Review

A review of on-ground recovery actions for threatened freshwater fish in Australia

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Abstract.   Freshwater fish are a highly threatened group and recovery of these threatened species is an increasingly difficult ecological and social challenge. There are many different on-ground recovery actions available to managers, but no synthesis of what, how or why these recovery actions have been deployed. The present paper reviews 428 reported on-ground recovery actions from a survey of practitioners of threatened freshwater-fish recovery in Australia. Recovery actions were grouped into 12 categories, with the most commonly utilised recovery categories being harvest control, translocation, habitat enhancement and stock enhancement. Major drivers of recovery actions were general conservation concern, recovery plans and emergency responses. The number of recovery actions grew significantly in the decade beginning 2000 as the impacts of prolonged drought in south-eastern Australia intensified. In all, 58% of recovery actions occurred in the Murray–Darling Basin, although this region holds only 27% of the 74 listed threatened freshwater fish in Australia. Few or no recovery actions were reported for many species, and few actions occurred in northern or western parts of the country. More than 80% of recovery actions reportedly had some form of monitoring. The diversity of management interventions is reviewed, and patterns and issues are identified to guide future recovery efforts.

Additional keywords: assessment of success, drought, monitoring, stock enhancement, threatened fish management, translocation.

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Introduction

Recovering threatened species is an increasingly difficult eco-logical and social challenge. The number of threatened species continues to rise globally (Hoffmann *et al.* 2010; IUCN 2012) with little evidence of a declining trend in listing for most groups. The IUCN Red List (version 2012.1) has grown from 10 533 species in 1996–1998 to 63 837 in 2012. Currently, 2041 fishes are listed as *Critically Endangered* (CE), *Endangered* (E) or *Vulnerable* (V), almost triple the 734 listed in 1996–1998 (IUCN 2012). Such increases are occurring across the spectrum of threat categories, with the number of CE, E and V fishes rising by 264%, 572% and 258%, respectively, between 1996–1998 and 2012 (IUCN 2012). Many countries have statutory national lists, national non-statutory lists, and state or regional lists, adding to the overall threatened species management burden. For example, in Australia, 36 freshwater fishes are listed as nationally threatened under the *Environment Protection and Biodiversity Conservation Act 1999* (*EPBC Act*), with a further 13 species nationally listed by the Australian Society for Fish Biology (Lintermans 2011) and another 25 species listed under State or Territory legislation (Lintermans 2013*a*).

The funds allocated to maintaining biodiversity and restoring threatened species are orders of magnitude less than required (Balmford *et al.* 2003; Joseph *et al.* 2009) and the shortfall is

unlikely to be addressed in the near future. Decisions to list species as threatened are justifiably decoupled from the man-agement costs that such listing might entail, but failure to devote adequate resources to recovery management means that such species will require perpetual conservation management, may not persist or never be delisted (Scott *et al.* 2005, 2010; Doremus and Pagel 2001; Joseph *et al.* 2008). Threatened species recov-ery plans guide management activities; however, prioritisation of resources among threatened species or among activities within a species recovery plan is problematic (Briggs 2009; Joseph *et al.* 2008, 2009). In the USA, 5.5% of listed threatened species accounted for 55% of funds spent on recovery between 1990 and 2002 (Kerkvliet and Langpap 2007). In Australia, the implementation of recovery plans for nationally listed species is devolved to and funded by the states and territories (Hawke 2009), which are also responsible for recovery actions for state-listed species. Consequently, competition for funds is fierce, there are inevitable shortfalls, and priorities are often identified on the basis of conservation status (Possingham *et al.* 2002).

There is relatively little information on the use or combina-tion of recovery actions deployed for threatened species. Large-scale reviews suggest that, on average, recovery actions are slowing or stabilising rather than reversing the decline of threatened species (e.g. Male and Bean 2005; Gibbs and Currie

2012), although there are notable exceptions. Where rapid recovery has occurred, it is usually for species with single or relatively easy to address threats (i.e. non-'wicked' problems (Abbitt and Scott 2001; Doremus and Pagel 2001). The influence of some specific management actions (e.g. the identification of critical habitat) on recovery trajectory has been scrutinised but the results may be contradictory (Taylor *et al.* 2005; Gibbs and Currie 2012) and the majority of management interventions have not been examined. For freshwater fish, there is a relatively common suite of management activities employed to recover threatened species, including stock enhancement with captive-bred individuals, translocation, habitat rehabilitation, legislative protection, remediation of barriers to fish passage, improved water-quality and flow management, and control of alien species (Cowx 2002; Helfman 2007; Lintermans 2013a). A large-scale synthesis of what, why and how these recovery actions have been deployed has not previously been documented at a national or continental scale, with such an approach potentially informative internationally. The present paper reviews the diversity of on-ground management interventions directed at Australian threatened freshwater fish, and examines patterns and issues that may guide future recovery efforts.

Reviews of recovery programs are essential if recovery science, legislation and management are to improve and valuable resources are to be better directed (see Clark *et al.* 2002; Taylor *et al.* 2005; Goble *et al.* 2006; Scott *et al.* 2010; Gibbs and Currie 2012). However, such reviews are dependent on the quality and availability of relevant data and the method of analysis (Abbitt and Scott 2001; Crouse *et al.* 2002; Gibbs and Currie 2012). Although the outcomes of numerous individual recovery case studies are available, there are relatively few reviews of intervention classes or for specific threatened animal groups. An exception is reintroductions where several reviews have identified critical components and processes (e.g. Griffith *et al.* 1989; Fischer and Lindenmayer 2000; Sheller *et al.* 2006) and an identifiable field of reintroduction science has developed (Seddon *et al.* 2007; Armstrong and Seddon 2008).

Methods

The goal of the review was to understand what on-ground management actions have been undertaken to recover threatened freshwater fish in Australia. A diverse group of practitioners involved in managing, researching or conserving threatened freshwater fish was surveyed by email, seeking information about on-ground actions to recover threatened freshwater fish in Australia (for survey details, see Table S1, available as Supplementary Material for this paper). As well as information on the recovery action and focal species, information was also sought on the drivers for the recovery action, whether monitoring was conducted, the adequacy of monitoring resources available, and whether actions were considered successful in achieving their goals. The target of the survey was threatened species with 'threatened' defined as any species listed on national, state or advisory listings in the higher-level categories of critically endangered, endangered or vulnerable (either as species or threatened populations). Seventy-four freshwater species are currently listed as threatened at national or state or territory level (Lintermans 2013a; see Table S2,

available as Supplementary Material for this paper). The primary or significant target of activities must have been threatened freshwater fish species. River-health projects and broad river or aquatic education programs with ancillary but untargeted benefits for threatened species were excluded. Threatened fish communities were not included as focal entities in the survey. The inclusion of threatened fish communities would have made such a wide range of management activities potentially relevant as to cloud interpretation.

'On-ground' was defined as management activities that manifest themselves in field management activity, with legislative actions such as prevention of take included. Research activities were excluded, because many research activities do not result in discernable on-ground management activities and if they did, they would be captured in the survey. There were no criteria for minimum or maximum size or cost of projects, nor on who the projects were conducted by; so, activities by catchment management authorities, government agencies, private individuals, public conservation organisations, water authorities and individual companies are all included in the survey.

Care was taken to remove duplicate records from the survey before analysis. For several projects, insufficient information on duration, effort, timing or focus was able to be collected, and so, these projects were excluded. However, projects with occasional missing fields were included, so as to present as representative a sample as possible. Undoubtedly, there are additional projects that have not been captured, but the aim was to gather a representative rather than exhaustive project list.

The diverse array of recovery actions was allocated into 12 categories on the basis of their primary activity (Table 1). Where responses included several activities within a single project, the project was included in the category tally for each of the components. Similarly, where more than one focal species was identified, the activity was allocated to all focal species identified. Recovery actions were grouped into 5-year blocks, based on the year the action commenced.

After receipt of responses, the reported drivers of recovery actions (i.e. what triggered the action) were categorised into six broad categories, as follows:

general conservation concern – often for species without or before the development of recovery plans, related to ongoing or potential declines, and long-standing identified conservation needs,

recovery plan priorities – for species that have existing state/ territory or national recovery plans,

emergency responses – actions in response to anthropogenic or natural events such as pollution events, bushfires, drought, flooding, or imminent invasion by alien species,

state and regional strategies – e.g. broad-scale fish-passage strategies, regional conservation strategies, environmental flow plans, catchment management plans, local conservation plans, and national park management plans,

identified management needs – actions stemming from prior management exercises, research projects, and

development condition of consent – arising from mandatory conditions attached to approved development proposals.

The scale of reported actions was also reviewed, including both the spatial extent of the management action, as well as the

Table 1. Categories of on-ground recovery activities (and their abbreviations as used in subsequent figures)

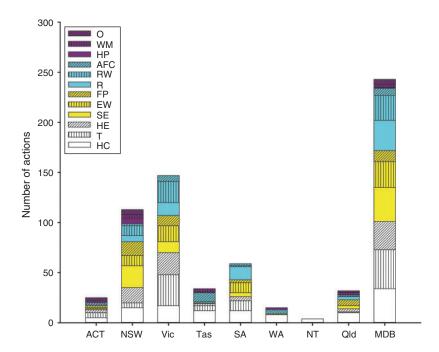| Category	Abbreviation	Definition
Alien-fish control	AFC	Direct removal of alien fish, installation or augmentation of barriers to limit dispersal, measures to prevent introduction.
Fish passage	FP	Removal of barriers to upstream and/or downstream migration of fishes. Includes the physical removal of barriers, installation of fishways, and alteration of existing fishways for target threatened species (NOT measures to limit the spread of alien species).
Habitat enhancement	HE	Installation of in-stream structures (natural, artificial) for cover or spawning, creation or modification of refuge habitats, modification of streambed to prevent stranding, in-stream structures to prevent erosion, artificial aeration.
Habitat protection	HP	Includes declaration of critical habitat, protection from management or development activities (e.g. bushfire control, highway construction), remediation from toxic-spill events.
Riparian works	RW	Riparian planting, weed control, fencing, stock exclusion, provision of off-stream stock watering, bank stabilisation.
Harvest control	HC	Legislative controls on take (NOT for recreational fishery management), specific area closures.
Environmental watering	EW	Release of environmental flows, floodplain watering, delivery of water to isolated environments (closely related to 'Water management' (see below) but has a focus on active water delivery, rather than controls on abstraction or manipulation of lentic water bodies).
Rescue	R	Rescues of wild fish from natural environment in the face of critical environmental threats (e.g. bushfire, desiccation, blackwater, alien fish, toxicants).
Translocation	T	Release of wild captured fish into locations within and outside their natural range.
Stock enhancement	SE	Initiation of captive breeding programs, release of hatchery-bred fish, and release of fish bred in surrogate sites.
Water management	WM	Management of water levels in lakes/reservoirs, restrictions on extraction/diversion from streams.
Other	O	Disease control, creation of protected areas, education activities targeted at specific issues for threatened freshwater fish (NOT general education programs).

Fig. 1. Distribution of recovery actions across Australian states and territories and for the Murray–Darling Basin (MDB). Note that the MDB total is extracted from the state and territory data. Abbreviations of recovery categories are given in Table 1. ACT = Australian Capital Territory, NSW = New South Wales, NT = Northern Territory, Qld = Queensland, SA = South Australia, Tas = Tasmania, Vic = Victoria, WA = Western Australia.

likely extent of impacts arising from the recovery action. For example, although fishways are constructed at a local/site scale, their impact can be larger than this (usually tens of kilometres before the next fish-movement barrier is encountered).
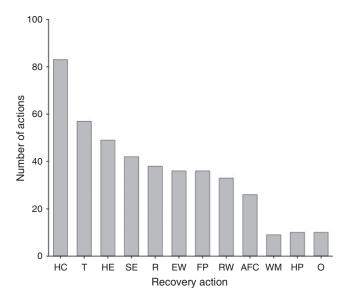

Fig. 2. Number of on-ground recovery actions by category for threatened freshwater fish in Australia. Abbreviations of recovery categories are given in Table 1.

Results

In total, 428 on-ground recovery actions were identified by respondents, with actions being recorded in all states/territories (Fig. 1). Most recovery actions were recorded in southern and eastern Australia, with relatively few being reported for western or northern states/territories (Fig. 1). The Murray–Darling Basin, which covers >1 million km² and includes part of Queensland (Qld), New South Wales (NSW), Victoria (Vic), South Australia (SA) and all of the Australian Capital Territory (ACT), contained 58% of reported actions. Recovery-action categories comprising more than 10% of the total were (in decreasing rank) harvest control, translocation and habitat enhancement, which, combined with stock enhancement, rescue, fish passage, environmental watering and riparian works, comprised 88% of all actions (Fig. 2). The only other category containing more than 5% of actions was alien-fish control (Fig. 2).

The diversity and number of recovery actions increased substantially over time (Fig. 3). Only a single recovery category was reported pre-1981 (harvest control), growing to four categories (harvest control, riparian works, stock enhancement, translocation) by the early 1980s, and including all 12 categories by the early 2000s (Fig. 3). The number of on-ground recovery actions peaked in 2006–2010, although it must be noted that at the time of review, the decade commencing 2011 contained approximately only 1 year of data. In the late 2000s, the number of rescue, environmental watering, translocation and stock-enhancement activities increased noticeably over previous periods.
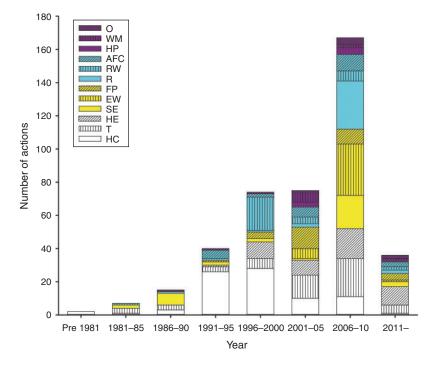

Fig. 3. Number of on-ground recovery actions by category directed at threatened freshwater fish in Australia in 5-year time periods. Actions are grouped into time blocks on the basis of when an individual action commenced and do not represent the cumulative number of actions over time. Abbreviations of recovery categories are given in Table 1.

On-ground recovery actions were reported for 54 of the 74 species listed, with most species where recovery actions were reported having six or fewer actions (Fig. 4a). Fifteen per cent of listed species had only a single recovery action reported, 64% of species had fewer than three actions and 73% had fewer than five actions. Species with more than 20 recovery actions reported were Macquarie perch, *Macquaria australasica* (74), Murray hardyhead, *Craterocephalus fluviatilis* (35), dwarf galaxias, *Galaxias pusilla* (32), freshwater catfish, *Tandanus tandanus* (27), and trout cod, *Maccullochella macquariensis* (26), with all of these species occurring in southern Australia and only one (*G. pusilla*) occurring outside of the Murray–Darling Basin. On average, species with recovery actions reported had actions in three recovery-action categories, with
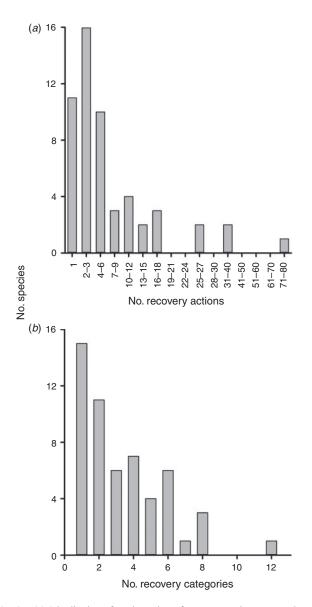
one species (Macquarie perch) having actions in all 12 categories (Fig. 4b). Only a single species from northern or western Australia (red-finned blue-eye, *Scaturiginichthys vermeilipinnis*) had actions reported from more than three recovery-action categories, and no northern or western species had more than six recovery actions reported. Forty-seven species had three or fewer recovery actions reported, with 20 of these having no recovery actions reported (see Table S3, available as Supplementary Material for this paper). These species with low or no recovery actions reported included nationally and state-only listed species and covered a range of threat categories, from *Vulnerable* to *Critically Endangered.*

Harvest control

Between 1991 and 2005, there was substantial activity to control harvest of threatened freshwater fish species, with this increased activity largely reflecting the surge in threatened species listings over this time period. As well as declarations of total protection from take, some regional closures were also implemented. Examples include closures of river reaches to all angling (such as the in the Cotter and Murrumbidgee rivers in the ACT to protect trout cod and Macquarie perch), and closures to commercial net fishing to protect freshwater sawfish *Pristis microdon* and *Glyphis* spp. (speartooth and river sharks) in Qld and the Northern Territory (NT). Note that harvest controls aimed at management of recreational fisheries (for species where legal take was permissible) are not included in this survey. For example, almost all of the management actions directed at Murray cod, *Maccullochella peelii*, have been driven by recreational fishery management, rather than conservation management.

Rescue and translocation

'Rescue and translocation' and 'rescue' were the fifth- and second-most common recovery actions, respectively (Fig. 2). There is a broad diversity of species that have been subject to rescue and/or translocation, including both large-bodied riverine (e.g. Macquarie perch, see Lintermans 2013b) or lacustrine species (e.g. freshwater catfish) and small-bodied wetland species (e.g. Murray hardyhead, Yarra pygmy perch, southern pygmy perch, see Ellis *et al.* 2013, Hammer *et al.* 2013, Saddlier *et al.* 2013; Table 2). Rescue actions often result in translocation when the animals are taken into captivity and the donor location is unable to have rescued animals returned (as a result of unsuitable habitat conditions (e.g. dessication)). Rescues and translocations occurred predominantly in southern Australia. The incidence of both of these recovery actions increased substantially in the 2000s during the millennium drought in south-eastern Australia (Table 2). All freshwater catfish translocations occurred in Vic and were largely driven by concerns over declining habitat condition in small lakes (P. Clunie, unpubl. data), as were Murray hardyhead rescues and translocations (Ellis *et al.* 2013). The number of individuals translocated varied considerably among species and locations. For example species that have a program of regular translocations over several years can involve thousands of individual fish (e.g. Arthurs paragalaxias, *Paragalaxias mesotes*, in Tasmania (Tas), 300–500 fish translocated per year for 8 years). More often, translocations

Fig. 4. (a) Distribution of total number of recovery actions reported per species (excluding species with no recovery actions reported). (b) Frequency of individual species with recovery actions reported across multiple recovery-action categories.

Table 2.   Rescue and translocation actions reported (total (all years) and those from 2000 to 2010)

Common name	Scientific name	Rescue		Translocation	
		Total	2000–2010	Total	2000–2010
Australian lungfish	*Neoceratodus forsteri*	3	2	0	0
Barred galaxias	*Galaxias fuscus*	3	3	0	0
Dwarf galaxias	*Galaxiella pusilla*	1	1	10	7
Freshwater catfish	*Tandanus tandanus*	1	1	15	12
Macquarie perch	*Macquaria australasica*	3	3	10	4
Murray cod	*Maccullochella peelii*	2	2	0	0
Murray hardyhead	*Craterocephalus fluviatilis*	11	10	7	6
Olive perchlet	*Ambassis agassizii*	1	1	1	0
River blackfish	*Gadopsis marmoratus*	2	2	1	1
Southern pygmy perch	*Nannoperca australis*	3	3	2	1
Trout cod	*Maccullochella macquariensis*	3	1	0	0
Yarra pygmy perch	*Nannoperca obscura*	3	2	2	2
Silver perch	*Bidyanus bidyanus*	1	1	0	0
Arthurs paragalaxias	*Paragalaxias mesotes*	0	0	1	1
Southern purple-spotted gudgeon	*Mogurnda adspersa*	0	0	1	0
Two-spined blackfish	*Gadopsis bispinosus*	0	0	1	1
Clarence galaxias	*Galaxias johnstoni*	0	0	1	0
Golden galaxias	*Galaxias auratus*	0	0	1	0
Pedder galaxias	*Galaxias pedderensis*	1	0	2	1
Red-finned blue-eye	*Scaturiginichthys vermeilipinnis*	0	0	1	1

involved much fewer individuals (usually 50–200), and were single events.

Habitat enhancement

Habitat enhancement was the third-most common recovery action (Fig. 2) and covered a diverse range of activities, including stream-bed stabilisation, addition of structural woody habitat, installation of rock groynes to promote pool formation, creation of refuge pools, addition of artificial spawning substrates, artificial aeration to combat low dissolved oxygen, construction of cover to minimise predation, in-stream works to minimise fish strandings downstream of dams, creation of artificial wetlands, and in-stream structures to prevent bank erosion. Habitat enhancement became a frequent practice from the late 1990s, and has primarily been deployed in Vic (20 actions) and NSW (15 actions) where it is often combined with other recovery actions such as riparian works, stock enhancement and fish passage.

Stock enhancement

Stock enhancement was the fourth-most common recovery action, and has a long history of involvement with recovering threatened freshwater fish species, with activities in Australia commencing in the early 1980s, and continuing to the present. Stock enhancement has been employed for 11 threatened freshwater species, with some programs having released more than 1 million individuals in programs spanning more than 20 years (Table 3; see Koehn *et al.* 2013). The larger (spatially and temporally) stocking programs have focussed on large-bodied individuals that were formerly favoured angling species (trout cod, Macquarie perch, eastern freshwater cod, *Maccullochella ikei*, Mary River cod, *Maccullochella mariensis*).

No reports were received of conservation-oriented (as opposed to recreational-fishery) releases of Murray cod, *M. peelii*. However, in recent years, breeding programs for small-bodied fish have been developed (Table 3; see Ellis *et al.* 2013; Hammer *et al.* 2013). Innovative approaches using artificial refuges (farm dams and created wetlands) were used for Yarra pygmy perch, *Nannoperca obscura*, Murray hardyhead, and southern pygmy perch, *Nannoperca australis*, allowing relatively small numbers of captive-bred fish to produce thousands of offspring for reintroduction (Hammer *et al.* 2013). Harvest of fertilised egg masses from the wild was employed for barred galaxias, *Galaxias fuscus*, with the captively hatched larvae then on-grown and juveniles released to the wild (T. Raadik, unpubl. data).

Environmental watering

Environmental watering was the equal sixth-most common recovery action. It increased in prominence in the early 2000s, peaking in the late 2000s, with the majority of actions undertaken in NSW (14 actions), Vic (10) and SA (9). There were no actions in this category reported for Qld, NT or Western Australia (WA) and only a single action in the ACT and Tas. Sixty-four per cent of the 36 actions reported were related to water-quality issues associated with evaporation in small remnant habitats (e.g. elevated salinity) and maintaining persistence of drought refugia. Another 17% involved supply of water to ameliorate water-quality problems from blackwater events (low dissolved oxygen). Nineteen per cent were to mimic components of natural hydrographs, to facilitate spawning or flush sediments from important feeding and/or breeding habitats. Most environmental-watering actions were directed at Murray hardyhead (12 actions), Murray cod (7) and dwarf galaxias (5).

Table 3. Stock-enhancement programs for threatened freshwater fish, with details of jurisdiction and numbers stocked, year span over which stocking occurred, and number of sites and river valleys stocked

Stocking of Murray cod, *Maccullochella peelii*, is not included because all stocking for this species is considered to be for recreational rather than conservation purposes

Species	State	Total no. stocked	No. years stocked	Stocked year span	No. of sites	No. of river valleys
Eastern freshwater cod, *Maccullochella ikei*	NSW	223 922	7	1989–2003	103	2
Trout cod, *Maccullochella macquariensis*	NSW/ACT	1 087 565	25	1986–2012	39	8
	Vic	468 555	24	1987–2011	14	6
Mary River cod, *Maccullochella mariensis*	Qld	653 970		1983–2011	44	7
Macquarie perch, *Macquaria australasica*	NSW	69 636	4	1988–2012	5	4
	Vic	440 140	13	1987–2011	?	5
Olive perchlet, *Ambassis agassizii*	NSW	2750	1	2010–2011	2	2
Southern purple-spotted, gudgeon *Mogurnda adspersa*	NSW	3120		2003–2004 to 2009–2010	5	4
	SA	871	3	2010–2012	2	1
Southern pygmy perch, *Nannoperca australis*	NSW	12 115	4	2007–2008 to 2010–2011	5	2
	SA	1350	1	2011–2012	3	1
Yarra pygmy perch, *Nannoperca obscura*	SA	4900	1	2011–2012	4	1
Murray hardyhead, *Craterocephalus fluviatilis*	Vic	640	3	2009–2012	2	1
	SA	3635	2	2010–2012	2	1
Barred galaxias, *Galaxias fuscus*	Vic	240	1	2010	2	1
Lake Eacham rainbowfish, *Melanotaenia eachamensis*	Qld	3000	1	1989	1	1

Fish passage

Fish-passage enhancement was the equal sixth-most common recovery action. Only a single instance of provision of fish passage for threatened species was reported before 1995, increasing by four in the latter half of the 1990s and then increasing by another 13 and 9 in the first and second half, respectively, of the 2000s. Fish-passage actions were reported in all jurisdictions except Tas and NT, with most being reported from NSW (12) and Vic (9). Common actions in this category comprised provision of fishways (17), physical or operational alterations to existing infrastructure (e.g. dams, road culverts) to improve fish passage (12) and removal of existing barriers (6). Species most commonly targeted were Australian grayling, *Protroctes maraena* (10), Australian lungfish, *Neoceratodus forsteri* (6), Macquarie perch (6) eastern freshwater cod (3) and congollis, *Pseudaphritis urvillii* (3).

Riparian works

Riparian works were most commonly reported in Vic with common activities including weed control, tree planting, willow removal, stock exclusion fencing and bank stabilisation. Riparian works are commonly employed by Catchment Management Authorities (CMA) or Natural Resource Management (NRM) boards, with broad responsibilities for riverine and land management within catchments. It can be difficult to distinguish which riparian activities are truly directed at recovery of threatened fish, as opposed to general river-health improvement, and few CMAs contributed to this dataset. However, as an example, the Goulburn Broken CMA in Victoria conducted 18 riparian works actions across 15 river reaches on six streams between 2000 and 2010, with the target species being Macquarie perch.

Alien-fish control

The 26 alien fish-control recovery actions have been relatively evenly distributed across the years, commencing in the early 1990s and continuing to the present. Examples are reported from all jurisdictions except NT, with Tas reporting the highest number of actions (9), followed by Vic (6). Target species vary by jurisdiction, with most activities in Tas and upland Vic focusing on salmonids and occasionally redfin perch, *Perca fluviatilis*, whereas activities in lowland Vic, NSW, ACT and SA were more focused on redfin perch, carp, *Cyprinus carpio*, and eastern gambusia, *Gambusia holbrooki*. In WA, attempts were directed at eradicating guppy, *Poecilia reticulata*, from cave habitats to protect blind gudgeon, *Milyeringa veritas*, and blind cave eel, *Ophisternon candidum*, and at eradicating eastern gambusia to protect Balston's pygmy perch, *Nannoperca balstoni*, and mud minnow, *Galaxiella munda*. Actions included barrier construction and/or augmentation to prevent invasion or spread (13 actions), manipulation of flows (to prevent upstream expansion) (1 action), bans on recreational angling (to prevent spread by bait bucket introduction) (1 action), and direct removal through netting, poisoning, and drying (11 actions). Barrier installation and/or augmentation and direct removal were sometimes used in conjunction.

Water management

Water management was a relatively uncommon recovery action, with only nine reported occurrences, all being in Tas, ACT, and NSW. Water-management activities were almost evenly split between lentic (4 actions) and lotic habitats (5 actions), with actions on streams usually to set limits on extraction under low flows to protect important habitats and/or allow fish passage. Water levels in lentic habitats have been manipulated to ensure

availability of spawning or refuge habitats, as well as facilitating movement of individuals from a reservoir to spawning streams.

Other

There were only 10 recovery actions included in 'other', with educational actions being the most numerous action in this category (6 actions). Educational actions included signage to improve species identification (where inadvertent recreational take through species misidentification was an issue for trout cod), and workshops with local councils to minimise potential for inappropriate habitat management (e.g. drainage works). Other activities included the purchase of a pastoral property (Edgbaston) to protect critical habitat for two spring-dependant species (red-finned blue-eye and Edgbaston goby *Chlamydogobius squamigenus*), and activities to protect Macquarie perch by preventing the introduction of a virus (epizootic haematopoietic necrosis virus) to a subcatchment (Lintermans 2012).

Habitat protection

Habitat protection was the least commonly reported on-ground recovery action (9 actions), used in NSW, Qld and Tas. Examples include the only case of declaration of critical habitat for a species (Oxleyan pygmy perch, *Nannoperca oxleyana*) in Australia, as well as activities to protect habitats from adverse water-quality impacts. A novel example was the removal of dead goats from a cave pool to prevent water-quality impacts on threatened stygofauna (blind gudgeon; blind cave eel). Limitations on the use of fire retardants adjacent to streams supporting threatened fish (Macquarie perch) is another example.

Monitoring

In all, 86% of recovery actions reported whether monitoring was conducted. If activities such as harvest control and habitat protection were excluded (because of the difficulty to directly and effectively monitor), the proportion of recovery actions reporting on monitoring was 83%, with 75% of these reporting the existence of a monitoring program, 19% had none, and 6% had irregular or *ad hoc* monitoring only. The reported existence of monitoring programs for individual recovery categories were alien fish control at 86%, environmental watering at 88%, fish passage at 74%, habitat enhancement at 68%, rescue at 65%, riparian works at 84%, stock enhancement at 59%, translocation at 78%, and water management at 67%. Sixty-one per cent of monitored recovery actions considered that resources available for monitoring were adequate, 17% considered that they were marginal, and 23% considered they were inadequate.

Scale of actions

Although problematic to characterise, the majority of individual recovery actions were small scale (54% of all actions), involving relatively few individuals (<250 for rescues and translocations), small lengths of stream, (usually <5 km for habitat enhancement, habitat protection, some riparian works, alien-fish control) or single sites (Table 4). Twenty percent of actions were moderate scale and 26% were large scale, although 75% of the

Table 4. Scale of projects (percentage of category count) for each recovery-action category
N = count of actions where scale could be identified

Recovery action	N	Small (%)	Moderate (%)	Large (%)
Alien-fish control	25	72	28	–
Fish passage.	35	26	51	23
Habitat enhancement	43	93	7	–
Habitat protection	10	90	10	–
Riparian works	31	61	32	7
Harvest control	82	2	1	96
Environmental watering	38	66	11	24
Rescue	37	84	16	–
Translocation	52	81	17	2
Stock enhancement	35	51	37	11
Water management	9	22	67	11
Other	10	40	50	10
Overall	407	54	20	26

large-scale actions were in a single category (harvest control) (Table 4). Within recovery-action categories, generally <25% of the actions were large scale (except for harvest control) and, on average, small-scale projects comprised 62% of actions (if harvest control is excluded). Recovery categories that had a larger proportion of moderate- and large-scale actions were fish passage (opening up tens of kilometres of stream), water management (where abstraction controls applied across tens of kilometres of river, or large lakes were subject to water-level controls) and harvest control (usually state-wide) (Table 4). Stock enhancement for most large-bodied species was large scale (e.g. trout cod, eastern freshwater cod, Mary River cod). However, for small-bodied species, and Macquarie perch (where stocking information was available for individual stocking locations), actions were generally moderate or small scale. Even actions that had broader-scale effects were usually delivered at local scales (e.g. construction of a single fishway might open up tens of kilometres of fish passage; release of environmental water from a single source might affect tens-hundreds of kilometres of stream).

Drivers of recovery actions

Drivers (triggers) were identified for a total of 380 recovery actions. General conservation concern (28% of actions), recovery-plan actions (27%) and emergency responses (23%) were almost evenly identified as major drivers. State and regional strategies were identified as responsible for 16% of actions, with identified management need and development condition of consent (both 3%) of relatively minor importance. Identified triggers for emergency responses were predominantly drought (65%), with drought-associated events such as bushfires responsible for 10%, poor water quality associated with flooding (e.g. blackwater) for 8% and alien-fish incursions for 6%. Toxic spills accounted for only 2% of emergency responses.

Harvest control actions were most often triggered by general conservation concerns (Table 5), and usually predated the preparation of recovery plans. In contrast, translocation, habitat

enhancement, stock enhancement, fish-passage works, and alien-fish control were more often driven by recovery-plan requirements. Emergency-response recovery actions were dominated by rescues, environmental watering, translocation and habitat enhancement, with these four categories comprising 85% of all emergency responses (Table 5). 'Identified

management need' was occasionally cited as a driver for action, with such actions often occurring before the development of recovery plans, or where management needs had not been identified in recovery plans. The number of actions triggered as an emergency response notably grew after 2000, with the number triggered by recovery-plan requirements growing steadily from the mid-1980s (Fig. 5).

Success of recovery actions

A total of 308 actions reported on whether they had achieved the recovery-action goals (Table 6). Of these, 63% reported that they had at least partially achieved the goals, 7% reported failure, 17% reported it was too early to judge, and for 14%, the outcome was unknown. Excluding those actions where the outcome was unknown or too early to judge, highest claimed success rates (full or partial) were for rescues and fish passage (both 100%), habitat enhancement (93%) and alien-fish control and stock enhancement (both 90%). Translocation had comparatively low reported success (57%) and riparian works, habitat protection, harvest control and other had too few conclusive reports to allow meaningful interpretation. Seventy-one per cent of riparian works actions were reported as too early to judge success.

Regional examples

In south-eastern Australia, 13 species had more than 10 recovery actions reported, with 11 of these species having actions in more
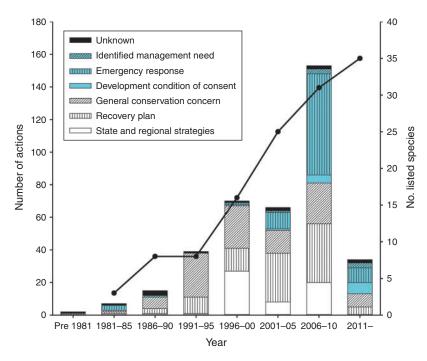
Table 5. Percentage frequency of recovery actions with drivers of general conservation concern, recovery plans and emergency response
Frequency of reported drivers is given in parentheses. Explanation of recovery-category abbreviations are given in Table 1

Recovery category	General conservation concern ($N = 111$)	Recovery plans ($N = 117$)	Emergency response ($N = 104$)
HC	63	9	0
T	10	22	14
HE	7	14	11
SE	7	15	8
R	0	3	33
EW	2	2	27
FP	1	10	1
RW	2	8	0
AFC	2	10	5
WM	2	2	0
HP	3	3	2
O	2	2	0

Fig. 5. Number of on-ground recovery actions by trigger type in 5-year time periods. Actions are grouped into time blocks on the basis of when an individual action commenced and do not represent the cumulative number of actions over time. The number of freshwater fish species listed in the higher-threat categories (vulnerable or above) under the *Environment Protection and Biodiversity Conservation Act (EPBC) Act 1999* or its predecessor is also shown for the final year of each time block (no species were listed nationally before 1981).

Recovery action	Yes	No	Partial	Too early	Unknown	Total
Alien-fish control	12	2	7	3	–	24
Environmental watering	16	5	4	2	7	34
Fish passage	24		2	4	2	32
Habitat enhancement	18	2	9	12	3	44
Habitat protection	3	–	1	–	3	7
Harvest control	6	–	2	–	1	9
Other	7	–	–	3	–	10
Rescue	24	–	7	1	4	36
Riparian works	4	–	4	22	1	31
Stock enhancement	20	3	7	2	7	39
Translocation	4	9	8	2	11	34
Water management	2	–	2	1	3	8
Total	140	21	53	52	42	308

than four categories. In the MDB, 10 species had more than 10 recovery actions, with several of these species being reviewed in detail, including Murray hardyhead (Ellis *et al.* 2013), trout cod (Koehn *et al.* 2013), Yarra pygmy perch and southern purple spotted gudgeon (Hammer *et al.* 2013). Macquarie perch had the most recovery actions reported of any species nationally, with activities across all recovery-action categories. The most common activity reported for this species was riparian works, with 18 activities reported by and within a single CMA (Goulburn–Broken) area and involving weed control, riparian planting, stock exclusion fencing and stream-bank stabilisation. This highlights that if a threatened species captures the attention of a local NRM group, a variety of generally small-scale actions can be applied to produce larger-scale benefits. Stock enhancement was another common activity for Macquarie perch, with ongoing government hatchery stocking programs in two states spanning 13 years (Table 3). Translocation was another popular action, with nine conservation translocations of the species occurring across ACT, Vic and NSW between 1980 and 2012 (see Lintermans 2013*b*). Habitat enhancement for the species has occurred predominantly in Victoria, involving stream-bed stabilisation, snag placement and prevention of bank erosion. Five fishways for Macquarie perch were constructed in the past decade. Most recovery actions for Macquarie perch have been conducted in streams; however, work has recently also been conducted in impoundments, including deployment of constructed predator refuges, prevention of disease spread, manipulation of water levels to facilitate access to spawning sites, and control of alien species (Lintermans 2012). Macquarie perch provides two good examples (Goulburn–Broken and Cotter catchments) where catchment-wide activities can deliver significant benefits to a focal threatened species.

Outside of the MDB in coastal drainages of Vic, Tas and SA, dwarf galaxias, *Galaxias pusilla*, was a focal species for many actions, particularly involving urban or peri-urban activities in Vic. Activities included 11 translocations and rescues (commonly in response to development or works proposals (e.g. housing development, road construction) or waterways works (flood management works requiring temporary relocation of fish)), stock exclusion from sensitive habitats, protection

from take (Vic, Tas), habitat protection, control of alien species (eastern gambusia), environmental watering (creation of bunds to prolong inundation, supplementary watering), and habitat enhancement (removal of weeds and rubbish; creation of artificial wetland and construction and/or deepening of refuge pools). The majority of actions was driven by conservation concern or response to drought conditions rather than recovery plans.

The blind cave eel and blind gudgeon were the only species from northern or western Australian with more than five recovery actions reported. Both species have a restricted distribution within the subterranean waters of the Cape Range Peninsula in north-western Australia (Humphreys 2001) and management actions are largely restricted to where the groundwaters interact with the surface, usually wells or caves. Activities directed at both species include protection from take, attempts at eradicating alien guppy, *Poecilia reticulata*, erection of educational signage, removal of dead animals that have fallen into sinkholes, and fencing around some caves to exclude visitation.

Discussion

This review provides a unique snapshot of on-ground actions specifically directed at recovering Australia's threatened freshwater fish. The concentration of recovery action in southern and eastern Australia, and particularly in the Murray–Darling Basin, highlights the imperilled nature of many freshwater fish species in these areas (DPIWE 2006; Koehn and Lintermans 2012; Lintermans 2013*a*). The relatively low number of threatened freshwater fish species and, hence, recovery actions in northern and western Australia highlights the opportunity to conserve these freshwater faunas and not repeat the mistakes of the south. However, the desire for more intensive agricultural enterprises (and hence increased river regulation) in these areas signals that vigilance will be required (Morgan *et al.* 2004; Pusey *et al.* 2004).

The reported high success rates of many of the categories of recovery actions may be overly optimistic, and it is not clear how such successes will be viewed in the long term. Success is notoriously hard to characterise for species rehabilitation and recovery, and is dependent on the initial goals of the project, the timeframe over which outcomes are measured, and the rigour and focus of the monitoring programs employed (see Seddon 1999; Martin *et al.* 2007; Armstrong and Seddon 2008; Lintermans 2013*b*). For example, one of the lowest claimed success rates from the current review was for translocations at 57%. This is still considerably higher than documented for freshwater fish internationally (~30%), although data are scarce (Hendrickson and Brooks 1991; Sheller *et al.* 2006). The high rate claimed in the current review possibly is inflated by the initial 'success' of survival after translocation, but which ultimately may fail to establish self-sustaining populations. Monitoring and assessment of interventions still tends to be the poor cousin compared with intervention itself. The inclusion of specific, measurable, achievable, realistic, time-bound (SMART) targets would be a valuable inclusion in management action plans and recovery plans, and would reduce the subjectivity or imprecision of many current assessments.

No reviews of the incidence of monitoring for threatened-fish recovery actions have been located internationally, so direct

comparison is not possible. However, reported monitoring levels in the current study were considerably higher than the 10–14% published for general river-restoration projects (Bernhardt *et al.* 2005; Brooks and Lake 2007), although the monitoring target (focal species, habitat, associated species) or type of monitoring (implementation: did we do what we said we would; intervention: how did our actions affect some parameter; surveillance: has river or fish-community condition changed) was not specified in the current review. In a review of 181 threatened-species recovery plans in the USA, Campbell *et al.* (2002) found that 66–82% of plans had implemented at least one of their proposed monitoring tasks. The higher incidence of monitoring for threatened-species recovery actions both in Australia and the USA is likely to reflect the generally more focussed nature of such actions (single species, confined spatial scale) than that of general river restoration. Only four recovery-action categories (habitat enhancement, rescue, stock enhancement, water management) in the current review reported less than a 70% incidence of monitoring programs, with only stock enhancement reporting <60%. The low incidence of reported success for water management should be viewed with caution because only six actions reported on monitoring. The lower incidence of monitoring associated with stock enhancement may reflect the view that stocking is a panacea and an assumption that simply reintroducing individuals 'solves the problem' (Harris 2003; van Poorten *et al.* 2011). Monitoring is a critical component of threatened-species recovery, because the response of the focal species to management interventions is often difficult to predict with any certainty. Well designed and appropriately funded monitoring programs allow informed choice of which recovery actions are most likely to deliver good conservation outcomes (Bernhardt *et al.* 2005; Lindenmayer and Likens 2010).

As a result of the lack of detail from the survey on the design of monitoring programs, it is difficult to evaluate the strengths and weaknesses of individual monitoring approaches. However, from the author's personal knowledge of many individual projects, it is apparent that monitoring efforts are often token or suboptimal and unlikely to deliver significant benefits to future recovery actions. Many so-called monitoring activities are just performance monitoring (e.g. have the treated weeds been killed, have the planted trees survived) and provide no information on the response of the target species, process or ecosystem. The design requirements for robust monitoring have been adequately outlined and reviewed elsewhere (see Lindenmayer and Likens 2010), but some key principles bear repeating. Because threatened species have usually declined in response to threats over a long time period, recovery will also be a long-term process and, so, long-term monitoring will be required; usually >10 years (Lindenmayer and Likens 2009). Good monitoring is also characterised by clearly articulated questions and conceptual models, involvement of statisticians in the study design (e.g. consideration of reference sites, replication, sampling design), and a clear understanding of what parameters to monitor (Lindenmayer and Likens 2010). Monitoring everything in the hope of devising questions and making sense of the data at a later date is not a good model to follow. Developing good partnerships among scientists, statisticians, managers and the community and treating interventions/actions

as experiments will often engender the mindset that delivers better monitoring and learning (e.g. Armstrong and Seddon 2008). For some recovery actions conducted at very small scales (either spatially, or in terms of level of investment/activity), a case could be made that monitoring is unlikely to deliver effective benefit and, therefore, should be abandoned. More rigorous exploration of the monitoring effort currently deployed for threatened-fish recovery in Australia would be fruitful, to avoid waste of scarce monitoring resources.

Monitoring alone is no guarantee of improved management; there are vast quantities of data from monitoring programs that are never reviewed or used (e.g. water-quality programs with pH values of >14; R. Norris, pers. comm.). Regular review of the data in an adaptive management process will deliver improved management outcomes (Walters and Holling 1990; Allan and Stankey 2009; Lindenmayer and Likens 2009) and contribute to the body of recovery science.

The significant increase in recovery action in the decade commencing in 2000 is likely in response to several factors. As the number of listed threatened species continues to rise both nationally and at state/territory level, the number of recovery actions is also likely to rise. Also, as the field of restoration science continues to develop, more activity is likely as approaches and techniques for addressing common problems become better understood. For example, developments in fish-passage remediation in Australia have advanced considerably over this time, with rockramp and vertical-slot fishways and improved culvert design now being routinely deployed across jurisdictions (e.g. Thorncraft and Harris 2000; Industry and Investment NSW 2009). Finally, the severe millennium drought that gripped much of south-eastern Australia from 1997 to 2010 (Murphy and Timbal 2008) and the following blackwater events in 2010 and 2011 (King *et al.* 2012; Whitworth *et al.* 2012) resulted in a significant rise in the number of 'emergency responses' required, particularly from 2006 to 2010.

Riparian works are regularly identified as a popular management action in river restoration (Bernhardt *et al.* 2005; Brooks and Lake 2007; Christian-Smith and Merenlender 2010) and, in the current study, ranked the eighth-commonest recovery action. The link between riparian works and recovery of particular threatened fish is sometimes tenuous, being more often a generic river-health activity; however, in the current study, riparian works were predominantly directed at Macquarie perch. This historically widespread species is now known to be largely confined to well-forested catchments with intact riparian zones and minimal sedimentation, with sedimentation thought to smother spawning sites and eggs, and infill refuge pools (Lintermans 2007). Consequently, in this case, there is a clear link between the focal threatened species and the recovery action.

Listing as a threatened species does not automatically equate to harvest control (protection from take). Listing nationally under the *EPBC Act* provides no protection from take, with individual states/territories deciding whether harvest of these species will be allowed. Similarly, some state/territory legislation does not automatically confer protection from take (e.g. NT) or automatic protection is dependent on the conservation status (e.g. ACT). In some jurisdictions, recreational angling for threatened species is allowed in specific locations

(e.g. Mary River cod in Qld and Macquarie perch in Vic) or in certain water-body types (e.g. silver perch *Bidyanus bidyanus* in impoundments in NSW). Allowing recreational take in specific locations has been suggested to be beneficial to conservation outcomes through maintaining the species in the public consciousness (Lintermans *et al.* 2005), but automatic protection from take upon listing should probably be the norm. Where protected from take, some mechanism for maintaining public interaction/connection with the species is essential; otherwise, recovery needs or actions can receive little support (or generate hostility) where competition for resources occurs (see Ellis *et al.* 2013).

No Australian freshwater fish is known to have become extinct since European settlement (although Kangaroo River Macquarie perch may be the first; Faulks *et al.* 2010). Without listing and recovery actions, there is little doubt that Pedder galaxias, *Galaxias pedderensis*, and barred galaxias would be extinct and the Mary River cod would be near extinction (Lintermans 2013*a*). However, no Australian freshwater fish has ever been down-listed or delisted as a result of conservation management; so, there is still much work to be undertaken. The lack of reported recovery actions other than harvest control for many listed species is concerning. Several of these species are listed in single states/territories and may reflect species on the edge of their range, with lower priority for on-ground actions. Some species are listed only on advisory lists, with no legislative status, and so have reduced priority for action. However, there are several nationally listed species that seem to be attracting very limited active recovery effort. Although listing provides other benefits (e.g. controls on development projects), the lack of active recovery efforts for many species suggest that the chance of down-listing such species is remote.

The relative scarcity of protected areas for freshwater fish in Australia is cause for concern because strict protected areas are associated with stable or increasing abundance of threatened species generally (Taylor *et al.* 2011). Protected areas declared primarily for terrestrial values are not assured of delivering conservation benefit to fish (Crivelli 2002), and adverse aquatic outcomes for fish may still occur if the majority of management actions are focussed on terrestrial components of the landscape (e.g. Kodric-Brown and Brown 2007). For example, 12 of 15 rivers in Kosciuszko National Park, NSW, are affected by dams and diversions with the highly regulated rivers likely to benefit alien salmonids rather than threatened native fish (Lake 2005). The purchase of the Edgbaston spring complex (the only location for two nationally listed freshwater fish) by the not-for-profit conservation organisation Bush Heritage Australia in 2008 is an example of protected-area activities that may be required for other species. However, the creation of protected areas may not be sufficient and active threats to freshwater fish still need to be addressed in such areas. To this end, an active program of alien fish control at Edgbaston is currently underway (Kerezsy and Fensham 2013). By contrast, the Dalhousie Springs complex in South Australia contains five state-listed endemic freshwater fish species (Dalhousie goby, *Chlamydogobius gloveri*, Dalhousie hardyhead, *Craterocephalus dalhousiensis*, Glover's hardyhead, *Craterocephalus gloveri*, Dalhousie purple-spotted gudgeon, *Mogurnda thermophila*, Dalhousie catfish, *Neosilurus gloveri*) and sits within a national park. However, no on-ground recovery actions directed at fish could be identified for four of the species and only a single action (protection from take) was identified for Dalhousie purple-spotted gudgeon. The difficulties of managing for terrestrial and aquatic recovery are demonstrated by the control of grazing around Dalhousie Springs adversely affecting threatened fish, with expansion of reedbeds decreasing open-water habitat and oxygen levels (Kodric-Brown *et al.* 2007). For such an important location for threatened freshwater fish with identified threats from the introduction of alien species, habitat modification, and adjacent resource development, specific fish-focused recovery actions must be implemented at Dalhousie Springs (Hammer *et al.* 2009).

Stock enhancement continues to grow as a favoured solution for maintaining and/or enhancing fish populations as a result of its perceived simplicity (Philippart 1995; Molony *et al.* 2003) and its perceived role as a panacea that 'solves the problem' (Harris 2003; van Poorten *et al.* 2011). Ideally, stock enhancement should be a short-term response, applied after the underlying reasons for a species decline have been removed or reduced (Cowx 2002). The fact that stocking programs for some species have been in existence for decades demonstrates that limiting factors often have not been addressed (or identified). Stock-enhancement activities for threatened fish have expanded considerably since the early 2000s, when only four threatened freshwater species had current hatchery programs, with most being large-bodied species of potential recreational interest in the future (Lintermans 2006). Eleven species have now been the focus of captive-breeding programs, including seven small-bodied species commonly found in floodplain or small-stream habitats. The precarious future of species not commonly found in large channel habitats has largely resulted from the millennium drought, with many smaller habitats subject to total or partial desiccation and consequent declining water quality. Although stock enhancement is a valuable tool for recovery of freshwater fish, genetic management of released fish is still a major concern (Philippart 1995; Araki *et al.* 2007), and the impacts from previous stocking practices are only now becoming apparent (e.g. Nock *et al.* 2011). Similarly, in Australia, the potential behavioural deficits associated with hatchery-reared fish (Brown and Laland 2001; Ebner *et al.* 2007; Ebner and Thiem 2009) still remain to be addressed. Trials on predator education or reducing post-release mortality of hatchery-reared fish have shown promise (Brown and Day 2002; Kawabata *et al.* 2011; Hutchison *et al.* 2012); however, more remains to be done.

Although there is wide recognition that the scale of restoration actions needs to be increased (Roni *et al.* 2002; Wheaton *et al.* 2006), the majority of actions are still being designed and conducted at site or local scales (e.g. Wheaton *et al.* 2006; Christian-Smith and Merenlender 2010). Recovery actions for threatened freshwater fish in Australia also demonstrated this small-scale approach, but maybe it is more justified for such species where populations are often localised or restricted to small areas of suitable habitat, or where specific threats are localised. For example, actions directed at species confined to single spring complexes or lakes (e.g. Edgbaston goby, Lake Eacham rainbowfish, *Melanotaenia eachamensis*, Elizabeth Springs goby, *Chlamydogobius micropterus*) are necessarily of small spatial scale. It must also be recognised that the

science of recovering threatened freshwater fish in Australia is still relatively young (the first recovery plan for an Australian freshwater fish was only published <20 years ago; Koehn *et al.* 2013) and many of the recovery actions are still somewhat experimental. However, mature approaches such as provision of fish passage are now being deployed at large scales through integrated programs addressing thousands of kilometres of stream (Barrett 2008). Wider use of threatened-species recovery teams is one way that managers can coordinate and prioritise issues, projects and actions, and potentially alleviate some issues with the predominance of small-scale actions. The importance of building partnerships for improving recovery outcomes has been discussed earlier, and the benefits of having a recovery team or coordinator for improving cross-jurisdictional coordination and species-recovery trajectory have been identified elsewhere (Lundquist *et al.* 2002; Lintermans 2013*b*). Since the early 2000s, there has been no national funding available for establishment or operation of national recovery teams (Lintermans 2013*b*). Increased use of recovery teams to assess and guide management responses would facilitate integration of small-scale actions into large-scale programs that will deliver conservation outcomes of benefit to more than just threatened species.

The dramatic rise in the number of emergency responses in the late 2000s highlighted the deficiencies in recovery planning for many threatened species. Most recovery plans had little or no consideration of how climatic extremes would affect recovery efforts, with the majority of emergency responses being examples of crisis management. Although it is difficult to plan for every emergency, droughts and floods are common in Australia, and planning for such events will likely enhance the success or feasibility of future emergency responses. Mapping important existing refugia, identifying potential translocation sites, and identifying the process, procedures and stakeholders likely to be involved in future activities are all achievable actions. Equally important is identifying what should not be done in future emergencies (e.g. knee-jerk reactions to increase stock-enhancement activities for recreationally desirable species) (Lintermans and Cottingham 2007). Extreme events are likely to increase in frequency in Australia with climate change (Alexander and Arblasterc 2009; Morrongiello *et al.* 2011), and incorporating into recovery planning the lessons from the past decade should be a priority.

The present review does not report on the substantial research efforts directed at obtaining basic ecological knowledge for species, which has and will continue to inform on-ground management (Cooke *et al.* 2012). The critical role of research in improving management approaches and outcomes is undeniable (see Ellis *et al.* 2013; Koehn *et al.* 2013). This review also does not deal with general river-health programs, or legislative and policy initiatives, all of which contribute to recovery of threatened freshwater fish. Similarly, not captured are the many general education and outreach activities based around freshwater fish, communities and habitats that include messages or themes of relevance to threatened freshwater-fish conservation. Without such programs to educate and engage the human community, recovery of freshwater ecosystems is unlikely. Further investigation of the uptake and efficacy of research, policy and education initiatives for threatened species management would be fruitful.

Locating and accessing information on recovery activities was a major difficulty in the current review. No centralised reporting mechanism or data repository for threatened-fish activities could be located in any of the jurisdictions, either state/territory or national. An exception is Qld where an existing framework for reporting on recovery actions exists (the Recovery Actions Database under the 'Back On Track' iniative (http://www.ehp.qld.gov.au/wildlife/prioritisation-framework/index.html, accessed 23 July 2013). However, this initiative currently contains project and species priorities and plans with little information on what has actually been done. Much of the information on recovery actions are either unpublished, resides in the memory of practitioners, or is 'published' in agency project reports. This problem of limited availability or accessibility of management information is not unique to freshwater-fish recovery (Lintermans 2004; Brooks and Lake 2007; Price *et al.* 2009) or Australia, with reviews of freshwater-habitat rehabilitation activities or threatened-species recovery in many countries reporting similar difficulties (see Abbitt and Scott 2001; Bernhardt *et al.* 2005). The current inability to easily consolidate, synthesise and evaluate past attempts to recover freshwater fish hampers our capacity to advance recovery science and management. The need for national databases, and reporting and evaluation protocols have been identified as priorities for other freshwater activities (Price *et al.* 2009), and the need is no less for threatened fish.

The lack of formal reporting requirements and trend indicators makes it extremely difficult to determine whether species status is improving, stable or declining, or which management activities have been successful. Assessment of trend is only possible at coarse temporal scales, usually when recovery plans are revised (often 5–10-year intervals). In 2006, the preparation of national recovery plans for Australian listed species became discretionary (Hawke 2009), so for species without recovery plans, assessing the existence or success of recovery actions is extremely difficult. For example, the Lake Eacham rainbowfish was listed as extinct in the wild by 1987 (Barlow *et al.* 1987), was rediscovered by the 1990s (Pusey *et al.* 1997; Zhu *et al.* 1998), does not have a recovery plan and none is proposed (TSSC 2011), has almost no previous recovery actions reported, no current recovery actions can be traced, and there is no formal monitoring program to track population or species trend. So, how can the effectiveness of current management arrangements be assessed? Using delisting or down-listing of a threatened species to judge recovery actions is a poor indicator of success (Doremus and Pagel 2001). Most species have taken decades to decline and the threats responsible are usually still operating (e.g. habitat loss, invasive species). The great majority of threatened freshwater fish in Australia are within the lifespan of their first recovery plan, and it is unrealistic to expect recovery to occur in the relatively short period of recovery action. The *US Threatened Species Act* (*TSA*) requires the identification of population trend as an indicator of whether a species is recovering or not (Scott *et al.* 2005; Taylor *et al.* 2005). Under the *TSA* biennial, reporting of population trend is required, providing insight into whether recovery actions are effective, and/or whether changes are required. Such a requirement for monitoring of population trend would be of benefit in Australia.

Conclusions

There has been considerable on-ground activity to recover threatened freshwater fish in Australia, with the most commonly utilised recovery categories being harvest control, translocation, habitat enhancement and stock enhancement. Major drivers of recovery actions were general conservation concern, recovery plans and emergency responses. The number of recovery actions grew significantly in the decade beginning 2000 as the impacts of prolonged drought in south-eastern Australia intensified. The increase in emergency-response activities in the past decade has highlighted deficiencies in the current recovery planning, particularly for events that occur regularly, such as drought, flood and fire. Assessing the success of individual projects or species recovery is problematic as a result of the dispersed and fragmented nature of essential information, the lack of critical information on monitoring efforts, the lack of trend monitoring and reporting for individual species, and the time lags for species recovery to become apparent. Although considerable monitoring has been reported associated with on-ground activities, little detail is available on designs or approaches used, and so the adequacy of monitoring efforts remains largely unknown.

It is disturbing that many listed threatened species have no identified recovery actions, and that the majority of recovery actions reported are directed at very few species. Also disturbing is the lack of progress in implementing a national or state system of freshwater protected areas, or in designating critical habitat. The small-scale nature of the majority of recovery actions, although understandable for species with small spatial distributions, is worrying if large-scale recovery of species (e.g. improved conservation status) is to be achieved. Increased use of, and funding for, recovery teams or coordinators would significantly value-add towards this goal. Choosing which recovery actions to employ is not an easy choice for NRM managers. The development of strong partnerships between research, policy, management and community stakeholders, delivered in an adaptive management framework including robust monitoring programs will deliver improved outcomes and assist future recovery planning and implementation.

Acknowledgements

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