

**Draft National Recovery Plan for the
Murray Hardyhead
*Craterocephalus fluviatilis***

Department of Environment, Land, Water and Planning



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This is a Recovery Plan prepared under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The Australian Government, in partnership with the relevant States, facilitates the development of recovery plans to detail the actions needed for the conservation of threatened native flora and fauna. This document revises the plan developed previously for the Murray hardyhead for the period 2008–2013 (Backhouse *et al.* 2008).

Disclaimer:

This Recovery Plan was written by Daniel Stoessel, Iain Ellis, Marcia Riederer and Andrea Keleher (Victorian Department of Environment, Land, Water and Planning (DELWP)), synthesising current knowledge on the species and threats, and drafting potential recovery actions, on behalf of DELWP.

The recovery objectives and actions were developed and agreed by DELWP Biodiversity Division, in consultation with stakeholders and other agencies, in accordance with the requirements of the *Environment Protection and Biodiversity Conservation Act 1999* and are not the responsibility of the authors.

Although a range of stakeholders have been involved in the development of this Recovery Plan, entities identified as the lead entity in relation to specific actions have not necessarily committed to undertaking those actions. The implementation of actions may be subject to budgetary and other constraints affecting the parties involved. Proposed actions may be subject to modification over the life of the plan due to changes in knowledge. This publication may be of assistance to you but the State of Victoria does not guarantee that the plan is without flaw or is wholly appropriate for your particular purposes and therefore disclaims all liability for any error, loss or other consequence that may arise from the use of any information in this publication.

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DRAFT

Abbreviations

ARI – Arthur Rylah Institute

CEWH – Commonwealth Environmental Water Holder

CMA – Catchment Management Authority

DELWP – Victorian Department of Environment, Land, Water and Planning

DEWNR – South Australian Department of Environment, Water and Natural Resources

DPI NSW – Department of Primary Industries New South Wales

DoEE – Australian Government Department of the Environment and Energy

GMW – Goulburn Murray Water

MDFRC – Murray Darling Freshwater Research Centre

MCMA – Mallee Catchment Management Authority

NCCMA – North Central Catchment Management Authority

MDB – Murray Darling Basin

MDBA – Murray Darling Basin Authority

SARDI - South Australian Research and Development Institute, Department of Primary Industry and Regions, South Australia

VEWH – Victorian Environmental Water Holder

Summary

Murray hardyhead (*Craterocephalus fluviatilis*) is a small freshwater fish endemic to the lower Murray-Darling River Basin in South Australia, Victoria and New South Wales. Once considered widespread and common throughout its range, the species has suffered a large decline in range and abundance, and is now one of the most threatened fish species in Australia.

The Murray hardyhead is listed as nationally Endangered under the *Environment Protection and Biodiversity Conservation Act* 1999. It is likely to be extremely rare in New South Wales and survives in only a few isolated locations in Victoria and South Australia. All populations are threatened by altered hydrology and alien species and are susceptible to localised extinction.

This document represents the third revision of the Murray hardyhead National Recovery Plan. The Plan summarises the species distribution, biology and ecology, threats and recovery objectives and actions necessary to ensure the long-term survival and recovery of Murray hardyhead.

Species Information

Description

Murray hardyhead (*Craterocephalus fluviatilis* McCulloch, 1912) is an endemic, small (<100 mm), gold to silver-green fish (<85 mm total length). Two dorsal fins are present, the first of which has 4–7 spines, the second, one spine and 5–8 rays. The anal fin is opposite the second dorsal fin, is small, and has one spine and 6–9 rays. The pectoral fins are located high on the sides close to the top of the operculum opening and consist of one spine and 11–13 rays. The pelvic fins are small, abdominal and consist of one spine and 5–6 rays.

The species has historically been confused with several closely related hardyhead (family Atherinidae) including the Lake Eyre hardyhead (*Craterocephalus eyresii*), Darling River hardyhead (*Craterocephalus amniculus*), and Unspecked (or Fly-specked) hardyhead (*Craterocephalus stercusmuscarum fulvus*). The Murray hardyhead and the Lake Eyre hardyhead have non-overlapping geographical ranges, with the Lake Eyre hardyhead endemic to the Lake Eyre Basin and Lake Torrens Catchment in South Australia. The Darling River hardyhead can be distinguished from the Murray hardyhead by the greater number of transverse scale rows above the lateral line (up to 17 for Darling River hardyhead and 10–12 for Murray hardyhead); while the Unspecked hardyhead has 7–8 transverse scale rows (Ivantsoff and Crowley 1996).

Conservation status

The Murray hardyhead is listed nationally as Endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), and the International Union for the Conservation of Nature (IUCN) Red List 2017; Critically Endangered by the Victorian Department of Sustainability and Environment (DSE 2013), the New South Wales *Fisheries Management Act 1994*, and under the Action Plan for South Australian Freshwater Fishes (Hammer *et al.* 2009), and; Threatened under the Victorian Flora and Fauna Guarantee Act 1988 (FFG Act) and Murray-Darling Basin Commission's Native Fish Strategy 2003–2013 (MDBC 2004).

Distribution

The Murray hardyhead is endemic to the mid and lower Murray-Darling River system in south-eastern Australia (Lloyd and Walker 1986, Ivantsoff and Crowley 1996, Ebner *et al.* 2003). Historically the species was recorded as far upstream as Narrandera on the Murrumbidgee River, Wentworth on the lower Darling River in New South Wales (NSW), in multiple wetlands near Swan Hill and Mildura in Victoria, and sections of the Murray River and its tributaries near Renmark, Swan Reach and the Lower Lakes near the Murray River mouth in South Australia (DPI 2006, Chessman and Williams 1974, McGuckin 1999, Raadik and Fairbrother 1999, Hardie 2000, Lloyd and Walker 1986, Hammer *et al.* 2002, Wedderburn and Hammer 2003, Stoessel 2010).

The last confirmed capture of Murray hardyhead in NSW was from the Murray River at Merinee North in 2005 (Gilligan pers. comm. 2013), and the species is now likely to be extremely rare within the State. In Victoria, the species is considered extinct at 9 out of 13 historically known sites. Three of these are near Mildura in the State's north-west (Cardross Lakes Basin 2 and 3 and Lake Hawthorn); with the

remainder near Kerang in north-central Victoria (Golf Course Lake, Tutchewop Lake, Cullens Lake, Long Lake, Lake Wandella, Lake Yando; Stoessel 2010, Ellis 2012, Stoessel 2012). At most, eight populations of Murray hardyhead remain within Victoria, two of which are historic (Round Lake and Cardross Basin 1), two potentially re-established via translocation (Lake Elizabeth, Woorinen North Lake), two new (non-historical) sites confirmed as established by translocation (Lake Koorlong and Brickworks Billabong), and one discovered following floods in Victoria in 2011 (Lake Kelly; Stoessel 2012). The capture of a single specimen in surveys of Reedy Lake in 2013 (Byrne *et al.* 2013), suggests the species may also persist at the site in low abundance. The status and extent of the population of Murray hardyhead in Reedy Lake is, however, yet to be determined. Most recent data intimates that populations in Cardross Lakes and Lake Kelly may have declined, while little data exists as to the success of attempts to re-establish populations in Lake Elizabeth and Woorinen North Lake.

In South Australia, the species has historically been recorded in the Murray River and several of its tributaries from Lake Alexandrina to the Victorian border (Lloyd and Walker 1986). During the “Millennium” drought (1997–2010), the species was extirpated in the Angus and Marne Rivers, Scott Creek Wetland, Lake Bonney, Lake Littra, and Turvey’s Drain (Stoessel 2010, Bice *et al.* 2011, Wedderburn and Sutor 2012). Due to additions of environmental water a small population persisted in Boggy Creek during the drought, however, Murray hardyhead have not been detected at the site since it reconnected with Lake Alexandrina during floods in late 2010 (Wedderburn *et al.* 2010). Capture of the species in the Lower Lakes and Goolwa Channel region since the drought ended however, suggest individuals within Boggy Creek may have dispersed during flooding to adjacent wetland habitat. Similarly, a population in Gurra Gurra Wetland in the Riverland has not been detected since flooding in 2011. Only four core, isolated, populations may therefore remain in the State: Disher Creek, Berri Evaporation Basin (near Berri), Rocky Gully Wetland (near Murray Bridge) and the Lower Lakes (Lake Alexandrina, Lake Albert, Dunn Lagoon, Mundoo Island Channel, Hunters Creek, Munday Dam and Finniss River confluence; Wedderburn and Sutor 2012, Wedderburn and Barnes 2013, Ellis *et al.* 2013, Bice *et al.* 2012). A small translocated population also persists in Causeway Lagoon near Berri, albeit in very low numbers (Sutor pers. comm. 2014). Importantly, re-stocking in the Lower Lakes following flooding in 2011 is implied to have been a success, leading to reestablishment of the species within the lake (Bice *et al.* 2012). Historical and extant populations and their status are shown in Figure 1, Table 1.

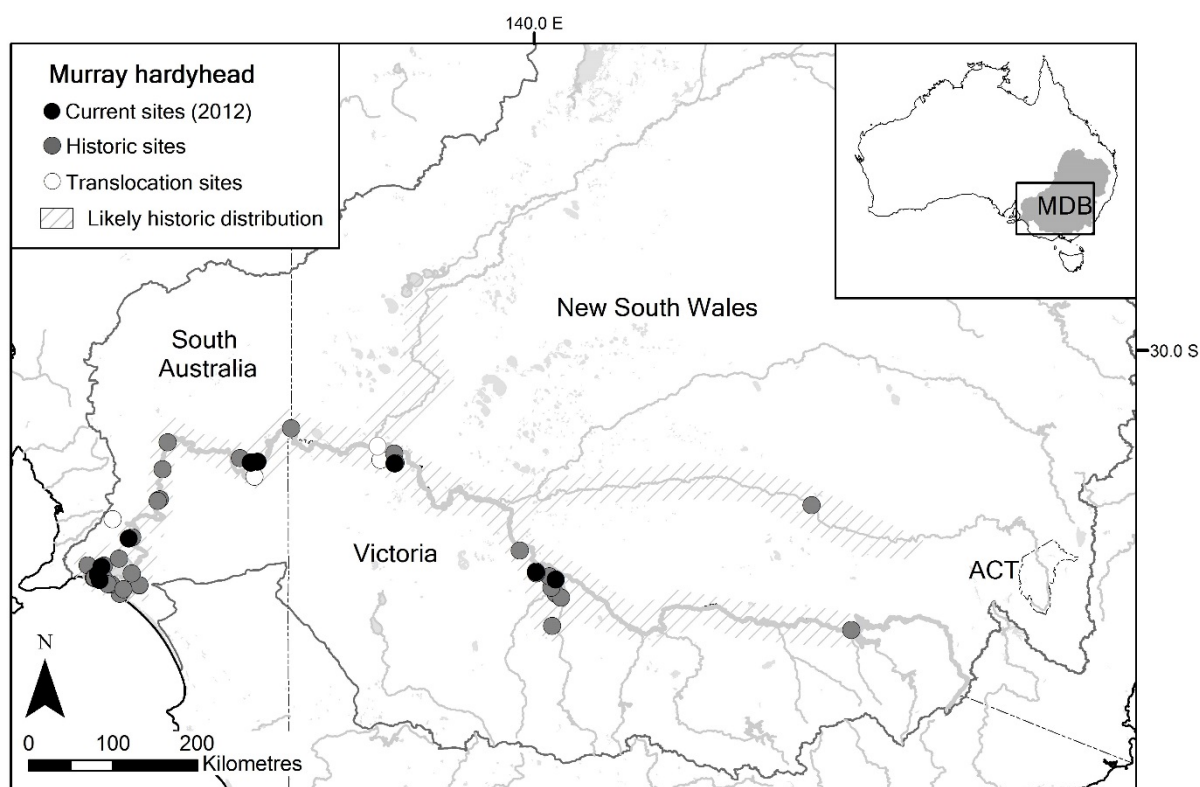


Figure 1. Location of known remnant populations of Murray hardyhead, and likely former distribution of the species.

Table 1 Locations where Murray hardyhead have been recorded.

State	Site	Latitude	Longitude	Status
New South Wales	Murray River	-33.980378	140.963173	Likely extremely rare – last confirmed capture occurred 2005 (Dean Gilligan pers. comm. 2013).
		to	to	
	Murrumbidgee	-36.008458	145.999589	
		-35.109676	147.374747	
	Lower Darling River	-34.728916	143.217945	
		-34.110668	141.905594	
	to	to		
		-32.361403	142.443237	
Victoria	Lake Yando	-36.042437	143.783312	Extinct – last recorded 1963; lake went dry in late 1990s (Backhouse <i>et al.</i> 2008).
	Lake Elizabeth	-35.698013	143.820648	Status unknown – historic population last reported as present by Lyon <i>et al.</i> (2002); was not recorded in subsequent surveys by Lyon (2004) and Stoessel (2007); lake went dry in 2008. Efforts made in 2015 to re-establish the population via translocation of a small number of fish captured from the Lake Kelly population. Result of translocation unknown.
	Lake Wandella	-35.74033	143.87764	Extinct – last recorded 1964 (Backhouse <i>et al.</i> 2008).
	Lake Cullen	-35.636025	143.774888	Extinct – last recorded 1971; absent by 1989; lake dry in late 1990s (Backhouse <i>et al.</i> 2008).

Table 1 cont'd

State	Site	Latitude	Longitude	Status
Victoria Cont'd	Lake Kelly	-35.546520	143.820230	Declining - Lake population extirpated, but remnant individuals persist in nearby Tutchewop Main Drain with 15 individuals captured in the drain in September 2015 and 101 captured in January 2016 (Keleher pers. comm. 2015). Approximately 353 individuals translocated to Woorinen North Lake 2013 and 30 individuals translocated in 2015. Water supply not guaranteed for the site into the future.
	Middle Reedy Lake	-35.663494	143.878965	Status unknown – One individual captured early 2013 (Biosis 2013); subsequent survey did not capture any individuals (Stoessel and Dedini 2013)
	Lake Tutchewop	-35.51361	143.75236	Extinct – last recorded 1971 (Backhouse <i>et al.</i> 2008).
	Golf Course Lake	-35.48213	143.614826	Extinct – c. 2000; last reported as present by McGuckin (1999); lake is now dry.
	Round Lake	-35.469967	143.609247	Unknown – last captured in 2014 and fish observed in lake in 2015 (Dedini pers. comm. 2015) and 2017 (Stoessel pers. obs. 2017).
	Long Lake	-35.459691	143.611994	Extinct – last recorded 1971; absent by 1989; lake dry in late 1990s (Backhouse <i>et al.</i> 2008).
	Woorinen North Lake	-35.237207	143.437672	Status unknown – last recorded 2009. Decline at the time suggested to be a result of a large increase of alien eastern gambusia (<i>Gambusia holbrooki</i>) at site (Stoessel 2012); Recent attempt to re-establish the population via translocation of fish from Lake Kelly. Result of translocation unknown.
	Lake Hawthorn	-34.20126	142.09838	Extinct - lake dried in 2009 (Ellis <i>et al.</i> 2012). Small number of rescued fish placed into captive breeding program; resultant offspring translocated to Lake Koorlong 2009 - 2013.
	Cardross Lakes (Basin 1)	-34.307995	142.098885	Persists in low numbers in January 2014 (Ellis pers. comm. 2014). Small number of captive bred offspring translocated to Lake Koorlong 2009 – 2013. Adult and juvenile size classes detected in low abundances (Ellis and Wood 2015). Low catch rates since 2012 are a concern for the viability of this population.
	Cardross Lakes (Basin 2)	-34.308136	142.105064	Extinct – c. 2006; last reported by Raadik (2001); surveys by Ellis (2007) did not locate any individuals.
	Cardross Lakes (Basin 3)	-34.303457	142.110214	Extinct – c. 2006; last reported by Raadik (2001); surveys by Ellis (2007) did not locate any individuals.
	Koorlong Lake (translocated population)	-34.269541	142.073307	Stable at present - population established via translocation of Lake Hawthorn and Cardross Lakes fish in 2009 - 2013 (Ellis <i>et al.</i> 2013). Good numbers of adult and juvenile fish caught November 2015 suggest this population is on the improve (Huntley pers. comm. 2015)
	Brickworks Billabong (translocated population)	-34.139160	142.035939	Stable - site connected to the Murray River in 2016 during floods. Flooding likely provided the opportunity for dispersal to additional floodplain wetland habitats along the Murray River. Population was found to persist at the site following the flood event.

Table 1 cont'd

State	Site	Latitude	Longitude	Status
South Australia	Disher Creek	-34.300479	140.568695	Status unknown – site connected to the Murray River in 2016 during floods. Monitoring required to identify if the species persists at the site. Infrastructure works undertaken 2012 to increase available habitat, environmental water delivered to site annually since 2011. Seasonal surveys 2014 – 2015 captured medium to high numbers at the site. Approximately 2000 fish were taken from the site in 2015 and translocated to Brickworks Billabong near Mildura for conservation efforts (Sutor 2014, Wegener <i>et al.</i> 2015: L. Sutor unpub. data)
	Berri Evaporation Basin	-34.298636	140.565863	Stable - site connected to the Murray River in 2016 during floods. Monitoring required to identify if the species persists at the site. Infrastructure works undertaken 2012 to increase available habitat, environmental water delivered to the site annually since 2011. Seasonal surveys 2014 – 2015 captured medium to high numbers at the site. Approximately 500 fish were taken from the site in 2015 and translocated to Brickworks Billabong near Mildura wetland for conservation efforts (Sutor 2014, Wegener <i>et al.</i> 2015: L. Sutor unpub. data)
	Causeway Lagoon (translocated population)	-34.310930	140.603107	Status unknown - A small number bred in captivity at MDFRC (Mildura) were translocated to Causeway Lagoon in 2010 (Ellis <i>et al.</i> 2013). Single individual recorded in October 2014 and October 2013 (L. Sutor, unpub. data)
	Gurra Gurra Lakes	-34.312718	140.658149	Status unknown - Identified in medium to high numbers at site in 2010, but not detected at the site since it was inundated during flooding in late 2010. Surveys undertaken in February 2015 did not detect any fish (L. Sutor unpub. data).
	Lake Littra	-33.934646	140.997984	Extinct – last recorded 2000, before lake dried (Backhouse <i>et al.</i> 2008).
	Lake Bonney	-37.766305	140.34957	Extinct – pre-1990 (Crowley and Ivantsoff 1990)
	Scotts Creek Wetland	-34.083303	139.677515	Extinct – last recorded early 2000s (Stoessel 2010).
	Marne River mouth	-34.666252	139.311104	Extinct – pre-1990; last recorded early 1980s (Lloyd and Walker 1986). Not recorded during recent sampling (2012 and 2015: N Whiterod, unpub. data)
	Jury Swamp	-35.054017	139.315683	Status unknown. Single individual (49mm) recorded in April 2015 (Whiterod unpub. data)
	Rocky Gully Wetland	-35.110501	139.263639	Status unknown. Last recorded in 2012, additional sampling in adjoining salt drains and stormwater basins was undertaken during the two most recent biannual fish surveys with no captures (Mason pers. comm. 2015).
	Riverglades Wetland	-35.095895	139.301405	Status unknown- Small numbers captured in April 2015 and 115 captured in October 2015. Prior to this no captures since 2012. (Mason pers. comm. 2015)
	Angas River	-35.395880	139.00019	Extinct – pre-1986 (Backhouse <i>et al.</i> 2008).
	Bremer River	-35.389261	139.051815	Seven individuals (29–48mm) recorded in autumn 2013 (Wedderburn and Barnes 2013)

Table 1 cont'd

State	Site	Latitude	Longitude	Status
South Australia cont'd	Lake Alexandrina (Hindmarsh/ Mundoo Islands, Goolwa channel + tributaries)	-35.491232	138.897787	Population declined 2008–2010; Population maintained in Boggy Creek refugia using The Living Murray environmental water dispersed when river flows returned in spring 2010 (Wedderburn <i>et al.</i> 2013); 10,420 fish reintroduced to two locations (Mundoo Island channel and Hunters Creek) in 2012; Captured in low to moderate numbers (333 fish) over spring 2012 to autumn 2014 at six locations (most at Finniss Junction, 281 fish); reintroduced fish on Mundoo Island not detected since autumn 2014 (Wedderburn and Barnes 2013, 2014; Bice <i>et al.</i> 2013; 2014). Population stable and widespread in the Goolwa Channel region, yet to re-establish in other former habitats (Wedderburn 2014).
	Lake Albert			Status unknown. Populations recorded from 2003–2008 at sites including Waltowa, Belcanoe and Campbell House (Wedderburn and Hammer 2003; Wedderburn <i>et al.</i> 2007; Wedderburn and Barnes 2008) but has not been detected since, despite continuous monitoring (Wedderburn 2014).
	Mundoo Dam (surrogate dam)			Stable Established with 221 fish, sourced from Boggy Creek/Rocky Gully over 2010 and 2011. Not sampled since 2014, at which time it was stable (Bice <i>et al.</i> 2013; N Whiterod, unpub. data).

Genetics

Five genetically distinct conservation management units are described (Wedderburn 2008, Adams *et al.* 2011). These are: 1) the now extinct Lake Elizabeth population, 2) the Kerang Lakes (Lake Kelly and Round Lake populations, and likely the Reedy Lake population), which display a greater genetic affinity to the Lake Elizabeth population than the remaining Genetic Management Units, 3) the extinct Woorinen North Lake population, 4) the Middle Murray Genetic Management Unit which includes Cardross Lake, Lake Hawthorn (now Lake Koorlong population), Disher Creek, Berri Evaporation Basin, Causeway Lagoon (translocated), Brickworks Billabong (translocated) and (probably given its proximity to Berri Basin) the Gurra Gurra Wetland population, and 5) Lower-Murray (all sites below Lock 1 the most downstream weir, 274 km upstream of the Murray River mouth), which includes the now extinct populations of Riverglades Wetland, Boggy Creek, and Turveys Drain, and the remaining sites of Rocky Gully Wetland and the Lower lakes meta-population (Finniss River confluence, Mundoo Channel East, Dunn Lagoon, Hunters Creek, Munday Dam, Milang Bay, Currency Creek, Holmes Creek). Of the five conservation management units described by Wedderburn (2008), only three remain: Kerang Lakes, Middle Murray, and Lower-Murray (Table 2).

Table 2 Murray hardyhead genetic management units.

State	Site	Genetic Management unit
Victoria	Lake Elizabeth	Lake Elizabeth*
	Lake Kelly Reedy Lake# Round Lake	Kerang Lakes
	Woorinen North Lake	Woorinen North Lake*
	Cardross Lakes Basin 1 Lake Koorlong (remnant Lake Hawthorn fish) Brickworks Billabong (translocated from Berri Evaporation Basin and Disher Creek fish)	Middle Murray
South Australia	Disher Creek Berri evaporation basin Gurra Gurra Wetlands Causeway Lagoon (translocated offspring of Berri Evaporation Basin and Disher Creek fish)	
	Rocky Gully Wetland Lower Lakes meta-population	Lower Murray

Record based on capture of a single individual. Inclusion in Kerang Lakes Genetic Management Unit is preliminary, and based on geographic locality of site and not genetic determination.

*Extinct genetic management unit.

Habitat

Very little is known of the habitat used by the now extinct riverine populations in the Murray, lower Darling, and the Murrumbidgee River systems (Stoessel 2010). Virtually all knowledge regarding habitat use of the species is based on observations of a small number of remnant isolated populations in wetlands in Victoria and South Australia (Stoessel 2010). Importantly, current occupied habitats may not be representative of preferred habitat, but of marginal refuge habitat (Stoessel 2010). Remnant populations of Murray hardyhead occupy still and slow-flowing waters including billabongs, lakes and margins and backwaters of lowland rivers (Lloyd and Walker 1986, Crowley and Ivantsoff 1990, Ivantsoff and Crowley 1996). Individuals are frequently observed schooling in open-water and amongst aquatic vegetation such as fringing emergent rushes (*Cumbungi* species and *Juncus* species), and submerged macrophytes including *Ruppia* and *Myriophyllum* species (Ivantsoff and Crowley 1996, Raadik and Fairbrother 1999, Ebner *et al.* 2003, Hammer and Wedderburn 2008). Remnant populations of Murray hardyhead are generally located in saline habitats, however, the species has been recorded in wetlands with salinities as low as 0.4 ppk in Riverglades Wetland in South Australia, to as high as 58.9 ppk in Lake Kelly (Wedderburn *et al.* 2007, Wedderburn *et al.* 2008, Stoessel 2012). Although salinity is implied as a key factor influencing distribution and abundance of remnant populations (Wedderburn *et al.* 2007), the species predominant habitation of saline sites may be a consequence of reduced competition from alien fishes that such sites afford (particularly from Eastern gambusia *Gambusia holbrooki* and Common carp *Cyprinus carpio*; Wedderburn *et al.* 2010, Stoessel 2012), rather than a species-specific preference for such sites (Stoessel 2010).

Reproduction

Murray hardyhead have a prolonged spawning season from September to March (spring and summer), with peak larval abundance occurring in late October to early November (Ellis 2005). Spawning is triggered by temperature and increasing day length (Ellis 2005, Ivantsoff and Crowley 1996). The species is a batch spawner, females depositing clutches of up to 80 adhesive eggs on submerged vegetation (Ellis 2005). Following spawning, reproductively spent adults suffer high mortality rates, with few surviving more than 12 months of age (Bice and Ye 2006, Ellis 2006). Eggs hatch between five to 10 days after fertilisation at temperatures of 20 to 26°C (Ellis unpub. data). Length at maturity is around 25 to 30 mm standard length, and fish in captivity reach maturity within six to seven months (Ellis 2005). The presence of three size classes in Round Lake in April 2008, nevertheless suggests, under ideal conditions, maturation may occur in the wild in less than three months (Stoessel pers. obs.). Individuals spawned early in a season may therefore reach maturity in the same season, and thus there may be multiple spawning's in a season (Ellis and Kavanagh 2014). Murray hardyhead is an annual species, with populations dominated by 0+ individuals (Ellis 2005). Any perturbations which disrupt spawning and recruitment may therefore result in the rapid local extinction of populations (Stoessel 2010).

Diet

Juvenile and adult Murray hardyhead feed predominantly on micro-crustaceans, although larger fish tend to have a more diverse diet, consuming larger prey items such as dipteran pupae (Ellis 2006). In captivity, larvae readily feed on rotifers and zooplankton, while adults will accept a range of food types including frozen dipteran larvae (bloodworms), zooplankton and processed flakes (Ellis 2010). In populations in wetlands in the wild, flooding during the spawning period (spring to summer) enhances zooplankton abundance (mostly rotifers and their eggs) which likely benefits recruitment success of the species (Wedderburn et al. 2010).

Threats

The rapid ongoing decline in the range and abundance of Murray hardyhead is a response to numerous compounding factors. Fragmentation, deterioration and loss of habitat, flow alteration, river regulation, drought, changes to irrigation practices and alien fishes have all undoubtedly contributed to the species decline. Threats are rarely mutually exclusive, with most sites impacted by more than a single threat. A list of identified threats is shown over page (Table 3).

Table 3 Summary of threats for Murray hardyhead.

Threat	Threat type	Comment	Populations known or likely to be affected
Decreasing irrigation drainage	Immediate	Modernisation of irrigation has resulted in a significant reduction in runoff and increased salinisation at several sites.	Cardross Lakes, Woorinen North Lake, Round Lake, Disher Creek Evaporation Basin and Berri Evaporation Basin.
Lack of water supply	Immediate	Environmental watering priorities are determined annually with no long-term guarantee of supply.	All remnant and historic sites within New South Wales, Victoria and South Australia.
Impact of alien fish	Long term; chronic	Eastern gambusia is suggested as the likely cause of the extinction of at least one population; predation by redfin (<i>Perca fluviatilis</i>) is likely to be underestimated in the Lower Lakes; the introduction of Common carp has likely played a direct role in the decline of Murray hardyhead due to the feeding behaviour of the species which increases turbidity and disturbs and uproots aquatic macrophytes.	All remnant and historic sites within New South Wales, Victoria and South Australia.
Habitat degradation	Immediate; long term	The loss of macrophytes in many river systems which are suggested as a critical habitat of Murray hardyhead for spawning and shelter, has likely contributed considerably to the decline of the species.	All historic sites within New South Wales, Victoria and South Australia.
Genetic issues	Immediate	There is concern that isolated wild, and captive populations may be at risk of genetic drift due to the often-small number of individuals at sites and the increased likelihood of inbreeding and domestication.	All captive and wild populations within Victoria and South Australia.
Parasitic infection and deformities	Immediate	The impact of parasitic infections is unknown, as is the cause of the deformities; consequences of infection and deformities at sites may be intensified in stressed environments; it has been implied that a nematode infection may have been the cause of high mortalities in captive fish.	Parasites - Round Lake, Woorinen North Lake, Cardross Lakes, Disher Creek Evaporation Basin; Deformities – Cardross Lakes, Hawthorn and Round Lake.
Increasing salinity	Immediate	With decreasing water levels (both long and short term), salts become concentrated which results in potentially lethal salinity levels; water quality monitoring at sites is therefore a vital component of management.	Lake Kelly, Disher Creek Evaporation Basin, Berri Evaporation Basin.
Decreasing salinity	Immediate; long term	Freshwater inflows combined with groundwater outflows are resulting in declining salinity levels in the long term; eventual invasion by less tolerant competitors and predator fish species is inevitable without exclusion screens.	Immediate – Cardross Basin 1 East. Long term – Woorinen North Lake, Round Lake and Lake Elizabeth (and possibly Disher and Berri Evaporation Basins).

Source: MDBC 2004, Backhouse et. al 2008, Hammer and Wedderburn 2008, Stoessel 2010, Stoessel 2012, Wedderburn *et al.* 2012a, Wedderburn and Barnes 2013.

Table 3...continued

Threat	Threat type	Comment	Populations known to be affected
Drought	Long term; chronic	Climate change predictions suggest declines in rainfall and increases in temperature are likely in much of southern Australia.	All remnant and historic sites within New South Wales, Victoria and South Australia.
River regulation	Long term; chronic	Connectivity is significantly reduced; fragmentation and isolation of populations has resulted; few opportunities now exist for dispersal and recolonisation.	All remnant and historic sites within New South Wales, Victoria and South Australia.
High nutrient levels	Implied	Possible concentration of nutrients is of concern in systems with little to no flow through.	No populations known to be affected at present.
Acid sulphate soils	Implied	Little work has been undertaken regarding the existence of sulfidic materials at sites.	It is unknown if sites are affected.
Barriers to Migration/ Movement	Implied	Dispersal during flooding was likely pivotal for recolonisation of sites and genetic exchange.	All remnant and historic sites within New South Wales, Victoria and South Australia.
Environmental contamination	Implied	Historically several lakes were used for the disposal of irrigation water, risk of chemical contamination is probable.	It is unknown if sites are affected.
Stocking native fish for recreational angling	Implied	Most sites at which the species presently exist are unsuitable for native recreational species; the present threat of stocking native fish is negligible in most systems.	Middle Reedy Lake possibly affected; status of population at site is, however, yet to be determined; water quality parameters suitable for recreational native fish at a small number of additional sites; introduction of predatory species would likely be to the detriment of Murray hardyhead.

Source: MDBC 2004, Backhouse et. al 2008, Hammer and Wedderburn 2008, Stoessel 2010, Stoessel 2012, Wedderburn *et al.* 2012a, Wedderburn and Barnes 2013.

Objectives, performance criteria and actions

Recovery objectives and timelines

The over-arching objective of the Recovery Plan (the Plan) is to improve the conservation status of Murray hardyhead, with the ultimate long-term goal being the removal of the species from the threatened species schedule. The present version of the Plan (i.e. this document) aims to ensure that the small number of known populations are stabilised through sound management, and that the area of occupancy is increased over the life of the Plan. An informal working group with representatives of key State agencies (DEWNR, DELWP) and other stakeholders (MDFRC, NCCMA, MCMA, SARDI, AquaSave, The University of Adelaide) has been formed to coordinate recovery actions and exchange information on conservation of Murray hardyhead. Further involvement by representatives of DoEE will be sought in the future. Lead agencies should continue to liaise and exchange research findings and species information, thereby ensuring the progression of the Plan's recovery actions and objectives.

Performance criteria

The criteria by which the Plan will be regarded as successful in reaching its desired objectives are: 1) no existing wild population becomes extinct, and; 2) the total number of populations of Murray hardyhead in the wild has increased by at least one per Genetic Management Unit in the next five years (from the time of acceptance of the Plan).

In addition, the co-operative management of the species must be maintained or enhanced. Currently representatives of South Australian and Victorian governmental agencies have input into the recovery planning process through an informal Murray hardyhead working group. For the recovery effort to be furthered, management responsibilities need to be formalised, knowledge exchange maintained, and input sought from comparable entities from NSW (e.g. NSW DPI). In addition, formalisation of the working group is likely to assist in the achievement of objectives of the Plan. Furthermore, a coordinated communication strategy aimed at increasing awareness and participation in the conservation and recovery of Murray hardyhead should be established to increase support of local communities for management and conservation efforts.

Evaluation

This Recovery Plan

The success of this Plan will be determined by assessing whether recovery objectives and actions (as outlined over page) are met. In partnership with relevant Australian Government (DoEE) and State Government agencies (Vic DELWP, SA DEWNR and NSW DPI), the working group will play an active role in monitoring the success of the Plan at annual meetings. The present Plan (i.e. this document) should be re-evaluated and updated after five years from the time of acceptance.

Previous Recovery Plan

The overall objective of the previous version of the Plan was to minimise the likelihood of extinction of Murray hardyhead in the wild, and to increase the probability of important populations becoming self-sustaining in the long term (Backhouse *et al.* 2008). Specific objectives of the Plan were to:

1. Investigate and manage threats to populations and habitats;
2. Determine population persistence and trends;
3. Determine habitat preferences;
4. Investigate important life history attributes;
5. Establish and maintain Murray hardyhead in captivity;
6. Establish new populations of Murray hardyhead in the wild, and;
7. Increase community awareness of the conservation of Murray hardyhead.

The management of the species through the recent drought has achieved the overarching objective of the previous Plan, in that extinction of Murray hardyhead has been prevented. At present, there are, however, fewer populations than that which existed at the inception of the prior Plan, and thus recovery has not been achieved. It must be noted however, that the prior Plan was launched at the height of a severe drought which affected much of southern Australia, and therefore management actions, particularly regarding water availability and supply to lakes sustaining populations, were comparatively restricted.

Many of the more specific objectives of the Plan have nevertheless been met, and significant knowledge of the species biology and ecology has been gained, particularly in regard to persistence and trends, habitat preferences, important life history traits and in maintaining the species in captivity (Adams *et al.* 2011, Ellis 2005, Ellis 2006, Hammer and Wedderburn 2008, Stoessel 2010, Wedderburn *et al.* 2010, Adams *et al.* 2011, Ellis 2011, Ellis *et al.* 2012, Stoessel 2012, Wedderburn *et al.* 2012b). Further work is nonetheless required to identify and manage emerging threats, and to further our knowledge of captive breeding techniques and important life history traits. In addition, greater community awareness of the species status and off-target benefits for threatened waterbird species (i.e. watering of sites has multi-species benefits) may result in increased efforts and funding for maintaining and recovering the species. Furthermore, a greater emphasis on proactive and sustained management and the establishment of additional populations is required, rather than simple maintenance of dwindling wild populations.

Recovery Objectives

The objectives of the Recovery Plan are to:

1. Protect, maintain and monitor presently known populations
2. Investigate and manage threats to populations and habitats
3. Increase area of occupancy
4. Investigate important life history traits
5. Establish emergency contingency
6. Conduct surveys to determine if unknown populations exist in the wild
7. Increase community awareness of the conservation of Murray hardyhead

Implementation of the objectives will remain primarily the responsibility of New South Wales (DPI Fisheries), Victorian (DELWP) and South Australian (DEWNR) State Government agencies subject to available resources. Under guidance and funding provided by DoEE, DELWP, DEWNR and other funding sources, additional agencies (ARI, CMA's, MDFRC, SARDI) will be responsible for preparing assigned recovery work plans within their jurisdiction. The environmental water available for use will depend on prioritisation processes undertaken by the Commonwealth Environment Water Holder (CEWH), the Victorian Environmental Water Holder (VEWH) and DEWNR. Objectives and their corresponding actions are listed below in order of priority. The estimated cost of implementing the recovery objectives is \$4,158,613 over five years (Appendix 1, Table 5).

Recovery Actions

Objective 1. Protect, maintain and monitor presently known populations.

Action 1.1 To the extent possible, supply environmental water to remnant "primary" populations.

A number of wetlands in which Murray hardyhead presently persist, or are likely to persist (Lake Elizabeth, Round Lake, Woorinen North Lake, Cardross Basin 1, Koorlong Lake, Brickworks Billabong, Disher Creek and Berri Evaporation Basin, Rocky Gully wetland, Dunn Lagoon, Mundoo Island and Hindmarsh Island channels) require a supply of environmental water to maintain conditions suitable for long-term sustainability of populations. These core populations should be regarded and managed as "primary" populations given their historical and present capacity to support Murray hardyhead.

Supply of environmental water to these primary sites needs to be considered during the annual planning process for management of environmental water. For example, in Victoria, delivery of environmental water to Murray hardyhead sites is proposed as part of the North Central and Mallee Seasonal Watering Proposals (SWP) then submitted to the VEWH. The VEWH considers SWPs and creates a seasonal watering plan that prioritise watering activities across the entire State in an integrated way. The seasonal watering plan considers the most appropriate use of environmental water entitlements held by the VEWH, as well as other environmental water entitlements available for use in Victoria, such as The Living Murray entitlements and those held by the Commonwealth Environmental Water Holder.

Action 1.2 Manage the timing and magnitude of delivery of environmental water to wetlands to maintain water quality and habitat suitability for the completion of life-stages of Murray hardyhead.

It is widely recognised that the health of aquatic fauna and flora communities is largely influenced by the timing and volume of hydrological events (Baumgartner *et al.* 2013). Over thousands of years, plants and animals have adapted and evolved to climatic conditions. Environmental watering therefore needs to occur at times which will maximise benefits to Murray hardyhead, and the species on which it relies as a food source (i.e. zooplankton) and shelter (i.e. aquatic macrophytes). Alternatively, as Murray hardyhead are highly tolerant to salinity, appropriately timed water level decreases in naturally saline wetlands (and subsequent natural increases in salinity) at ecologically appropriate times, may be beneficial to the control of alien species at sites (Stoessel 2012). A watering regime (devised by fish ecologists) which aims to maximise ecological benefits for Murray hardyhead, while also controlling alien species is therefore required to be developed for individual lakes (if not already present).

Objective 2. Investigate and manage threats to populations and habitats.

Action 2.1 Develop and implement water quality, habitat and population monitoring programs at all sites.

As Murray hardyhead live for a maximum of 18 months and only breed once in their life-time, decline and extinction of populations can be rapid. Regular monitoring in the form of fish (at least biannually), water quality (monthly) and habitat surveys (annually) are required to check for, and remediate threats to populations and assess recovery and security of populations. Results of these surveys need to be reviewed regularly to inform management interventions as part of an adaptive management process (Lintermans 2013).

Action 2.2 Identify current/potential threats for all extant populations.

Threat assessments are required for all extant populations of Murray hardyhead. Where an immediate controllable threat is identified, suitable actions are to be undertaken by relevant authorities to rectify and/or halt the threat.

Action 2.3 Assess effectiveness of management interventions in recovery of species.

A critical aspect of the Plan is to demonstrate that the implementation of recommended management interventions has contributed to the recovery of the species beyond that expected to occur naturally. The success of management interventions to date have been considered in Ellis *et al.* (2013). The effectiveness of future management interventions requires similar expert scrutiny. The working group, including expert State representatives, will be required to track and share progress and outcomes of management interventions, and provide direction and management advice as to future intervention (based on this Plan) to relevant State and Federal stakeholders. Progress towards implementation of recovery actions are to be recorded in central databases held within each State (e.g. Actions for Biodiversity Conservation system used by DELWP).

Objective 3. Increase area of occupancy.

Action 3.1 Identify suitable translocation sites to establish “secondary” populations of Murray hardyhead.

Due to fewer flood events, opportunities for natural colonisation of floodplain wetlands by Murray hardyhead through migration of individuals from one wetland to another is virtually none existent. Identification of floodplain wetlands suitable for Murray hardyhead establishment and translocation is therefore a key strategy in the recovery of the species. It is envisaged that these “secondary” populations would ideally be in wetlands on floodplains, thereby acting as potential dispersal nodes during any future flood event, thus improving the chances for recovery of the species in the wild. Fish to be translocated to secondary sites would be sourced from either secure primary sites (see Action 1.1.), or from established temporary surrogate refuge sites (see Action 3.5). A preliminary list of suitable translocations sites has been developed for the Kerang region in north-central Victoria by Stoessel (2013), and more broadly over the species range by Ellis and Kavanagh (2014).

Action 3.2 Prepare and implement a translocation plan which considers interstate translocations to previously important sites and potential new sites, and complies with National and State policies and guidelines for the translocation of aquatic organisms.

Prepare a translocation plan which complies with the 'National Policy for the Translocation of Live Aquatic Organisms' (Ministerial Council on Forestry, Fisheries and Agriculture MCFFA 1999), plus any relevant State requirements (e.g. DPI 2003), including appropriate permits.

Action 3.3 Supply environmental water to a minimum of three new translocation sites identified by ecologists (at least one site per existing Genetic Management Unit).

The extirpation of several populations of Murray hardyhead in recent years suggests that without mediating risk, total extinction is likely. A minimum of three new translocation sites (at least one per existing Genetic Management Unit) is required (see Action 5.1). Where water delivery infrastructure exists, a watering regime that maximises ecological benefits for Murray hardyhead needs to be developed for each site into which fish are translocated, and included in an environmental water management plan or similar. As per Action 1.1, provision of environmental water to secondary sites for the benefit of Murray hardyhead needs to be considered during the annual planning process for managing environmental water.

Action 3.4 Maintain and monitor the health of translocated populations.

Once translocation of Murray hardyhead occurs, be it to primary or secondary sites, there will be an ongoing requirement to maintain habitat, limit invasive species incursions, and to maximise benefits to Murray hardyhead populations through management of the timing and volume of environmental water delivered to sites. In addition, a monitoring protocol needs to be developed and employed which is sufficient to detect survival, dispersal and recruitment of the species, and to identify emergent threats to populations.

Action 3.5 Identify, establish and maintain suitable temporary surrogate refuge sites that can be used to temporarily maintain a portion of individuals from at risk populations, and/or to act as temporary breeding sites to ensure sufficient Murray hardyhead stocks are available for translocation and/or supplementation.

Due to the short life-span of Murray hardyhead, decline and extinction of populations can be rapid (Stoessel 2012). Where population declines are suspected, the use of refuge sites (dams, wetlands etc.) may aid in decreasing extinction risk and in reducing costs associated with captive maintenance. Prior use of a temporary surrogate site in South Australia (Munday Dam) suggests rapid increases in the abundance of Murray hardyhead may be possible using the strategy, the result of which was a large number of fish available for translocation or supplementation (Bice *et al.* 2013). A preliminary list of surrogate refuge sites across the three states has been developed by Ellis and Kavanagh (2014), however the list may not be exhaustive and require on-ground validation.

Objective 4. Investigate important life history traits.

Action 4.1 Investigate salinity tolerance at critical life history stages.

While adult Murray hardyhead are known to tolerate salinities of 0.4 to 64 ppk (Wedderburn *et al.* 2008, Stoessel 2012), the tolerance of early life stages, particularly eggs and fry, is unknown. Knowledge of the tolerance of these life stages is critical to management of salinity in isolated

wetlands and in determining the suitability of potential translocation sites. This action will involve a laboratory-based study.

Action 4.2 Investigate implied negative interactions of eastern gambusia on Murray hardyhead.

Eastern gambusia is known to predate and be aggressive toward native species, to compete for food resources and habitat, and is implicated in the decline of more than 30 fish species worldwide (Allan *et al.* 2003, Lintermans 2007, Macdonald and Tonkin 2008). Perhaps it is unsurprising therefore that the species has been suggested as the cause of extinction of at least one population of Murray hardyhead (Stoessel 2012). However, as the impact of the species occurrence at sites containing Murray hardyhead is largely unknown, further research is required to understand the consequences of the presence of eastern gambusia, and to investigate possible options to control negative aspects of the species presence (e.g. through habitat augmentation, salinity increases etc.). This action will involve a laboratory-based study.

Action 4.3 Investigate implied negative interactions of redfin on Murray hardyhead.

The impacts of redfin perch are likely underestimated, especially in the Lower Lakes (Wedderburn *et al.* 2012a). Given the predatory nature of redfin, the species may pose a significant threat to Murray hardyhead. This action will involve a laboratory-based and/or field study to assess the extent of redfin predation on Murray hardyhead.

Objective 5. Establish emergency contingency.

Action 5.1 Develop captive breeding protocols for temporary risk mediation to ensure populations, if required, can be maintained in captivity for periods longer than one year.

Although captive maintenance is costly and labour intensive, it undoubtedly preserved important populations of Murray hardyhead during the “Millennium” drought. In future, a captive maintenance program should only be used as a temporary measure of last resort in response to the impending extirpation of a wild population, and when no alternative surrogate refuge site exists (see Action 3.5). As Murray hardyhead is an annual species, long term captive maintenance programs (i.e. of greater than a year) for risk mediation require that individuals spawn in captivity. Attempts at inducing individuals to breed in captivity have had varied success, and appear largely dependent on the source of individuals (i.e. from which populations the individuals were sourced). Developing techniques in the form of artificial fertilisation, and/or the use of hormones to induce individuals to spawn in captivity, therefore need to be considered. This action will involve a laboratory-based study and will only occur when stocks of wild fish are sufficient to allow the removal of an appropriate number of individuals for use as a brood stock.

Action 5.2 In the event of loss of water to a system (due to unavoidable circumstances), seek to translocate a portion of the at-risk population to a new suitable site identified by fish ecologists.

The recent drought has highlighted that despite best efforts of natural resource managers, maintenance of a population at a site may not always be possible (Ellis *et al.* 2013). Where such a situation occurs in the future, an appropriate translocation site (as determined by fish ecologists) should be sourced, and translocation of a portion of the at-risk population undertaken. Ideally >500 fish would be collected from at risk sites to ensure sufficient genetic diversity of founding individuals.

Action 5.3 In the event of a Management Unit being represented by a single population in the wild, establish a captive population and/or surrogate refuge site to mitigate extinction risk of the Genetic Management Unit.

The maintenance of genetics is critical to the recovery of Murray hardyhead. In the event of a Management Unit being represented by a single population, a captive maintenance program will be undertaken to minimise the risk of extinction and total loss of the Genetic Management Unit.

Objective 6. Conduct surveys to determine if unknown populations exist in the wild.

Action 6.1 Conduct surveys to identify potentially unknown populations

Although considerable fish sampling programs have, or are occurring in the Murray-Darling Basin, there has been few programs which have surveyed wetlands which are potentially used by Murray hardyhead. This action would involve fish ecologists identifying sites potentially used by Murray hardyhead, and subsequent surveys of the sites to determine presence/absence of the species at sites.

Objective 7. Increase community awareness of Murray hardyhead conservation.

Action 7.1 Publicise results of Murray hardyhead investigations.

Publishing research and conservation efforts is an important aspect of the recovery program. This information will be made available not only to the scientific community, but also, to allow adaptive management, in more accessible forms such as technical reports for land/water managers. Relevant information could also be published in popular literature such as magazines and media articles to inform the community and to build support for management and conservation efforts.

Action 7.2 Promote awareness of, and identify opportunities for, community involvement in the conservation of Murray hardyhead.

Community support for the conservation of Murray hardyhead, particularly from managers and landowners adjacent to wetlands containing the species, is important to ensure the success of conservation and recovery efforts. Opportunities for promoting conservation and recovery of Murray hardyhead include educational activities such as information brochures, interpretive signs, school visits and field days. In addition, opportunities for direct community involvement in maintaining the species should be investigated, including establishing refuge sites on public and private land (e.g. schools, TAFES universities, farm dams etc.), as well as encouraging the public to assist in field surveys and community events such as fish releases (Hammer *et al.* 2012). Furthermore, as appropriately timed environmental watering of wetlands containing Murray hardyhead has resulted in large increases of waterbirds at sites, several of which have been identified as migratory and/or threatened (Dedini pers. comm. 2016), it should also be recognised and promoted that multi-species are benefiting from the watering of wetlands and sound management of populations.

Affected interests

Although management is primarily the responsibility of State Government departments and agencies in New South Wales (DPI NSW), Victoria (DELWP) and South Australia (DEWNR), a range of agencies and organisations are involved either directly or indirectly in the recovery of Murray hardyhead (Table 4).

Table 4 Agencies and organisations involved in recovery of Murray hardyhead

Organisation	Type
National/Regional	
Department of the Environment and Energy (including the Commonwealth Environmental Water Holder)	Federal Government
Department of Agriculture and Water Resources	Federal Government
Murray Darling Basin Authority	Statutory Authority
Murray Darling Freshwater Research Centre	Research Institute
Native Fish Australia	Community Group
New South Wales	
Department of Primary Industries – NSW Fisheries	State Government Authority
Murray, Western and Riverina Local Land Services	Regional Authority
NSW Office of Water	State Government Authority
Victoria	
Department of Environment, Land, Water and Planning	State Government Authority
DELWP - Arthur Rylah Institute	State Government Research Institute
North Central Catchment Management Authority	Regional Authority
Mallee Catchment Management Authority	Regional Authority
Goulburn-Murray Water	Regional Authority
Parks Victoria	State Government Authority
Victorian Environmental Water Holder	State Government Authority
South Australia	
Department of Environment, Water and Natural Resources	State Government Authority
South Australian Research and Development Institute	State Government Research Institute
University of Adelaide	Federal Government Research Institute
Hindmarsh Island Landcare Group	Community Group
Riverglades Landcare Group	Community Group
Clayton Environmental Landcare Group	Community Group
Goolwa to Wellington Local Action Plan Group	Community Group
Alexandrina Council	Local Government Authority
Rural City of Murray Bridge	Local Government Authority

Role and interests of Indigenous people

Consultation has occurred with the Ngarrindjeri people of the lower Murray and Coorong, including the Raukkan Community Association, as part of a PhD program (Backhouse *et al.* 2008). Members of the Ngarrindjeri Regional Authority (NRA) were involved in the release of captive bred Murray hardyhead into preferred habitats in the Lower Lakes during 2012 (Bice *et al.* 2012) and in monitoring populations from 2011–2013 (Wedderburn and Barnes 2012). The Murray Lower Darling Rivers Indigenous Nations (MLDRIN), were approached in December 2012 to provide comment on the Plan if so desired. No comments were received. Opportunities to involve Indigenous communities in the implementation of the Plan will be explored once it is finalised.

Benefits to other species/ecological communities

Additional biodiversity benefits of achieving the objectives of the Plan will be the protection and management of wetland habitats. Off target benefits to wildlife have been detected at sites managed for Murray hardyhead, with sites often used by large numbers of native birds (some of which are threatened and/or migratory) for resting, feeding and breeding (Stoessel pers. obs.) and similarly for other endangered fish species (e.g. Yarra pygmy perch, Wedderburn *et al.* 2012b). The Plan will also provide an important public education role, recognising threatened fish act as ‘flagship’ species for highlighting broader nature conservation issues in aquatic habitats, such as habitat degradation, barriers to migration and invasive species.

Social and Economic Impacts

The conservation program for Murray hardyhead has received support from community environment groups (Backhouse *et al.* 2008). Increased communication, education and participation of local communities is integral to increasing the general public’s understanding of the Endangered status of Murray hardyhead, and management practices required to assist recovery of the species.

The Murray River is the focus of considerable community attention, especially through the Murray-Darling Basin Authority’s “The Living Murray” and the “Basin Plan” program, which aim to restore significant environmental flows to the Murray River floodplains. Increases in environmental flows and a shift to a more natural flooding regime will benefit species like Murray hardyhead which are adapted to natural floodplain conditions. Wetland restoration is also seen in the community as a major benefit to the environment, and rehabilitation of riparian zones is being undertaken in many regions by management agencies and local communities (Backhouse *et al.* 2008).

The most pressing and immediate need in the recovery of Murray hardyhead however, is to secure the small number of dwindling remnant populations. To do this, direct investment will be required to ensure that environmental water can be secured long term, monitoring of populations and threats can occur, and sites (and watering regimes) can be managed using the best available scientific knowledge. Once this occurs, further investment will be required to ensure species recovery.

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Appendix 1

Table 5 Estimated costs of recovery objectives.

Objective	Cost estimate (\$)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
1. Protect maintain and monitor presently known populations						
1.1 Supply environmental water to remnant “primary” populations	135,000	139,050	143,222	147,518	151,944	716,733
1.2 Manage environmental water delivery	42,000	43,260	44,558	45,895	47,271	222,984
2. Investigate and manage threats to populations and habitats.						
2.1 Develop and implement monitoring programs	212,000	218,360	224,911	231,658	238,608	1,125,537
2.2 Identify current/potential threats for all extant populations	80,000	0	0	0	0	70,000
2.3 Assess effectiveness of management interventions	42,000	43,260	44,558	45,895	47,271	222,984
3 Increase area of occupancy						
3.1 Identify sites suitable for translocation	90,000	0	0	0	0	90,000
3.2 Prepare and implement translocation plan	30,000	0	0	0	0	30,000
3.3 Provide environmental water for a minimum of three new translocation sites (one per Genetic Management Unit)	85,000	87,550	90,177	92,882	95,668	451,277
3.4 Maintain and monitor translocated populations	32,000	32,960	33,949	34,967	36,016	169,892
3.5 Identify and maintain temporary surrogate refuge sites	80,000	42,000	43,260	44,558	45,895	255,712
4. Investigate important life history traits						
4.1 Investigate salinity tolerance at critical life history stages	50,000	0	0	0	0	50,000
4.2 Investigate implied effects of eastern gambusia	0	50,000	0	0	0	50,000
4.3 Investigate implied negative interactions of redfin on Murray hardyhead.	50,000	0	0	0	0	50,000

Table 5...continued

Objective	Cost estimate (\$)					
	Year 1	Year 2	Year 3	Year 4	Year 5	Total
5. Establish emergency contingency						
5.1 Develop captive breeding techniques for temporary risk mediation	60,000	0	0	0	0	50,000
5.2 Translocate at risk wild population to a new suitable site*	22,000	22,660	23,340	24,040	24,761	116,801
5.3 Establish a captive population to mitigate extinction of genetic unit*	32,000	32,960	33,949	34,967	36,016	169,892
Objective 6. Conduct surveys to determine if unknown populations exist in the wild.						
Conduct surveys to identify potentially unknown populations	180,000	0	0	0	0	180,000
6. Increase community awareness of Murray hardyhead conservation						
6.1 Publicise results of Murray hardyhead investigations	11,000	11,330	11,670	12,020	12,381	58,400
6.2 Promote community awareness	11,000	11,330	11,670	12,020	12,381	58,400
Total	1,244,000	734,720	705,262	726,419	748,212	4,158,613

N.B. Ongoing cost estimates have been adjusted yearly for an inflation rate of 3%. *Only required in emergency circumstances.