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Monitoring populations and threats to range-restricted freshwater fishes: A case study of the Stocky Galaxias (*Galaxias tantangara*)

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Summary **Monitoring is critical for conservation, to track the status of threatened species, assess the relative impacts of threats, inform management responses and prioritise them according to their efficacy. Globally, freshwater fish are impacted by a range of threats including deterioration in water quality, climate change, habitat loss and degradation, introduced predators and herbivores, and wildfire. Monitoring of freshwater fish can be challenging because aquatic conditions can make detecting and identifying population trends difficult for many species. Galaxiidae is the most speciose family of Gondwanan-distributed freshwater fishes, and over 75% of species assessed by the IUCN Red List have been classified as threatened. Many Australian galaxiids are highly imperilled and monitoring effort and adequacy is low. We prepared a detailed monitoring plan for the Stocky Galaxias (*Galaxias tantangara*) that is representative of the conservation status and level of threat facing many congeneric and other similar species. Our protocol provides details of species biology, pertinent threats, and management options with sampling methods to gather these data, and options to link with management actions for maximum benefit. Improved monitoring linked with threat management should improve the conservation status of Stocky Galaxias. By providing this example, we have sought to improve monitoring for range-restricted freshwater fishes more generally.**

Key words: *Conservation, decline, extinction, recovery, salmonid, survey.*

Introduction

Freshwater fishes represent approximately 50% of global fish diversity, and around one quarter of vertebrate diversity (Dudgeon *et al*. 2005; IUCN 2021; Fricke *et al*. 2022). Recent reviews on the state of global biodiversity estimate approximately one million species could face extinction over the coming decades (IPBES 2019). This crisis affects all vertebrate groups. However, freshwater fish are particularly vulnerable to anthropogenic environmental change (Radinger *et al*. 2019), and negatively affected by deterioration in water quality, habitat degradation and fragmentation, exotic species, and over-exploitation (Dudgeon *et al*. 2005; Radinger *et al*. 2019).

Conservation action for freshwater fishes is further impeded by shortfalls in conservation assessments (Dudgeon *et al*. 2005; Radinger *et al*. 2019). Globally, the percentage of bony fishes that have been assessed by the IUCN Red List is lowest among all vertebrate groups, and proportions of threatened species have been estimated for taxonomic subsets of bony fishes only (IUCN 2021). Good monitoring is crucial for understanding the status of species, and to adequately respond to threatening processes (Legge *et al*. 2018).

Monitoring freshwater fish can be challenging as many species are difficult to detect directly (e.g. water turbidity precludes visual observation), and the indirect indicators that are available for many other groups of vertebrates (e.g. tracks or vocalisations) do not apply (Lintermans & Robinson 2018). Monitoring also must incorporate spatial variability in stream order and water depth, as well as temporal fluctuations in waterway condition driven by flow (e.g. flood and drought) (Lintermans & Robinson 2018). Understanding the spatial distributions, patterns of temporal decline and effectiveness of management interventions is even more challenging for small, threatened, cryptic species because detection and monitoring efficiency can be low (Lyon *et al*. 2014).

Ecological Management & Restoration *Linking science and practice*

Long-term monitoring of freshwater fish is severely lacking, with many species and habitats unmonitored (Dudgeon *et al*. 2005; Lintermans & Robinson 2018). Moreover, a global review of freshwater fish revealed that monitoring programmes are heavily biased towards the Northern Hemisphere (Radinger *et al*. 2019). Monitoring programmes in Australia were lacking, even though levels of endemism and threat are high for Australian freshwater fish (Collen *et al*. 2013). The proportion of threatened freshwater fish that are monitored is the lowest among all Australia's vertebrate groups at 53% (Scheele *et al*. 2019). Furthermore, of the monitoring programmes that are in place, monitoring extent and quality is also poor. Of nine metrics to score monitoring adequacy for Australia's threatened fauna only 31 of 57 threatened freshwater fish had monitoring programmes in place, and 15 programmes were suboptimal because they used rudimentary designs or provided limited capacity to detect trends in abundance. Many monitoring programmes also used generic methods that were not targeted at the species of interest (Lintermans & Robinson 2018).

The Galaxiidae is the most speciose family of freshwater fishes spanning temperate regions of the Southern Hemisphere (McDowall 2006). Globally, approximately 75% (56) of the 74 taxa classified under the IUCN Red List are considered Critically Endangered, Endangered, or Vulnerable (IUCN 2021). In Australia, approximately 66% of galaxiids are classified as threatened on the IUCN Red List (IUCN 2021).

Here we aimed to improve the extent and adequacy of monitoring for range-restricted threatened galaxiids by providing a detailed monitoring protocol for the Stocky Galaxias (*Galaxias tantangara*). Effective monitoring must be fit-for-purpose for the focus species, consider the statuses of major threats, and track the results of management interventions (Legge *et al*. 2018; Lindenmayer *et al*. 2020). We clarify this by outlining relevant threats, management actions, and species traits for Stocky Galaxias, and provide methods to successfully include data on these in a long-term monitoring programme.

Implications for Managers

- Effective monitoring that tracks population abundance and distribution, the status of threats, and responses to management actions is critical for the conservation and recovery of threatened species.
- However, there are unique challenges to monitoring freshwater fish, few species are monitored, and fewer are monitored effectively because programmes are sub-optimal, poorly resourced, or badly implemented.
- We focus on a representative of a large group of highly threatened fish species, the Gondwanan Family Galaxiidae, and provide examples of the considerations for effective monitoring that apply to many small fishes. Parameters covered include sampling methods, coverage, periodicity, longevity, demographics, threats, coordination, data management, and management linkages.
- By systematically demonstrating the relevance of each parameter, we intend to form a template that can prompt government agencies, natural resource managers and other conservation practitioners to develop effective monitoring for other range-restricted freshwater fish.

Species Profile

Stocky Galaxias (Fig. 1) is presumed to have been formerly distributed throughout Tantangara Creek, and further across parts of Australia's alpine country, including stretches of the Murrumbidgee River catchment (Raadik 2014; NSW FSC 2016; Allan & Lintermans 2018; Allan *et al*. 2021) (Fig. 2). The Ngunnawal, Monaro Ngarigo, Wiradjuri, Wolgalu, GunaiKurnai, Bidawal, Dudhuroa, Jaithmathang, Mitambuta, Ngarigu-Currawong, Taungurung, Waywurru and Wurundjeri are traditional custodians of the alpine country including waters that currently support, and may have formerly supported Stocky Galaxias.

Stocky Galaxias was previously considered as part of the *G. olidus* hyper-species complex until described as a distinct species (Raadik 2014). The species is classified as Critically Endangered under the IUCN Red List (Lintermans & Allan 2019), the New South Wales *Fisheries Management Act* (*1994*) (NSW FSC 2016), and the Australian *Environment Protection and Biodiversity Conservation Act 1999* (Lintermans 2016a; TSSC 2021). Like many threatened galaxiids, it is now restricted to a single locality, a 3 km section of the headwaters of Tantangara Creek in Kosciuszko National Park, New South Wales.

In 2002, Stocky Galaxias was the only fish species found inhabiting the upper reaches of Tantangara Creek at a density of 1.8 fish/m^2 (Raadik 2014), and similar densities were reported from surveys between 2016 and 2020 (Allan & Lintermans unpub. data). No quantitative information on total population size or trends is currently available (Lintermans & Allan 2019). Fecundity is low (200–800 eggs per season) and spawning occurs in late spring (November–December) (Allan *et al*. 2021). Lifespan is unknown but likely <6–10 years based on observed size-age classes in the wild, and knowledge of closely related species. Research indicates individuals' home range extends over only a ca. 5 m total linear range (Allan & Lintermans 2018).

Threats to Stocky Galaxias

Introduced predators

The widespread introduction of Northern Hemisphere Brown Trout (*Salmo trutta*) and Rainbow Trout (*Oncorhynchus mykiss*) (both species herein referred to as 'trout') has had clear, pervasive and enduring impacts on galaxiids across the Southern Hemisphere (McDowall 2006; Lintermans *et al*. 2020). Trout are a threat to 94% of known Australian galaxiid taxa

Figure 1. Stocky Galaxias, *Galaxias tantangara*. Source: Tarmo A. Raadik / Arthur Rylah Institute.

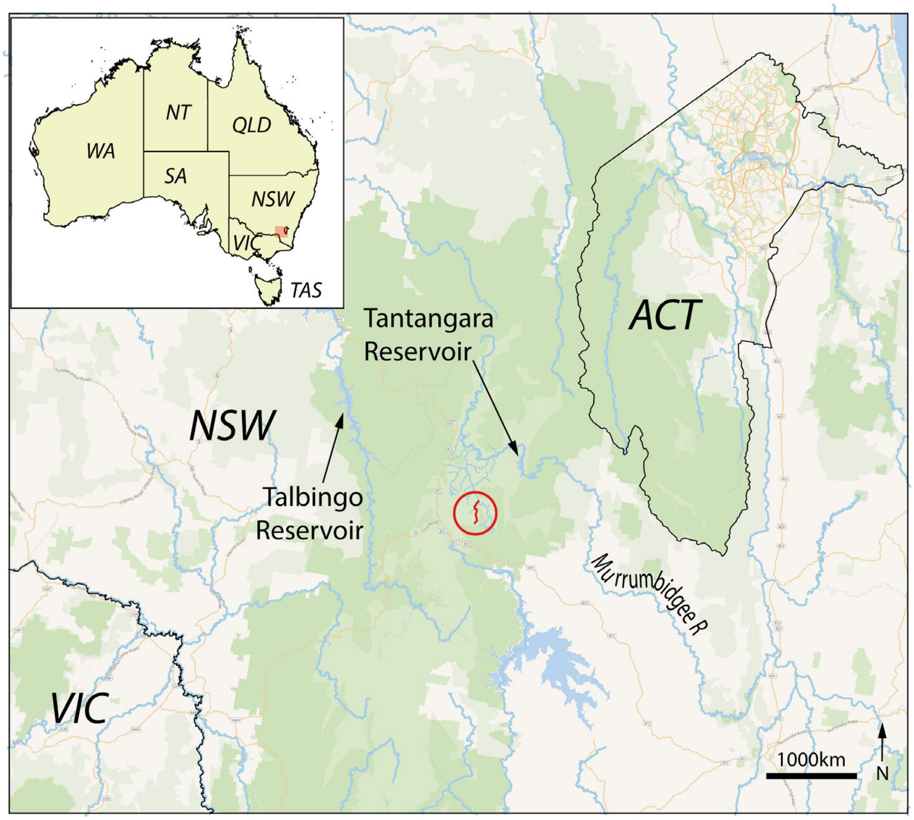

Figure 2. Type locality and known distribution of Stocky Galaxias (*Galaxias tantangara*), New South Wales. Tantangara Creek is highlighted in red, Stocky Galaxias is now restricted to a 3 km section of the upper reaches of this waterway, above an instream barrier that prevents incursion by Rainbow Trout and Brown Trout.

(IUCN 2021) and a major threat to Australia's most imperilled freshwater fish (of which 14 of 22 are galaxiids) (Lintermans *et al*. 2020). The 3-km stretch of Tantangara Creek to which this species is now confined is upstream of a waterfall that forms a natural barrier preventing trout ingression (Allan & Lintermans 2021).

Rapid declines have been documented for numerous Australian galaxiids following incursion by trout (Lintermans 2000; Raadik *et al*. 2010; Raadik & Nicol 2015). In the case of barred galaxias (*G. fuscus*), trout invasion can result in the loss of smaller age class individuals within 3–4 months and extirpation of the remaining adult population within 6–18 months (Raadik *et al*. 2010). Incursion by trout (even one or two individuals) into the upper reach of Tantangara Creek is predicted to result in a similar rapid decline, and the likely extinction of Stocky Galaxias (Fisheries Scientific Committee 2016).

A recently documented threat from introduced fish is the inter-basin transfer of a native galaxiid species the Climbing Galaxias (*G. brevipinnis*). This species, native to coastal streams, was unwittingly transferred to inland drainages by the Snowy Mountains hydro-electric scheme (Waters *et al*. 2002). A new pumped hydro scheme now threatens to introduce the species to the headwaters of the Murrumbidgee River and Tantangara Creek where it will likely compete with and prey on Stocky Galaxias (Lintermans & Allan 2019; TSSC 2021).

Wildfire (heat and sedimentation)

Wildfires pose a direct and indirect risk to Stocky Galaxias (Lintermans *et al*. 2020). Direct heat from fire will kill fish in short sections of small waterways, and partial eliminations of populations have been documented (Cushing & Olson 1963; McMahon & deCalesta 1990). More importantly, severe fires followed by rainfall can increase sedimentation and deteriorate water quality (Gresswell 1999; Lyon & O'Connor 2008). This can be devastating for threatened galaxiids because the resulting reductions in dissolved oxygen can directly kill fish, and because the sediment covers potential spawning sites, smothering eggs or reducing their ability to adhere to the substrate (Fisheries Scientific Committee 2016; Lintermans *et al*. 2020; Allan *et al*. 2021).

Overgrazing and loss of riparian vegetation (wild horses and deer)

Wild horses and deer are abundant in the Australian Alps, including Kosciuszko National Park (Allan & Lintermans 2018; Driscoll *et al*. 2019; Robertson *et al*. 2019). Well-worn trails are present throughout the Tantangara Creek catchment, and highly disturbed crossings are present in Tantangara Creek where Stocky Galaxias is found (Allan & Lintermans 2018). Horses have significant impacts on hydrological regimes by damaging riparian zones and increasing flow variability by degrading peat soils that take thousands of years to accumulate (Driscoll *et al*. 2019). Horses damage bank structure and vegetation, increasing stream widths and reducing depths, and causing boulder and cobble-dominated substrates to be filled with fine gravels and silt (Robertson *et al*. 2019). Increased stream turbidity in Kosciuszko National Park has been directly linked to horse activity (Scanes *et al*. 2021).

Altered flow regimes, exacerbation by climate change

Climate change has been identified as the greatest overall threat to Australia's most imperilled freshwater fishes (Lintermans *et al*. 2020). The small, shallow, headwater habitats to which many Australian galaxiids are now confined are prone to desiccation and this is predicted to increase under climate change with increases in evaporation and rainfall variability (Hughes 2003; Morrongiello *et al*. 2011; Lintermans *et al*. 2020). Predictive modelling suggests tunnelling from Snowy 2.0 works will reduce groundwater supply to many small streams in the Tantangara Creek catchment, reducing baseflow to the point where some will cease to flow for days or weeks at a time (most often in summer months) (EMM, 2018).

Monitoring Stocky Galaxias Abundance, Distribution, and Threats

This monitoring protocol is focussed on two priorities: (i) Tracking the abundance and demographic parameters of the only known population of Stocky Galaxias; and (ii) monitoring the intensity, extent and impacts of threats to enable rapid and appropriate management responses.

Broader regional surveys are urgently needed to define the distribution and abundance of Stocky Galaxias (Raadik 2014; Lintermans & Allan 2019), and the establishment of wild or captive insurance populations are valuable actions for long-term conservation. However, we have limited the scope of this monitoring protocol to the existing known population, albeit noting that the protocol could readily be adapted should additional populations be found. Furthermore, experimental testing of management actions is not considered appropriate for such a small population size and narrow distribution, and is thus not contemplated in this protocol.

Monitoring is a critical component of threatened species management and recovery and when well-designed should provide an understanding of population trends, threats, necessary management responses, and the efficacy of conservation interventions (Lindenmayer *et al*. 2020). Monitoring strategies that do not achieve these objectives are unlikely to adequately describe and help improve the trajectories of species facing extinction. For Critically Endangered species like Stocky Galaxias, it is especially important that monitoring is carefully designed and fit-for purpose. Here we provide recommendations of monitoring metrics specific to Stocky Galaxias including appropriate methods, periodicity, timing, coverage, management links, and trigger points. Most of the 17 Australian *Galaxias* classified as threatened on the IUCN Red List have ranges that have been reduced to extents similar to that of Stocky Galaxias (IUCN 2021). Hence, although this protocol is specific to Stocky Galaxias, the sampling methods and monitoring principles presented here broadly apply to other highly threatened galaxiids (e.g. Barred Galaxias *G. fuscus*, Swan Galaxias *G. fontanus*, and Spotted Galaxias *G. truttaceus*).

Sampling Methods

Population size and dispersion

The most appropriate method available for detailed monitoring of shallow stream-dwelling galaxiids is backpack electrofishing (Copp 1989; Lintermans 2016b; NSWF 1997). Species-related biases are inherent in electrofishing; however, these are well understood regarding fish size and morphology (Copp 1989; Dolan & Miranda 2003). By appropriately reducing anode size relative to the cathode (e.g. 10 cm anode: 60 cm cathode), larvae, smaller individuals, and adults can be sampled simultaneously, with sampling then more representative of population structure than other methods (Copp 1989).

Electrofishing surveys should be conducted in accordance with the Australian code of electrofishing practice (NSWF 1997), and when adhered to by trained personnel, there is minimal risk of injury or mortality posed to Stocky Galaxias. The method requires a two-person team to work sections of waterways, usually from mid-morning to late afternoon. Effort protocols for sampling of fish community structure by the Sustainable Rivers Audit (Davies *et al*. 2010) apply to backpack electrofishing, prescribing 8 x 150 seconds electrofishing 'on-time' as the standard. Less effort is required in small streams where much smaller species pools are usually present, and sampling is more efficient. Alternatively, small stream surveys can be standardised using a series of 30-metre sample distances (e.g. Lintermans *et al*. 2013). Based on previous sampling of Stocky Galaxias (Allan & Lintermans unpublished), sampling for this species using 4–5 sites (30-metre sample distances of creek, or 150 seconds of electrofishing) at 2–3 locations along the 3-km stretch of Tantangara Creek is appropriate. Stunned fish should be collected from the waterway using dip-nets and placed in an aerated container of water for measuring before release. All captured fish should be identified to species level, examined for external parasites, length to caudal fork (LCF) measured to the nearest mm, and weights recorded (Lintermans 2016b).

The restriction of Stocky Galaxias to a single, small, isolated area of marginal habitat increases the potential for deterioration in genetic diversity; continued monitoring of the genetic diversity is likely to be critical for long-term conservation of the species. Genetic diversity data will be essential to assist planning for long-term conservation, and guide protocols for artificial breeding if translocation or hatchery interventions prove necessary. Collection of caudal fin-clips from 20 to 30 individuals at each site provides a non-injurious method to document genetic diversity. Preservation of caudal fin samples would also open avenues for mark-recapture population size estimates using individual profiles, and profiling of population demographics using genetic analyses.

Demographic Parameters

Annual monitoring of age/length cohorts should be timed in the months of late February or March when there is opportunity to detect both adults and juveniles from the most recent annual spawning event in November (Allan *et al*. 2021).

Sampling Coverage, Periodicity, and Longevity

The entire range and population of Stocky Galaxias can be surveyed by electrofishing over a two-day period. Annual population monitoring is the minimum required sampling interval, but additional sampling may be necessary in response to catastrophic events (see later section).

Baseline Water Quality

Baseline environmental conditions of the waterway should be monitored continuously using data loggers. Fundamental parameters to be gathered are: water depth, velocity, substrate particle size, water electrical conductivity (EC standardised to 25°C µS/cm), pH, dissolved oxygen (mg/L and % saturation), turbidity (NTU), and temperature (°C) (Stoessel *et al*., 2015). A qualitative in-stream visual assessment should be undertaken during field sampling to identify signs of disturbance. This should aim to track changes in stream substrates and increases in sedimentation that would impact the interstitial spaces of stream beds needed for Stocky Galaxias reproduction. Any apparent smothering or infilling of streambed substrate with sediment, and any development of side-attached bars, and active bank erosion should be noted, and the plausible causes of such degradation identified.

Specific Threat Monitoring

Trout and climbing galaxias incursion

Electrofishing surveys in March (for Stocky Galaxias population demography) provide an opportunity to detect trout. However, trout incursion could potentially cause extinction of Stocky Galaxias within 6 months (Raadik *et al*. 2010; Lintermans *et al*. 2020). It is therefore imperative that trout detection sampling be conducted at least biannually. Environmental DNA (eDNA) is an extremely effective surveillance tool to detect non-native fish and protect threatened species (Bylemans *et al*. 2016; Schumer *et al*. 2019). Trout detection via eDNA should be conducted simultaneously with annual electrofishing surveys to bolster detection power, and independently at a roughly six-month interval when site access is possible (September–October). Moderate sampling frequency (3–5, 2.0-litre samples filtered through a 0.45 µm filter × 3 technical replicates per sample) was adequate to detect a single brook trout (*Salvelinus fontinalis*) at 500 m intervals with a probability over 86% (Schumer *et al*. 2019). However, eDNA technology is evolving rapidly, and optimal methods would need to be reviewed prior to application in the field (see Wang *et al*. 2021). The natural in-stream barrier that prevents trout incursion into Stocky Galaxias habitat also should be inspected annually during population surveys to ensure it continues to provide an effective barrier. Repairs to any barrier deterioration must be undertaken promptly.

The barriers that preclude trout are not effective against Climbing Galaxias and incursion by this species into the upper Murrumbidgee and Tantangara catchments via the Snowy 2.0 scheme is another major threat (Lintermans & Allan 2019; TSSC 2021). Surveillance for eDNA of this species in parallel with trout sampling would enable early detection and timely management responses.

Riparian condition and horse disturbance

Robertson *et al*. (2019) provided a comprehensive system for assessing riparian condition and impacts of feral herbivores in the Australian Alps. Nine indicators (stream bank stability, pugging damage, longitudinal profile characteristics, sediment levels on stream beds, level of impact of defined animal paths, grazing disturbance, projected foliage cover, and proportion of foliage projection cover that is native) are each scored using numerical categories to gauge an overall understanding of impact. Assessment of riparian condition using this method should be undertaken during annual monitoring surveys in late February or March.

Coordination

Coordination of monitoring activities for Stocky Galaxias is simplified by the species' small distribution that effectively confines responsibilities to a limited number of jurisdictions and stakeholders (Table 1). At a federal level, Stocky Galaxias is listed as Critically Endangered under the EPBC Act (TSSC 2021), and the recent state and federal approvals associated with the Snowy 2.0 scheme mandate Snowy Hydro's responsibilities in survey, monitoring, and assessment for this species. In New South Wales, threatened species legislation responsible for aquatic organisms is administered by the Department of Primary Industries. Much of the research that has been conducted to date has been undertaken by independent researchers at the University of Canberra, with no formal monitoring programme established. Management of the single locality for this species falls within the jurisdiction of the NSW National Parks

Table 1. Selected stakeholders with interests and responsibilities for the conservation and management of Stocky Galaxias

Stakeholder	Type	Interests and responsibilities related to Stocky Galaxias
Australian Government Department of Agriculture Water and the Environment	Government department	National level threatened species listing, conservation, management, monitoring and funding
New South Wales Department of Primary Industries (DPI)	Government department	Administration of key pieces of legislation to identify and protect threatened fish, and management of trout stocking and recreational fishing under the New South Wales *Fisheries Management Act 1994*. Fish conservation assessments are prepared by the DPI Fisheries Scientific Committee
New South Wales Department of Planning, Industry & Environment	Government department	Administration of terrestrial threatened species legislation, the *Biodiversity Conservation Act 2016*. Coordination of threatened species conservation programmes including the *Saving our Species* programme.
New South Wales National Parks and Wildlife Service	Government department	On-ground management and conservation of Kosciusko National Park, and wider New South Wales biodiversity and cultural heritage
Monaro Ngarigo and other Indigenous organisations	Traditional Owners	Cultural and biological heritage, management, and conservation of Kosciuszko National Park
The University of Canberra, Centre for Applied Water Science	University research	Scientific research related to the biology, conservation, and management of Stocky Galaxias. Leader of all species research and assessment efforts conducted to date.
Charles Sturt University	University research	Scientific research into captive husbandry and breeding of Stocky Galaxias
Snowy Hydro Ltd	Government-owned integrated energy company	Responsibility for developing and implementing threatened fish and biosecurity plans for Stocky Galaxias
Victoria Department of Environment, Land, Water and Planning, Arthur Rylah Institute	Government department – research	Scientific research related to biology, conservation and management of southeast Australian *Galaxias* species.
Australian Society for Fish Biology	Civil Society Organisation	Promote research, education and management of fish and fisheries in Australia. Preparation of conservation assessments where lacking, and coordination of research and conservation efforts.
Australia and New Guinea Fishes Association	Civil Society Organisation	Promote the study, conservation, and culture of the native freshwater fish species of Australia and New Guinea, and to provide a forum for the exchange of information.
Recreational Fishing Alliance of New South Wales	Civil Society Organisation	Outreach and awareness surrounding the importance of preventing trout incursion into the upper Tantangara Creek.
Environmental consultants and consultancy companies	Private organisations	Ad hoc surveys, impact assessments, bushfire rescue, collection of fish for captive husbandry and breeding research.

and Wildlife Service. However, National Parks and Wildlife Service has no jurisdiction over threatened fishes, the responsibility for which falls to the NSW Department of Primary Industries (Fisheries). Opportunities for Indigenous communities to preserve cultural and biological values are increasingly being reinstated in National Parks, and Monaro Ngarigo solidified such a role in Kosciuszko National Park via a 2016 memorandum of understanding with the New South Wales government. The threat posed by trout introduction demands a proactive relationship be developed with recreational anglers, to help prevent the human-mediated spread of this threat into upper Tantangara Creek.

Data Availability and Reporting

A condition of NSW and Australian Government approvals for Snowy 2.0, was that monitoring data must be made publicly available (DAWE 2018; DPIE 2020). Monitoring data and their interpretation should thus be stored in a reliable, accessible, and secure facility available to the public (Woinarski 2018). Specifying who is responsible for long-term data management is an important part of this, including a preparedness to migrate data across any technological and platform changes. An ideal framework for this in the case of Stocky Galaxias is provided by the New South Wales Department of Environment, Energy and Science, *Saving our Species database* (NSW EES 2020).

Management Actions and Trigger Points

Clearly established trigger points are important for guiding heightened management responses when thresholds (such as a population size or rate of decline) are breached (Woinarski 2018). In the case of Stocky Galaxias, the most appropriate trigger points to elicit the necessary rapid management responses are related to threat detection, rather than subsequent population declines. However, in the event of a sustained population decline, options for maintaining captive insurance populations may need further investigation. We provide appropriate trigger points and actions for the most important threats to Stocky Galaxias: introduced predators and bushfire, and flow conditions.

Trout and Climbing Galaxias Detection and Breeding Failure

If trout are found upstream of the trout barrier, immediate (or urgent) removal is required. Similarly, if Climbing Galaxias are detected above or adjacent to the trout barrier, an emergency intervention would be required. However, unlike trout, complete removal of Climbing Galaxias following incursion beyond the instream barrier would be extremely difficult. Instead, opportunities for translocation or ex-situ conservation would need to be further assessed, otherwise extirpation of Stocky Galaxias would almost certainly follow.

Absence of smaller age classes in Stocky Galaxias annual monitoring can provide an alternative early warning sign that predators may have breached the instream barrier in low numbers, or that spawning or recruitment failure has occurred. Such a result should trigger more intensive predator surveys (e.g. eDNA screening) and removal to prevent an irreversible population decline. Additional actions to monitor Stocky Galaxias spawning or recruitment success in subsequent years may be required.

Bushfire and Flow Conditions

A bushfire in the vicinity of Tantangara Creek would pose dual risk to Stocky Galaxias via heat and direct mortality, and vegetation loss and subsequent deterioration in water quality from ash and sediment runoff (Legge *et al*. 2021). Rapid reconnaissance surveys should aim to document the level of disturbance on the population, provide qualitative assessments of significant ash and/or sediment input (or likelihood of subsequent input), measure water quality parameters, and estimate numbers of fish remaining (Southwell *et al*. 2021). Emergency rescue may be required, as occurred in 2020 (see Lintermans 2020; Shelley *et al*. 2021). Monitoring of stream flow is critical in relation to underground tunnelling for Snowy 2.0, and periods of extreme drought. Permanent stream flow meters are recommended to provide a greater understanding of stream flow fluctuations and ensure the population is not extirpated by stream drying. Following high-flow events, rapid assessments are again imperative to inspect the integrity of instream barriers and carry out predator detection using eDNA sampling.

Conclusions

The limited distribution and small population size of Stocky Galaxias both simplifies and complicates the requirements for adequate monitoring. Monitoring is simplified in that the entire range of the species can be surveyed over a short annual monitoring period to generate a robust population census. Timing this appropriately to coincide with months in which adults and juveniles can be detected also allows for an estimate of reproductive success from recent breeding. Small distribution corresponds with a small group of relevant stakeholders (a single state government, and a limited number of experts) that presumably can make the administration of monitoring more simple (compared to widely distributed species). However, the substantial risk of extinction that coincides with a tiny distribution also raises the monitoring and management stakes. Monitoring must therefore be carefully designed and properly executed, with the variability of data periodically analysed to ensure there is the statistical power to identify critical population changes. Moreover, rapid management responses to any identified changes in types or levels of threat will be imperative, as will continued monitoring to ensure any management responses are effective. Similar scenarios exist for many range-restricted threatened freshwater fish in Australia and worldwide. Adopting carefully designed programmes that adequately incorporate monitoring of species-specific variables, threats, and management actions can provide a means to improve the conservation outlook for such species.

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