doi: 10.1111/emr.12090

FEATURE

Laying the foundations for fish recovery: The first 10 years of the *Native Fish Strategy* for the Murray-Darling Basin, Australia

By John D. Koehn, Mark Lintermans and Craig Copeland

The Native Fish Strategy aimed to return fish populations in Australias largest (1 million square kilometre) river basin from an estimated 10 to 60% of pre-European settlement levels after 50 years of implementation. While funding for implementation of this programme has now ceased (despite native fish remaining in a poor state), the achievements of the Strategy's first 10 years provide a solid basis for implementing the work necessary to rehabilitate native fish populations in the future.

Key words: *Australia, fish populations, recovery, rehabilitation, threatened species.*

Figure 1. The 'Sea to Lake Hume' fishway programme was a key highlight of the *Native Fish Strategy* providing connectivity to 2225 Km of the Murray River through the construction of fishways at 13 weirs and five barrages. Evidence of its success is provided through a comprehensive monitoring programme indicating large numbers of native fish making successful passage. Here hundreds of Golden Perch and nationally endangered Silver Perch passed through the Euston fishway in a 24 hour period (Photo: Lee Baumgartner).

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Introduction

Freshwater species comprise about 48% of the world's fishes (Dudgeon *et al.* 2006; Nelson 2006), with many species and ecosystems considered to be highly threatened (Smith & Darwall 2006; Jelks *et al.* 2008; Garcia *et al.* 2010). The threats to these fishes and their habitats are many and generally have been well documented (Malmqvist & Rundle 2002; Dudgeon *et al.* 2006). The status of native fish populations and communities can provide an overall indicator of the health of rivers and catchment condition (Harris 1995) with declines being a warning that natural ecological functioning is at risk. Native fish populations in the Murray-Darling Basin (MDB) in south-eastern Australia have declined markedly, especially over the past century (Cadwallader 1977) with many species now being of conservation concern (Lintermans 2013). The threats to MDB fishes are many (Cadwallader 1979; Koehn & Lintermans 2012), reflecting a range of modifications to rivers and their catchments resulting in MDB rivers generally being in poor condition (Davies *et al.* 2010, 2012). Given the relatively low number of endemic native fish species (only 44 naturally

Ecological Management & Restoration *Linking science and practice*

occurring for the MDB; Lintermans 2007), the poor status of populations, and existing and projected threats, there has been considerable concern for the future of these native fishes.

The MDB covers over 1 million km^2, has two million residents, contributes 39% of Australian agricultural production and is subject to six different legislative jurisdictions (Koehn 2013). Its rivers have low run-off on average (<4% of rainfall; ABS 2012) and highly variable flows compared to the rest of the world (Puckridge *et al.* 1998). The management of fishes is largely undertaken by individual state/territory jurisdictions (hereafter referred to as 'States'), usually by agencies that have differing objectives to those that manage the land and water (Koehn & Lintermans 2012). Recreational angling has a high participation rate in Australia (19% of population annually), especially in rural areas such as the MDB (Henry & Lyle 2003). The MDB has many species that are highly valued by recreational anglers (Lintermans 2007) and have iconic status, with important ecological, social, aboriginal cultural, conservation and economic values. Commercial fisheries ceased in 2003, but substantial recreational fisheries have established over the last 40 years (e.g. for Murray Cod *Maccullochella peelii*; see Rowland 2005; Ginns 2012; Koehn & Todd 2012). Given the multiple values of fish to the Australian community and the decline of MDB fish populations, there was recognition of the need to progress fish restoration, resulting in the development of a 50-year strategy to address key threats: *Native Fish Strategy for the Murray-Darling Basin 2003–2013* (NFS; Murray-Darling Basin Commission 2004). Funding for the NFS programme has now ceased, after implementation for only the first 10 years, but the process and outcomes achieved provide some key lessons relating to a wide range of issues for fish management. This paper forms part of the synthesis of outcomes from this programme and aims to provide an overview of the development, governance and achievements of the NFS; provide links to more detailed NFS publications; consider the lessons learnt over the last decade; and provide direction for the management of MDB fishes into the future.

Development of the NFS

The development of the NFS has been described and evaluated in detail by Koehn and Lintermans (2012) and was an ecosystem-based approach that used research and best available knowledge for on-ground management to improve the status of native fishes in the MDB. The NFS took a coordinated, long-term approach with an emphasis on rehabilitation through actions to address key threats. It fitted within existing governance structures, built on previous work (Lawrence 1991) and provided valuable information to support ongoing water reform (Koehn *et al.* 2014). The NFS involved a wide range of activities that included research projects; policy and operations changes; structural rehabilitation measures (Fig. 1); and engagement of a wide array of stakeholders (Hames *et al.* 2014). In particular, it coincided with an increased connection between fish and natural resource management issues and the more traditional water resource management responsibilities within the MDB (see timeline; Fig. 2).

Some progressive steps were taken in the design of the NFS that distinguish it from other (and previous) strategies and are worth highlighting. In particular, the NFS:

- was large scale; MDB wide (1 million km^2), involving six jurisdictions and many agencies;
- focussed on rehabilitation, not just managing the *status quo*;
- took a threat abatement approach;
- considered both native fish and alien species;
- included all native fishes (whole of native fish community approach) not just angling species;
- was developed as a long-term approach given the scale of the problem (50 years, but operationalized in sequential 10-year plans);
- set an aspirational recovery target;
- undertook significant public engagement; and
- incorporated an independent review of progress.

Justification for the NFS was supported by an expert panel assessment that estimated that, overall, native fish populations in the MDB were at about 10% of their pre-European settlement levels (from early 19th century; MDBC 2004). While this assessment is somewhat subjective given the difficulty of assessing all fishes across the whole MDB and the lack of historical data for almost all fishes, it was developed using multiple lines of evidence including: declines in commercial and recreational catches; half of the species now being listed as threatened; reduced distributions; and reduced abundances passing through the Euston fishway (Mallen-Cooper & Brand 2007). This assessment was often challenged in public meetings, but the challengers could only ever provide site-specific, anecdotal information in support of their contrary claims. The assessment did provide an important baseline for the poor level of fish populations from which an aspirational target could be made.

Objective setting

The overall vision of the NFS was 'to sustain viable fish populations and communities throughout the MDB'. This vision was further supported by the aspirational target 'to rehabilitate native fish communities back to 60% or better of their estimated pre-European settlement levels after 50 years of implementation'. This aspirational

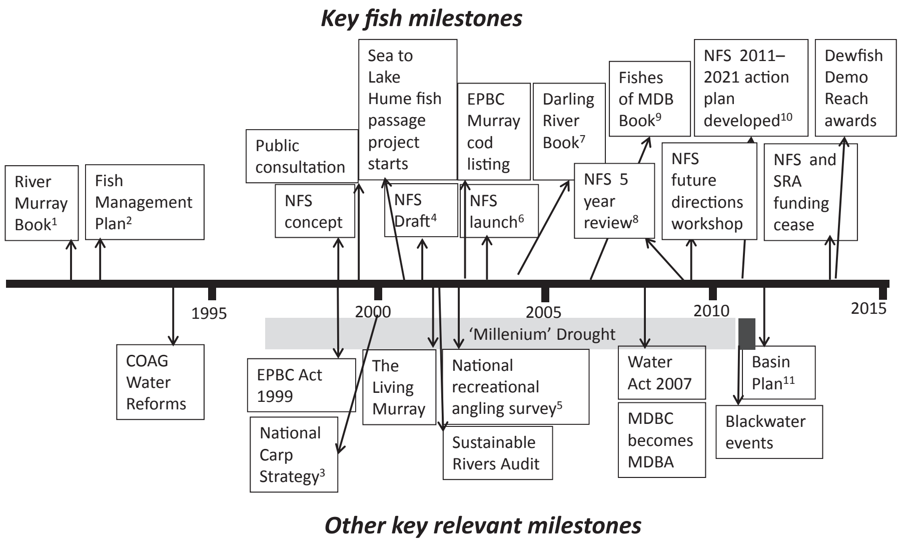

Figure 2. Timeline of key milestones for the NFS and relevant water and natural resource management programmes. References within: [1]Mackay & Eastburn (1990); [2]Lawrence (1991); [3]Braysher & Barrett (2000); Carp Control Coordinating Group (2000a,b); [4]Murray-Darling Basin Commission (2002); [5]Henry & Lyle (2003); [6]Murray-Darling Basin Commission (2004); [7]Breckwoldt *et al.* (2004); [8]Cottingham *et al.* (2009); [9]Lintermans (2007a,b); [10]Barrett *et al.* (2013); [11]Murray-Darling Basin Authority (2010); Murray-Darling Basin Authority (2011). Grey shading indicates 'Millenium' drought; Black shading indicates flooding.

target provided an indicative recovery target often missing from many such strategies and was viewed as providing some accountability for governments and agencies. The 50-year time frame was recognition of the long-term nature of rehabilitation processes, and the 60% target provided some 'commitment' to defining the outcome and clarified what was an acceptable outcome (i.e. not seeking a return to presettlement levels). This vision and target was to be achieved through 13 objectives, amalgamated into six Driving Actions (Murray-Darling Basin Commission 2004; Fig. 3) from which activities were developed to address the suggested causes of decline.

Governance and operation

The NFS was governed by the Murray-Darling Basin Commission (MDBC), which was comprised and funded by the five Australian States within whose boundaries its rivers flow (Queensland, New South Wales, Victoria, South Australia and the Australian Capital Territory). The MDBC [and later the Murray-Darling Basin Authority (MDBA); part of the Commonwealth government, Fig. 2] established a coordinating committee to provide advice on the direction of the programme. This Native Fish Advisory Panel (NFAP) consisted of a policy and science representative from each state together with representatives from the MDBA and major Commonwealth agencies. It was supported by taskforces (Community Stakeholder; Alien Fish; Fish Passage; Demonstration Reach; Habitat Management Areas and Murray Cod) that were created and disbanded, as required (see Fig. 4 in Koehn & Lintermans 2012; Barwick *et al.* 2014a). NFS actions were undertaken by a project team, the NFAP, the taskforces and regionally based NFS coordinators, each with differing responsibilities (Fig. 4).

Delivering on-ground improvements to fish populations within the 50-year time frame was a task challenged by a range of factors that included:

- Lack of detailed knowledge of MDB fish ecology.
- Generally poor level of understanding by catchment and other natural resource management bodies/agencies of the status of native fish or the factors that impact on their ecology.
- A lack of recognition of the historical level of fish abundances and distributions ('shifting baselines' see Pauly 1995; Humphries & Winemiller 2009).
- A lack of recognition of the complexity of aquatic ecosystems, multiple impacts on freshwater fishes and the time frames needed for recovery.
- A mistaken perception that activities undertaken to manage flows for colonial nesting waterbirds and River Redgum (*Eucalyptus camaldulensis*) forests would also improve native fishes.
- The absence of a significant peak community or industry group to support native fishes.
- Other environmental factors such as the 'Millenium Drought', bushfires and blackwater events.

While the NFS established clear actions, like most natural resource management programmes, limited resources meant that prioritization was required. This was undertaken pragmatically by the NFAP to deliver the greatest benefits to native fish and underpin future work. In this regard, the NFS was intended to be managed as a series of 10-year plans to recover native fish populations by: the generation of new knowledge; building a collaborative approach; communicating existing and newly acquired science; and demonstrating the benefits of multiple, coordinated actions.

Key achievements

A key component of the NFS was the philosophy that management should be underpinned by good science. To this end, new knowledge was generated through a comprehensive Research and Development programme that targeted priority issues

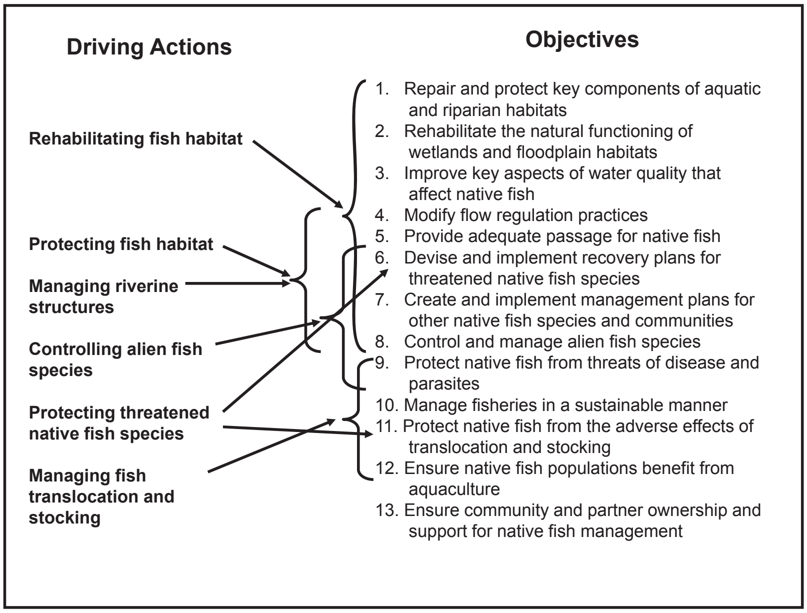

Figure 3. Objectives and Driving Actions of the NFS (from Murray-Darling Basin Commission 2004; Koehn & Lintermans 2012).

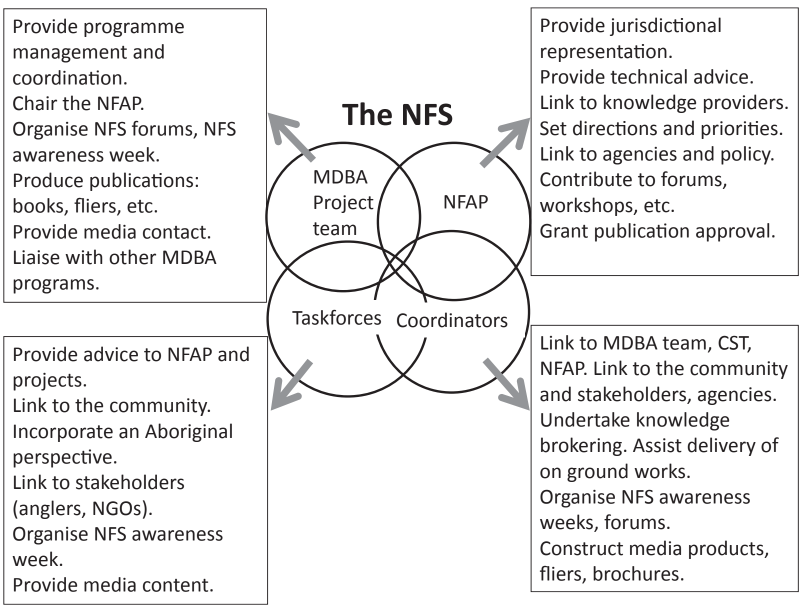

Figure 4. Roles and responsibilities of the MDBA NFS project team, Native Fish Advisory Panel (NFAP), taskforces and NFS coordinators.

(Koehn & Lintermans 2012) which were commissioned through an open tender process. The research portfolio included workshops on priority issues, scoping studies, desktop reviews and (more commonly), field-based investigations (Barrett *et al.* 2013). A key initial step in development of the research portfolio was the hosting of synthesis workshops that were used to inform directions in priority areas (e.g. stocking and translocation, downstream movement, habitat rehabilitation, management of Murray Cod). The NFS Research and Development programme delivered approximately 100 projects between 2002 and 2011 at a cost of more than $12 M (see project summaries (www.emrprojectsummaries.org or www.finterest.com.au)) and with them, key advances in knowledge to assist in recovering native fish (see Table S1 for a project list). Uptake of research knowledge by management agencies has commenced and will likely accelerate in future years as the more recent knowledge gains from the NFS are incorporated (Barrett *et al.* 2013). An indicative breakdown of project activity across the six Driving Actions is shown in Fig. 5, with a number of projects being of a general nature, addressing all Driving Actions.

The synthesis workshops played a key role in consolidating previous research and facilitating the identification and subsequent targeting of priority knowledge gaps. This synthesis of knowledge was also used to further develop both the science and its application towards management solutions. For example, the 2003 workshop on *Downstream Movement of Fish* (Lintermans & Phillips 2004) identified that the diversion or extraction of water from rivers was likely to be resulting in significant losses of native fish through pumping and diversion into irrigation channels. This initiated a pilot investigation of larval fish mortality at weirs (Baumgartner *et al.* 2006), prompting a larger study of mortality due to pumps (Baumgartner *et al.* 2010). An investigation of selected irrigation practices (diversion of fish into irrigation channels, and extraction of fish via irrigation pumps; Baumgartner *et al.* 2009) also commenced as a result of the recommendations of the *Downstream Movement of Fish* workshop. Once the extent of fish impacts from water extraction or diversion was appreciated, a subsequent project from 2008 to 2011 investigated designs for screens at off-takes and developed screening criteria for a range of fish species and structures across the MDB (Boys *et al.* 2012, 2013). The benefits of this 10+ year

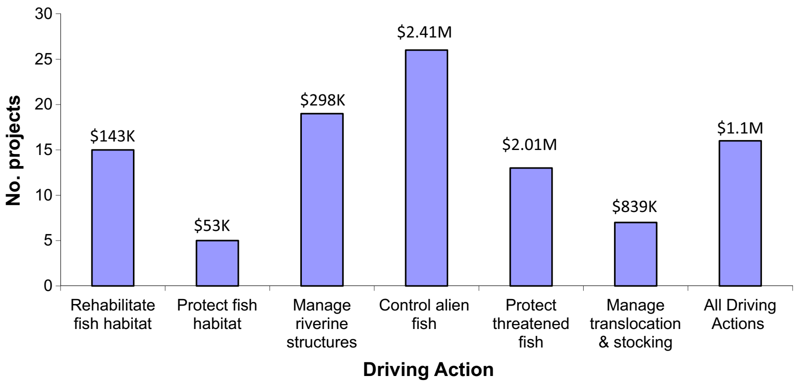

Figure 5. The number of projects in the NFS research portfolio categorised by Driving Action. The total cost of all projects for each Driving Action is indicate above each bar (K = $1000; M = $1000000). 'All Driving Actions' indicates projects that addressed all Driving Actions (from Barrett *et al.* 2013).

programme investigating downstream movements and impacts on fish of various infrastructure have been substantial. Weir designs and operations are now informed by the fish mortality data generated. As well, the extent of extraction and damage to fish individuals and populations has been quantified for some locations, and criteria and designs for fish screening at water diversions in the MDB are now available. If sequential targeted funding had not been available, these outcomes would have been unlikely to have been delivered.

Another highlight of the NFS was retrofitting a series of fishways on 15 barriers, restoring fish passage over 2225 km of the River Murray (the Sea to Hume programme; Barrett & Mallen-Cooper 2006). This programme aims to provide passage for large- and small-bodied fishes, a task made easier by the generally low height of instream barriers (<8 m) and the low gradient of the river (150 m elevation change over 2225 km). It included a significant multijurisdictional monitoring programme, which has resulted in continual adaptive, cost-effective improvement of fishway designs and approaches (Baumgartner *et al.* 2014). Most fishways have been fitted with an automated PIT (Passive Integrated Transponder) telemetry system to assess the effectiveness of the fishways with more than 35 000 fish tagged and now at liberty along the river Murray (Barrett 2008). The Sea to Hume programme was judged to be one of the top 25 Australasian projects listed by the Global Restoration Network: (http://www.globalrestorationnetwork.org/countries/australianew-zealand/).

Another significant outcome of the NFS has been the investment in developing new approaches to alien fish management, particularly Carp (*Cyprinus carpio*; Barrett *et al.* 2014). The development of the innovative Williams' Carp Separation Cage (Stuart 2009) which exploits the innate jumping behaviour of the species has provided a method for harvesting substantial volumes of Carp and can be deployed at fishways. A similar 'push trap' has been developed for Carp capture at wetland entrances (Thwaites *et al.* 2010). The potential of the cages can be gauged by the capture of 600 kg of Carp in the first two minutes of a trial at one fishway, and it is estimated that tens of thousands of Carp per year could be removed by each separation cage (Barrett *et al.* 2013). In conjunction with the use of Carp screens to protect important wetlands (Hillyard *et al.* 2010; Smith *et al.* 2010), the development of a range of Carp control plans for particular river reaches and identification of Carp 'hotspots' (areas of significant Carp breeding), an improved capacity and mature approach to Carp control is now possible.

While the status of fish populations has been widely used for many years as a measure of river or ecosystem health (Harris & Silveira 1999; Davies *et al.* 2010), the potentially confounding effects of stocked (as opposed to wild) fish on such assessments have remained problematic. Similarly, the assessment of the success of stocking programmes has also been difficult, with both river health and stocking assessment programmes hampered by an inability to nondestructively distinguish between stocked and wild fish in the field (Barwick *et al.* 2014b). A suite of NFS research and adoption projects has effectively addressed this technical deficiency by developing a rapid, cost-effective, large-scale method for marking hatchery-produced individuals (Crook *et al.* 2009, 2011). The use of osmotic induction and calcein dye has enabled the batch-marking of tens of thousands of individuals at a time, with a field-based portable detection kit enabling rapid, nondestructive discrimination of the hatchery mark (Crook *et al.* 2011). This has enabled the contribution of stocked individuals to wild populations to be evaluated in experimental trials over 5 years, with proportions of stocked Golden Perch (*Macquaria ambigua*) comprising 18–38% in one stream but up to 100% in another (Crook *et al.* 2011). Calcein marking is now being applied in a range of commercial and government hatcheries across the MDB, as well as in threatened fish management programmes.

The provision of environmental watering events is a key management activity for sustaining and recovering aquatic ecosystems (Koehn *et al.* 2014), but actually delivering on the concept has proved problematic (Le Quesne *et al.* 2010). However, much of the focus of such events in the MDB had previously been directed at floodplain vegetation (River Redgums) or colonial nesting waterbirds, with little information available on how fish respond to such events. The NFS and the Living Murray programme co-funded a series of projects to examine the response of native fish to a managed flow release that prolonged floodplain inundation in the Barmah-Millewa Forest by 2 months. These projects delivered major new knowledge on the responses of fish species both in the river and on the floodplain, with increased spawning or recruitment of young of year fish detected for some species (King *et al.* 2009, 2010; Koehn *et al.* 2014).

The delivery of coordinated on-ground outcomes through targeted 'Demonstration Reaches' supported by appropriate science and monitoring (Barrett 2004; Boys *et al.* 2014) has been another success story for the NFS. Seven Demonstration Reaches are now active across the MDB, covering almost 800 river km and involving a range of management interventions (Barrett *et al.* 2013; Boys *et al.* 2014) with a key success being the engagement of the local community in the ongoing management of their rivers and associated fish populations. The kudos earned by the Condamine Alliance for their Demonstration Reach (2012 Banksia Award for Water; 2013 Australian Riverprize; 2013 United Nations Association of Australia World Environment Day Award for Biodiversity) not only points to success at this site but broader recognition of the value of the concept of Demonstration Reaches.

Emergency responses

The NFS was delivered during a period of climatic extremes with the Millennium Drought (van Dijk *et al.* 2013) resulting in the lowest inflows to water storages on record, followed by severe flooding and 'blackwater' events in 2010–2012 (King *et al.* 2012). These stressors resulted in significant loss of habitat via desiccation or altered water quality and necessitated a series of emergency interventions (Lintermans *et al.* 2014). To facilitate rapid intervention, a NFS Emergency Contingency Fund was established to provide support for the initial phases of interventions (Lintermans *et al.* 2014), with nine interventions funded (Table 1). These emergency responses ultimately resulted in the likely prevention of regional extinctions Southern Purple-spotted Gudgeon (*Mogurnda adspersa*), Barred Galaxias (*Galaxias fuscus*) and Yarra Pygmy Perch (*Nannoperca obscura*) with all rescued populations now either returned to their wild habitats or supplying thousands of captive-bred fish for restocking.

Partnerships, communication and engagement

Given the disparate nature of management responsibilities within the multi-jurisdictional framework of the MDB and the variable appreciation of issues impacting native fishes, a key success of the NFS was the collaborative approach and development of partnerships between scientists, managers and the community. This was achieved using a range of communication, knowledge transfer and engagement activities to promote understanding, ownership and empowerment (Barwick *et al.* 2014a; Hames *et al.* 2014). These activities included the employment of Native Fish Coordinators in each jurisdiction, the development of the Community Stakeholder Taskforce (CST), annual Native Fish Forums that exhibited new knowledge generated by research projects and the establishment of Native Fish Awareness Week. Following the premature cessation of the NFS, it is hoped that these relationships will endure and benefit native fish recovery into the future.

The engagement and contributions by local communities in the ongoing

Table 1. Projects funded by the NFS Emergency Contingency Fund 2007–2012

Year	State	Stressor/Issue	Project
2008	SA	Drought and loss of refugia	Emergency watering and rescue for River Blackfish (*Gadopsis marmoratus*) at Rodwell Creek
2008	SA	Drought (desiccation of habitats)	Establishment of captive maintenance facilities, breeding programme and reintroduction plan for Southern Purple-spotted Gudgeon (*Mogurnda adspersa*)
2009	NSW	Drought and loss of refugia	Rescue of Murray Cod (*Maccullochella peelii*) and Silver Perch (*Bidyanus bidyanus*) from Merran Creek
2009	SA	Declining water quality in refugia	Emergency watering for endangered Murray Hardyhead (*Craterocephalus fluviatilis*) in Rocky Gully
2009	VIC	Bushfire and subsequent sedimentation	Rescues and husbandry of endangered Macquarie Perch (*Macquarie australasica*) and Barred Galaxias (*Galaxias fuscus*)
2009	NSW	Drought and loss of refugia	Rescue of Southern Pygmy Perch (*Nannoperca australis*) from Coppabella Creek
2010	NSW	Blackwater	Rescue of Murray Cod from the Edwards-Wakool rivers
2011	VIC	Blackwater	Aeration of Gunbower Creek and lagoons to improve water quality for Freshwater Catfish *Tandanus tandanus*)

Note also there is a Table S1. List of NFS projects (see Koehn & Lintermans 2012; Barrett *et al.* 2013 for additional details and references).

management of their rivers and associated fish populations were achieved through Demonstration Reaches (Boys *et al.* 2014) and through accessing the knowledge held by recreational anglers (as demonstrated by oral history projects) which further highlighted the decline of native fishes (Trueman 2011; Frawley *et al.* 2012). These projects helped engage recreational anglers, the group with the most obvious gains from restored fish populations. This stakeholder group (external to government) could be a powerful advocate for the improved management of fish and their habitats, and the recent formation of a Murray-Darling Recreational Fishing Council and a Fish habitat Network, are important steps in this regard.

Lessons learnt

Fish provide a key link between people and their waterways, especially for aboriginal and rural communities (Koehn 2013). A significant result from the NFS is that there is greater community awareness and recognition of the need to rehabilitate waterways of the MDB to recover native fish populations. With the benefit of hindsight, many lessons were learnt through the process of delivering the first 10 years of the NFS, and it is important that these are not lost, but harnessed for future management of fishes in the MDB.

While communication undertaken by the NFS was extensive, using many delivery platforms and covering many subjects, breakthrough into the national media remained limited, especially when compared to coverage of River Redgums and colonial nesting waterbirds. It is our view that apart from the fact that these organisms were above ground and easily seen in comparison to fish, they also had 'champions', such as Dr Richard Kingsford (University of NSW). Champions are recognised as authoritative, willing and able to speak to the media. The absence of such a spokesperson to promote native fish, limited media coverage and publicity to the broad community, senior government officials and politicians. Support from recreational anglers, the National Irrigators Association and the Australian Conservation Foundation for continuation of the NFS and the ongoing delivery of native fish projects (despite the cessation of the NFS) points to some belated success in this area. Such support, however, was needed much earlier in this programme.

River Redgums, waterbirds and Ramsar Wetlands (such as Macquarie Marshes) have been used as icons to easily convey values of restoration. Murray Cod were also initially identified as an icon species for the Living Murray programme, but intense interest by anglers proved to divert attention from other important key messages. Also, misinterpretation of scientific survey results (e.g. nil or low catches from randomly selected sites within larger areas where Murray Cod were known to occur; Harris & Gehrke 1997) led to criticism of these studies by anglers. This highlights the potential for important messages to be distorted (scientists were not saying that cod were absent, just that they were rare or patchily distributed, indicating decline). The careful use of Murray Cod as an iconic fish species, however, is recognised as a useful asset in harnessing the recreational fishery and conservation stakeholders through common recovery objectives (Koehn & Todd 2012) and should be pursued in future MDB-wide fish recovery efforts.

The success of the NFS was in part due to the continued enthusiasm and long-term commitment of MDBA NFS staff, NFAP members and state-based NFS coordinators. This 'staying the course' allowed corporate memory to build and to be utilised in efficient delivery of projects. In addition, a confirmed funding stream for projects (initially up to 3 years) enabled forward planning and the creation of more strategic approaches to problems. The transformation of the MDBC to the MDBA, as part of a Commonwealth government bureaucracy, constrained the ability to pursue strategic, multi-year projects and caused funding uncertainty.

Unfortunately, the governance bodies above the NFAP Panel had their representatives drawn from agencies largely without fish/fishery responsibilities, and as a consequence, many decisions were delayed, or not strongly supported as they were either not fully comprehended or not closely aligned to the priority responsibilities of their agencies. Recently, the Australian Fisheries Management Forum (Chief Executives of all Australian fisheries management agencies) created a MDB Fisheries Working Group to report to them on issues previously addressed by the NFAP. Should funding be secured to continue a fish programme, a mechanism to broaden stakeholder involvement must be instigated to ensure continuation of the wider collaborative approach. Such 'independence' may also reduce the risks associated with the funding model (Koehn & Lintermans 2012) and political 'popularity', whereby the budget was susceptible to reduced monetary contributions from any of the five state jurisdictions.

The delivery of most NFS activities occurred during the 'Millenium Drought' which ran from 1997 to 2010 (van Dijk *et al.* 2013; Fig. 2) and while the drought assisted in drawing community attention and government resourcing to the plight of the MDB, it made some fish recovery/management tasks more difficult, as the attention of most landholders in the MDB was on survival of their farming enterprises or supply of domestic water. The delivery of essential environmental flows was limited, and where it occurred, the amounts of water were small and were generally not targeted at fish (Koehn *et al.* 2014). The impacts of this prolonged drought and subsequent fish kills due to 'blackwater' events (Fig. 1; King *et al.* 2012) affected some fish populations regardless of other recovery progress that may have been made. The switch from drought to flooding, and the subsequent change in focus of management activities, demonstrates the fickle and short-term memory of both management agencies and the community and demonstrates the need for future programmes to institutionalise the lessons from such climatic extremes.

Successive reports from the Sustainable Rivers Audit indicate that fish populations remain in a very poor state (Davies *et al.* 2010, 2012). A comprehensive external review of the NFS (Cottingham *et al.* 2009) outlined that while the NFS had been successful in the delivery of programmes (albeit under a limited budget and therefore scale of operations), activities would need to be increased if basin-scale changes were to be detected in the time frame of the strategy. Native fish populations have taken decades to decline to their current levels and will also take decades to recover. Progress towards the overarching NFS target for fish populations being recovered to 60% of pre-European levels after 50 years of implementation is not expected to necessarily be a straight linear response (i.e. 20% improvement after 10 years of action). Given the common ecological response times to disturbance, it could be expected that fish populations were still declining when the NFS commenced. Populations usually take some time develop a critical reproductive stock before recovery accelerates (Koehn & Todd 2012). The climatic environment with which the first decade of NFS action has had to contend with has not assisted recovery efforts. The Millennium Drought, extreme bushfires and blackwater events in 2010 and 2011 have all affected fish populations. However, while the foundation has been laid for recovery, increased efforts will be needed (Cottingham *et al.* 2009), as will effective monitoring, to measure results. There have been indications of improvements to Murray Cod populations in NSW and Silver Perch (*Bidyanus bidyanus*) populations in the River Murray, but these need to be quantified.

What does the future look like

Despite its successes, the NFS has only completed the initial 10 years of an estimated 50 years of programme effort needed to achieve its target. Prior to its cessation, a Murray-Darling Native Fish Action Plan was developed for the next 10 years (Barrett *et al.* 2013). This plan was developed by adopting many of the lessons learnt in the first 10 years particularly focussing on a smaller set of actions but at a much broader scale. The lessons learnt in the first 10 years of the NFS have also not been lost with a recent synthesis project (Barrett *et al.* 2013), the creation of a NFS 'legacy' website (www.finterest.com.au) and the compilation of papers in this special issue, ensuring that most of the NFS knowledge generated is available for future programmes whether pursued at the MDB or local river-reach scale.

The key issues that still need to be prioritised include: maximising the benefits of environmental flows; additional fish passage problems at remaining weirs as well as at small barriers such as culverts and road crossings; coldwater pollution; water extraction (that also removes fish); engaging the community in the management of rivers and fish; reducing the impacts of alien species; and supporting the science necessary to underpin and direct these activities. Incorporation of the likely impacts of climate change, including embedding lessons from the 'Millennium Drought', bushfires and blackwater events into regular management of fish (e.g. concepts of resistance, resilience and protection of refugia) will also be important. The potential impacts of climatic extremes have been clarified since the writing of the NFS and highlighted by the recent drought (Lintermans & Cottingham 2007), but have not been addressed by the NFS or included in the national recovery plans of most threatened freshwater fishes in Australia (Koehn *et al.* 2011; Lintermans 2013).

Establishing greater linkages between recreational fishers and fisheries management agencies and enhancing the transfer of new knowledge between the two will help gain greater public and political support. Native fish actions have the potential to provide many 'good news' stories that generate public interest, and this may be assisted by the use of Murray Cod and other iconic fish species to highlight their importance as components of river health.

Conclusion

The *Native Fish Strategy* has provided a substantial shift in the management of fishes in the MDB within the first 10 years of its implementation. It has placed an emphasis on the need for restoration and set clear objectives and aspirational goals within a long-term time frame (50 years); necessary for such a major task. It has taken a whole of fish community approach that coordinates across jurisdictional boundaries. The NFS objectives address key threats to fishes and are supported by new knowledge that has been transferred to both managers and the community. It has been recognised that additional time, effort and funding are required to meet the stated rehabilitation objectives and that this is now unlikely due to the cessation of the NFS programme. The NFS has laid the foundation for future management to recover fishes in the MDB, in whatever form that may be. Any such programme, however, must incorporate many of the key aspects of the NFS. To restart the process will now require extra efforts from all those concerned for fish and the progress and lessons learnt to date provide a valuable starting point.

Acknowledgements

The authors wish to thank the many people who have worked so hard to

support and progress the NFS with the vision of rehabilitating native fish populations. A full version of the *Native Fish Strategy* is available at: www.mdba.gov.au. Comments on this manuscript were kindly provided by Jason Lieschke and two anonymous reviewers.

Science informing management

The Native Fish Strategy was developed to address key threats to declining fish populations in the Murray-Darling Basin and guide a process of recovering its fish populations by taking a coordinated, long-term, multijurisdictional approach. The NFS successfully delivered more than 100 research projects across six 'Driving Actions' in its first 10 years, with highlights including the implementation of the 'Sea to Hume' fishway programme (restoring fish passage to >2200 km of the Murray River), improved knowledge of fish responses to environmental water allocations, development of new technologies for controlling alien fish, methods to distinguish hatchery-bred from wild fish, and a community partnership approach to 'ownership' of the Strategy and rehabilitating fish habitats using multiple interventions at selected river reaches. While funding for the implementation programme has ceased after only the first 10 years, the process and outcomes achieved provide some key lessons relating to a wide range of issues for fish management and have laid the foundations for future fish recovery. Native fish populations in the MDB remain in a poor state and improvements will not be achieved without continued concerted management efforts and the incorporation of the knowledge generated and lessons learnt through the NFS.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. List of Native Fish Strategy projects.