species in the *Gadopsis marmoratus* complex (Hammer *et al.* 2014; Unmack *et al.* 2017). Multiple genetic results confirm this lineage as a new species, with morphological analysis underway, to be followed by its' formal description (T. Raadik, unpublished data). A Victorian endemic, it persists as three very small, isolated populations in the Hopkins River and Portland Coast catchments. The adult population is suspected to have declined by > 50% in the past three generations (18 years). Major threats include (i) drought (reducing water quality and availability), (ii) loss of habitat (i.e. instream structural habitat and shading), (iii) fire (post-fire debris flow during high intensity rainfall events) and fire suppression impacts (i.e. toxic retardants)and (iv) severe storms and flooding (through mobilising sediments and erosion impacts) (Hammer *et al.* 2014; Unmack *et al.* 2017).

Red-fin blue-eye *Scaturiginichthys vermeilipinnis*

A Queensland endemic, this species is only known from the Great Artesian Basin spring complex at Edgbaston, a group of isolated aquatic islands within a semiarid landscape. This species has survived in an extremely harsh environment but has been unable to adapt to invasion of its habitat by the alien species Eastern Gambusia (*Gambusia holbrooki*). Its successful conservation relies on reintroductions into renovated habitat and prevention of further eastern gambusia colonisation (Radford *et al.* 2018). It is one of three focal taxa to be formally listed as threatened under the EPBC Act (as at November 2019), where it is listed as Endangered.

Little pygmy perch *Nannoperca pygmaea*

This species is endemic to Western Australia, where it is restricted to areas of the Denmark, Mitchell/Hay and Kent rivers as well as Lake Smith, on the south coast. The species is highly fragmented (with up to 200 km between the nearest known populations) and relies on a small number of refuge pools (< 5 in each stream and one from Lake Smith) to survive the summer base flow period. Its current habitat is in relatively remote reaches with undisturbed riparian habitat and complex instream habitat that includes large woody debris and emergent riparian vegetation such as sedges and rushes. The principal threat is secondary salinization as it is unlikely to tolerate salinities much above current levels (Beatty *et al.* 2011), with severe flow declines due to climate change an ongoing threat to its habitat availability (Allen *et al.* in press).

Barrow cave gudgeon *Milyeringa justitia*

This species is a Western Australian endemic, known only from three boreholes within a petroleum production and exploration lease on Barrow Island, despite sampling of more than 60 sites over several decades (Humphreys 2000). All seven specimens have been obtained from 3–5 km inland, the fish apparently persisting in freshwater within a well-developed subterranean karst system (Humphreys *et al*. 2013). The major threats to this species include (i) water contamination, (ii) habitat loss and (iii) seismic data acquisition.

Bloomfield River cod *Guyu wujalwujalensis*

A Queensland endemic, restricted to approximately 8 km of the main channel of the Bloomfield River upstream of the Bloomfield Falls and downstream of Roaring Meg Falls (Pusey and Kennard 1994, Pusey *et al.* 2004) but apparently absent upstream or further downstream. First collected in 1993, it was detected in four river reaches in the 1990's (Pusey and Kennard 1994; Pusey and Kennard 2001; Hanson 2000) and on two occasions in the last decade (Ebner and Donaldson, unpublished data) but trends in abundance across time are confounded by differences in survey technique. The major threat to this species is the translocation of either native fish (particularly sooty grunter *Hephaetus fuliginous* or khaki grunter, *H. tulliensis*) or the introduction of alien fishes (particularly cichlids and poeciliids) which have been widely introduced elsewhere in the Wet Tropics region (Burrows 2004; Burrows 2009; Kroon *et al.* 2015). Feral Pigs may also threaten the cod by damaging streamside vegetation, causing riverbank erosion and in-stream siltation (Commonwealth of Australia 2015). Illicit harvesting, water resource development and climate change were also identified as potential future threats to this taxon.

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