A translocation strategy to ensure the long-term future of threatened small-bodied freshwater fishes in the South Australian section of the Murray-Darling Basin

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A report to Natural Resources, SA Murray-Darling Basin & the Riverine Recovery Project

Natural Resources
SA Murray-Darling Basin

Government of South Australia
Department for Environment and Water

Australian Government




April 2019

This report may be cited as:

Whiterod, N. (2019). A translocation strategy to ensure the long-term future of threatened small-bodied freshwater fishes in the South Australian section of the Murray-Darling Basin. A report to Natural Resources, SA Murray-Darling Basin and the Riverine Recovery Project. Aquasave–Nature Glenelg Trust, Goolwa Beach.

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ACKNOWLEDGEMENTS

This project was funded by the Riverine Recovery Project, a $98 million joint Australian and South Australian Government initiative to improve the health of the River Murray and its wetlands and floodplains from the South Australian border to Wellington. Thanks to Darren Willis and Kate Mason (Natural Resources, SA Murray-Darling Basin) for project management and logistical support and Andrew Rettig, Maria Marklund, Sally Maxwell, Tumi Bjornsson, and Glenn Shimmin (DEW) for input from a Riverine Recovery Project perspective. Thanks to Scotte Wedderburn (University of Adelaide), Kate Mason (Natural Resources, SA Murray-Darling Basin), Sylvia Zukowski and Ruan Gannon (Aquasave–NGT) who provided specific content. Members of the Big Little Four working group – (Chris Bice (SARDI); Todd Goodman (DEW); Luciano Beheregaray (Flinders University); Chris Brauer (Flinders University); Jo Clarke – and several additional colleagues, including Michael Hammer (MAGNT), Iain Ellis (NSW Department of Primary Industries) and Brenton Zampatti (SARDI) have contributed thoughts and insight that has helped formulate the present translocation strategy. The report was reviewed by Rose Thompson (Nature Glenelg Trust) and Brenton Zampatti (SARDI) and David Cheshire, Maria Marklund and Andrew Rettig (SA DEW). Lastly, it is acknowledged that without the efforts of a wide range of people, from managers to surrogate refuge and wild site custodians, who have been involved previously or continue to be involved in the conservation of the target species, there would not be the potential for the present translocation strategy to be implemented in the future.

EXECUTIVE SUMMARY

Small-bodied freshwater fishes are under threat across the Murray-Darling Basin. These species have experienced historical declines, which were compounded most recently by the prolonged and extreme Millennium Drought. The SA MDB region – representing a hotspot for small fishes – was profoundly impacted by the drought, with the significant deterioration and loss of aquatic habitat. Four threatened small-bodied freshwater fishes – Murray Hardyhead, Southern Pygmy Perch, Southern Purple-spotted Gudgeon and Yarra Pygmy Perch (the four target species of the present report) – were significantly impacted, with the latter two species believed to have become regionally extinct. The foresight of certain researchers and managers to rescue fish from deteriorating habitats at this time, has allowed translocations aimed at returning fish (and species) to former habitats. These translocations have been warranted given the severity of the impact of the Millennium Drought on already threatened species and limited post-drought recovery. In reality, translocations, along with other conservation actions such as improved water management, will be necessary to reestablish resilient, connected populations to help secure the long-term survival of four target species in the SA MDB region.

The present report represents an important step forward in that it articulates a translocation strategy that seeks to be realistic; in acknowledging the severity of the problem and greater understanding of scope of efforts required. The strategy specifically documents the (a) present status of wild as well as captive and surrogate populations of each target species, (b) overarching strategy outlining the necessary scope and extent, (c) approach to implement the strategy; and (d) preliminary application of the strategy to potential translocation sites. Central to strategy will be the requirement for expanded fish production to fulfil the greater numbers of fish required to be released over a longer duration, at each translocation site (i.e. more fish, more often). In time, a network of wild subpopulation (known and reestablished) are needed to reduce the risk of regional extinction of the four targeted species. Appropriate genetic management and monitoring and evaluation is critical, as will be consideration of drought and future climates. Equally important will be the identification of high priority translocation sites, which maintain abiotic and biotic conditions, as well as appropriate management. The challenge now is to commit to the implementation of the translocation strategy.

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Section 1 BACKGROUND

1.1 Introduction

Globally, many species have experienced population declines in range and abundance, and are at risk of extinction (Dudgeon 2014; Pimm *et al.* 2014). Freshwater fishes appear disproportionately at risk, with almost one-third of assessed species deemed extinct or at risk of extinction (Darwall and Freyhof 2016). Many threats have been imposed on freshwater fishes including habitat loss and degradation, invasive species, over-exploitation and water abstraction and flow alteration (Dudgeon *et al.* 2006; Arthington *et al.* 2016). Small-bodied fishes – those obtaining a maximum total length (TL) of less than 150 mm – typically possess traits, such as limited dispersal, short longevity and small ranges, that make them inherently at risk, with the risk exacerbating when species decline to small, fragmented populations (Kopf *et al.* 2017; Liu *et al.* 2017; Olden *et al.* 2007). Additionally, small fishes are often overlooked or neglected in management as they are often of little economic value (Closs *et al.* 2016; Olden *et al.* 2007).

The expansive Murray-Darling Basin (MDB) is now home to 49 species of native freshwater fishes (Lintermans 2007; Lintermans, unpublished data). The diverse habitats of the South Australian section of the MDB (i.e. SA MDB region), including the Murray River and associated floodplain wetlands, the expansive lakes Alexandrina and Albert (Lower Lakes) and tributary streams of the eastern Mount Lofty Ranges (EMLR), support 36 of the Basin's freshwater fish species (Figure 1-1) (Hammer 2004; Wedderburn and Hammer 2003; Wedderburn *et al.* 2017). Importantly, almost 80% of the Basin's small-bodied freshwater fish species are found in the SA MDB region. Yet, freshwater fishes of the MDB (and SA MDB region) have been severely impacted, with native fish populations estimated to be at only 10% of pre-European settlement levels and almost three-quarters of fish species recognised as either rare or threatened on State, Territory or National listings (Lintermans 2007; MDBC 2004). Some of the most threatened are small-bodied freshwater fishes and the SA MDB region supports significant MDB populations of these species, so regional actions are critically important (Hammer *et al.* 2009b).

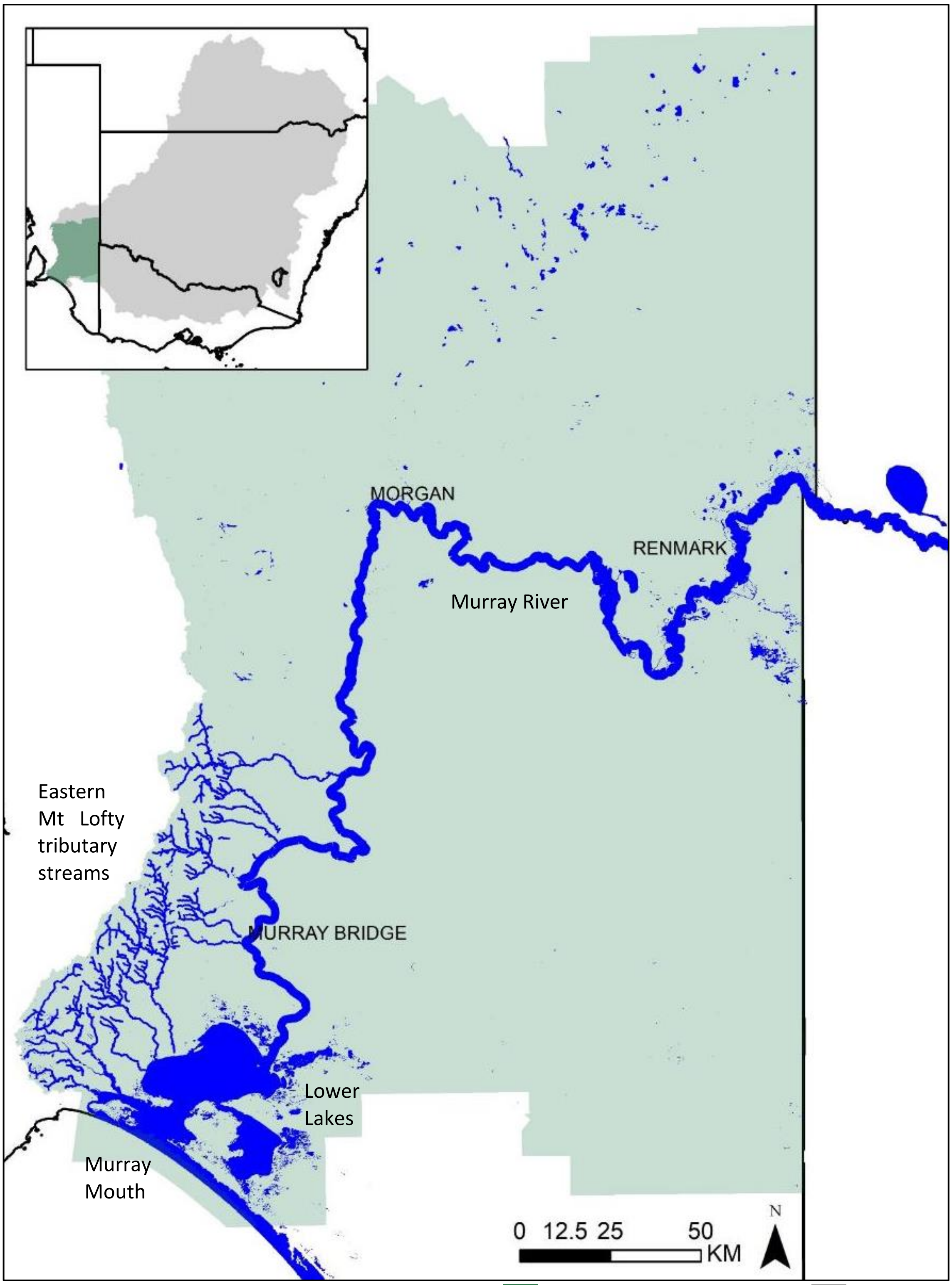


Figure 1-1. Waterways (—) of the South Australian region ( ) of the Murray-Darling Basin ( ).

1.2 Small freshwater fishes under threat

The small-bodied freshwater fishes Murray Hardyhead (*Craterocephalus fluviatilis*), Southern Purple-spotted Gudgeon (*Mogurnda adspersa*), Southern Pygmy Perch (*Nannoperca* *australis*) and Yarra Pygmy Perch (*Nannoperca obscura*) are under threat (hereby referred to as the four target species). Three of these, Murray Hardyhead, Southern Purple-spotted Gudgeon and Yarra Pygmy Perch, are classified as *Critically Endangered* at the state level (Southern Pygmy Perch is classified as *Endangered*), while Murray Hardyhead and Yarra Pygmy Perch are also threatened nationally (EPBC Act) and globally (IUCN Red List of Threatened Species) (Table 1-1) (Hammer *et al.* 2009b).

Table 1-1. Summary of targeted threatened small-bodied freshwater fish species in the SA Murray-Darling Basin region. Conservation status is coded as Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Rare (R); and Protected (P) at national (Environment Protection and Biodiversity Conservation Act 1999), state (Fisheries Management Act 2007) and SA Action Plan 2009 (Hammer et al. 2009b).

Species	Conservation status				SA MDB significance
	International (IUCN)	**National** (EPBC Act)	**State Fisheries**	**Action Plan 09**	
Murray Hardyhead	EN	EN	-	CR	Few fragmented populations remain across two genetically distinct populations (i.e. Lower Murray and mid-Murray)
Southern Purple-spotted Gudgeon	-	-	P	CR	Only known southern MDB population present in the Lower Murray
Southern Pygmy Perch	-	-	P	EN	SA MDB fish are genetically distinct populations observed across Lake Alexandrina and separate catchments of the EMLR
Yarra Pygmy Perch	VU	VU	P	CR	The genetically distinct MDB population is only known from Lake Alexandrina (and terminal wetlands of EMLR)

Each of the four target species is a short-lived (<5 years) and dispersal limited wetland ecological specialists. These species were historically more abundant and widespread (Hammer *et al.* 2009b; MDBC 2004; Wedderburn *et al.* 2017), as extensive and diverse habitats would have prevailed under natural flow regimes across the SA MDB region (Mallen-Cooper and Zampatti 2018; Robinson *et al.* 2015). With river regulation and water abstraction across the MDB, altered flows and less water have diminished the extent and quality of habitat available to freshwater fishes, including wetland specialists. Specifically in the SA MDB region, floodplain wetlands are now either permanently inundated or infrequently flooded; whereas Mount Lofty tributary streams experience less flow resulting the disconnection and deterioration of habitats; and less productive fringing habitat now occurs with stable water levels of the Lower Lakes (VanLaarhoven and van der Wielen 2009). Other threats such as alien species and habitat modification have also impacted freshwater fishes across the region. Combined, these threats act to simplify the regional fish assemblage by favouring generalist and alien species, whilst ecological specialists such as the four target species have declined to small and fragmented populations.

1.3 Enter the Millennium Drought

Droughts are a recurring feature that shape freshwater ecosystems and species (Lake 2011; Matthews and Marsh-Matthews 2003). Indeed, freshwater fishes of the MDB have evolved to cope with climatic and hydrologic variability and are anticipated to possess resistance (*ability to withstand*) and resilience (*ability to recolonise and recover*) traits that make them well-adapted to cope with drought (Bunn and Arthington 2002; Crook *et al.* 2010). Yet, the consequence of prolonged and extreme drought is anticipated to be severe, particularly for species that have experienced declines in range and abundance and persist as small and fragmented populations. Small-bodied fishes, such as the four target species, possess biological traits that make them particularly vulnerable to drought impacts (Chessman 2013; Crook *et al.* 2010).

The Millennium Drought was an extreme drought that severely impacted southern Australia, including the MDB during the period 2001–2009 (van Dijk *et al.* 2013). A sustained period of below average rainfall during the Millennium Drought, undoubtedly exacerbated by water abstraction and flow alteration (Mallen-Cooper and Zampatti 2018; van Dijk *et al.* 2013), led to significantly diminished river flows and critical water shortages across the SA MDB region. Notably, dramatic water level recession (up to 2m) in the Lower Lakes (Alexandrina and Albert) of the lower River Murray was accompanied by significant reductions in submerged aquatic vegetation cover, disconnection of fringing vegetation and elevated salinity (Kingsford *et al.* 2011; Mosley *et al.* 2012). Similarly, in the nearby EMLR tributary streams, diminished stream flow resulted in reduced habitat availability and pool permanency. The reduced water availability and habitat, substantially impacted freshwater fishes across this period (Hammer *et al.* 2013; Wedderburn *et al.* 2012b; Whiterod *et al.* 2015; Zampatti *et al.* 2010). Notably, the four target small fishes experienced a contraction in known range and reduction in abundance, which place them at extreme risk of extinction, with Southern Purple-spotted Gudgeon and Yarra Pygmy Perch believed to have become extinct regionally (Hammer *et al.*

2013; Hammer *et al.* 2015; Wedderburn *et al.* 2014). The status of Yarra Pygmy Perch suggests it may be the first freshwater fish that have become extinct from the MDB (Wedderburn *et al.* 2019; Whiterod and Wedderburn 2017).

1.4 Conservation of freshwater fishes in SA MDB region

The conservation of freshwater fishes is guided by several legislative acts. In South Australia, protection is afforded by the South Australian *Fisheries Management Act 2007* rather than the *National Parks and Wildlife Act 1972*, which covers rare and endangered terrestrial plants and animals. Additionally, the Action Plan for South Australian Freshwater Fishes 2009 (Hammer *et al.* 2009b) provided conservation assessment and guidance to managed freshwater fishes of the region. Freshwater fish are also considered in the MDB Plan and associated basin-wide environmental watering strategy (MDBA 2012) and both Murray Hardyhead and Yarra Pygmy Perch have national recovery plans (DELWP 2017; Saddlier and Hammer 2010). The relevance of each policy document is detailed below.

1.4.1 South Australian Fisheries Management Act 2007

The South Australian Fisheries Management Act 2007 prohibits the *'take, or injury, damage or otherwise harm*' as well as to *'interfere with, harass or molest'* an aquatic resource of a protected species. Presently, Southern Purple-spotted Gudgeon and both pygmy perch species, but not Murray Hardyhead, are classified as protected under the Act. Yet, the Act does not articulate a framework for conservation of protected species.

1.4.2 SA MDB Regional NRM Plan

The SA MDB Regional NRM Plan provides broad guidance for the management of South Australian natural environments (SA MDB NRM Board 2015). The vision of the plan is '*a healthy and ecologically productive environment that sustains biodiversity and is valued by the community*'. A key objective is that no '*native species and ecological communities at lower or no greater risk of extinction by 2030'.* In the associated Regional Action Plan a range of actions are recommended, such as habitat enhancement, to ensure that this objective is met (SA MDB NRM Board 2016). Specifically, the Regional Action Plan identifies the implementation recovery plans for priority threatened species as a high priority.

1.4.3 Action Plan for South Australian Freshwater Fishes 2009

All four target species are considered in the Action Plan for South Australian Freshwater Fishes (Hammer *et al.* 2009b). Specifically, the Action Plan provides state-level conservation assessment, indicating heightened threat categorisation for each species (i.e. *Critically Endangered*: Murray Hardyhead, Southern Purple-spotted Gudgeon and Yarra Pygmy Perch; *Endangered*: Southern Pygmy Perch), as well as comprehensively detailing issues and actions to protect and restore populations of each target species. In the decade since the Action Plan was developed, some actions have been initiated (e.g. '*monitor distribution and recruitment at core populations*' for Murray Hardyhead) but others remain unresolved (e.g. '*comprehensive targeted surveys*' for Southern Purple-spotted Gudgeon).

1.4.4 MDB Basin Plan

Broadly, the Basin Plan establishes high-level targets relevant to the target species, including protecting and restoring water-dependent ecosystems and associated ecosystem functions and ensuring resilience to climate change and other risks and threats (MDBA 2012). Thus, the objectives of the Basin Plan are to improve habitat for freshwater fish. The associated Basin-wide environmental watering strategy articulates the expected outcomes as (by 2024):

- No loss of native species currently present within the Basin,
- Improved length structure of key species through regular recruitment,
- Increased movement of key species,
- Expanded distribution of key species and populations.

For short-lived species such as the four target species, these outcomes are linked to distribution and abundance recorded pre-2007 (i.e. prior to major loss caused by Millennium Drought). The strategy further defines targets for increasing the distribution of key native fish; however, there has not been specific actions directed towards these outcomes.

1.4.5 Recovery planning

Natural recovery plans have been developed for Murray Hardyhead and Yarra Pygmy Perch (DELWP 2017; Saddlier and Hammer 2010), which have an overarching objective of improving the conservation status of each species, with the ultimate long-term goal being the removal of species from the threatened species schedule (DELWP 2017). The original recovery plan for

Murray Hardyhead, released in 2010 has been revised (presently in draft form) to detail seven recovery objectives, including '*protect, maintain and monitoring presently known populations*', '*increase area of occupancy*' and '*establish emergency contingency*'. The Yarra Pygmy Perch recovery plan has similar scope across a greater number of recovery objectives. For both plans, each recovery objective has a set of recommended actions necessary to fulfil the objective (Murray Hardyhead: 19 actions; Yarra Pygmy perch: 27 actions). Although recovery plans are rarely evaluated, Saddlier *et al*. (2013) provided assessment of the Yarra Pygmy Perch recovery plan in 2012, indicating that only one action has been successfully completed (i.e. develop targeted survey techniques) and whilst, all but one has commenced, almost half of outstanding actions are less than 60% completed. The revision of the Murray Hardyhead recovery plan did not provide this evaluation.

1.5 The role of translocations

It is acknowledged that a range of conservation actions are required in the attempt to recover the four target species. Among these actions are improved water management (flow regime and wetland inundation), habitat restoration and alien species control. In addition to these conservation actions, translocations are required given the (1) the severity of the impact of the Millennium Drought on already threatened species, and (2) limited post-drought recovery and fragmented present distribution. Put simply, without translocations, particularly for Yarra Pygmy Perch and Southern Purple-spotted Gudgeon, there will not be any capacity to reestablish resilient, connected populations.

Translocations are becoming increasingly proposed as tools to aid threatened species persistence and recovery in the face of the combined pressures of habitat degradation, changes in water availability and climate change (Armstrong *et al.* 2015; Corlett 2016; IUCN/SSC 2013). Specifically, conservation translocations are defined as the '*the intentional movement and release of living organisms where the primary objective is a conservation benefit*' with differentiation as either population restoration or conservation introduction (IUCN/SSC 2013). Population restoration involves the intentional release of individuals within the natural range to either enhance existing populations (*reinforcement*) or reestablish populations from where they have disappeared (*reintroduction*). Conservation introduction focuses on releasing a species outside its natural range to avoid extinction of populations (*assisted colonisation*) or to perform a specific ecological function (*ecological replacement*).

To date, conservation translocations have overwhelmingly focused on terrestrial species (namely mammals and birds) (Bajomi *et al.* 2010; Fischer and Lindenmayer 2000; Seddon *et al.* 2014). In South Australia, for instance, considerable effort has centred on Arid Recovery, a multi-organisation ecosystem restoration program, where four locally extinct threatened mammals have been successfully reintroduced into a feral-proof fenced reserve near Roxby Downs (Moseby *et al.* 2018). When employed in freshwater, translocations have typically been implemented for large, recreationally valuable species (Bajomi *et al.* 2010; Fischer and Lindenmayer 2000; Seddon *et al.* 2014). Equally, species under threat with greatest extinction risk are not always prioritised, but rather popular species are often the focus of translocations regardless of conservation status (Díaz *et al.* 2018). Thus, threatened small freshwater fishes are particularly under-represented although, encouragingly, there has been some increased focus more recently (Lintermans *et al.* 2015). A prominent exception is the translocation of Rio Grande Silvery Minnow (*Hybognathus amarus*), where more than 2,600,000 fish, some of which have been produced in a purpose-built conservation refugium (Hutson *et al.* 2012; Hutson *et al.* 2018) have been reintroduced to former habitats of the Rio Grande, a river in south-western United States and northern Mexico (Edwards 2017). Although there has been some short-term recovery as a result, ultimately prevailing habitat (namely water availability) have limited regional recovery the importance of incorporating species-habitat associations in relocation programs in order to conserve the ecosystem functions upon which the reintroduced species depend (Edwards 2017).

The translocation of threatened small freshwater fishes must consider several factors that may influence the likelihood of success. Firstly, in contrast to terrestrial ecosystems, freshwater habitats are linear and highly dynamic in terms of habitat availability and connectivity (Lintermans *et al.* 2015). Secondly, these ecosystems are often impacted by threats, such as river regulation and alien species that cannot be effectively controlled. Thirdly, traits linked to vulnerability and extinction, such as small body size, small home range, limited dispersal and high degree of ecological specialisation, will influence the ability of small fishes to persist and reestablish (Kopf *et al.* 2017; Olden *et al.* 2007). Lastly, persistence as fragmented populations and reduced capacity for natural recolonisation emphasise the importance of translocations to reestablish locally-extinct populations. These considerations must be taken into account during planning and implementation of translocations that focus on threatened small freshwater fishes.

Many translocation projects fail as they do not adequately account for the complexity and scope required to establish populations (Armstrong and Seddon 2008; Fischer and Lindenmayer 2000; Pérez *et al.* 2012). With this recognition, guidelines have been established to inform translocations, which recommend setting of translocation objectives, understanding expectations of the scope required (i.e. numbers, duration), and articulating robust strategies for implementation and evaluation (Batson *et al.* 2015; IUCN/SSC 2013; Pérez *et al.* 2012). As part of implementation, it is necessary to consider the status of source populations, receiving habitats (habitat quality, resource availability and competitors/predators), genetic status (Attard *et al.* 2016a; Weeks *et al.* 2011) as well as logistics (timing, holding and transfer) and biosecurity (IUCN 2013). The success of translocation must be assessed through adequate monitoring against defined objectives.

1.5.1 Previous translocations in SA MDB region

Since the Millennium Drought, conservation translocations have been a critical aspect of the management of the four target species (see Hammer *et al.* 2013). Initially, to establish captive maintenance and breeding, as well as surrogate populations, small numbers of each species were removed from known locations. This method is a form of *assisted colonisation* with individuals moved to isolated waterbodies mostly outside of their natural range to provide a safeguard for the species (see Section 2). As conditions improved following the return of flows and water availability over 2010–11, reintroductions and subsequent reinforcement was undertaken (Table 1-2).

During the Critical Fish Habitat (CFH) project, 15,840 fish from the four target species were released at ten locations (Bice *et al.* 2012; Bice *et al.* 2013; Bice *et al.* 2014). The CFH project ceased in mid-2014 (Bice *et al.* 2014) with limited conservation actions continuing since that time. Over 2014–2019, these actions focused on maintaining and securing captive breeding facilities and surrogate refuges, and a further 22,293 fish were released.

Table 1-2. Summary of total number of fish released and number of locations over two post-drought periods for the four target small-bodied freshwater fishes in the SA MDB region.

Species	Time period		Locations
	2011–2014	2014–2019	
Murray Hardyhead	7520	16,350	7 – Hindmarsh and Mundoo islands; Rocky Gully wetland; Lake Albert
Southern Pygmy Perch	1350	0	3 – Hindmarsh and Mundoo islands; Turvey's Drain
Southern Purple-spotted Gudgeon	1120	5043	2 – lower Finnnis River; [redacted] Swamp
Yarra Pygmy Perch	5850	900	6 – lower Finniss River; Hindmarsh Island, incl. Shadows Lagoon
TOTAL NUMBER	15,840	22,2938	18 locations

Post-release monitoring demonstrated short- to medium-term establishment (i.e. survival, evidence of wild recruitment) for all species; however, self-sustaining wild populations requiring minimal management intervention, have yet to be achieved. It is acknowledged that the scale of releases were insufficient to combat post-release mortality as to allow for persistence and reestablish of populations (Bice *et al.* 2014). Equally, poor habitat condition and the high abundance of invasive species (e.g. Common Carp (*Cyprinus carpio*)), which can contribute to habitat and water quality deterioration and Redfin Perch (*Perca fluviatilis*) that can directly predate and compete on these species) was thought to have limited reintroduction success (Wedderburn *et al.* 2016; Wedderburn *et al.* 2015).

1.6 Project scope and objectives

The focus of this report is to present a strategy of how translocations can assist to reestablish resilient, connected populations to help secure the long-term survival of each of the four target species in the SA MDB region. The translocation strategy seeks to be realistic; in acknowledging the severity of the problem and greater understanding of scope of efforts required and specifically documents the:

- Present status of wild as well as captive and surrogate populations;
- Provide an overarching strategy outlining the necessary scope and extent of translocations;
- Approach to implement the strategy; and
- Preliminary application of the strategy to potential translocation sites.

We are at a critical point in time; where the severity of the risk facing each of the four target species must be matched with commitment and greater understanding of the magnitude of the undertaking that is required to re-establish healthy populations and, crucially, to alleviate pressures upon target species through critical complementary management actions. Without appreciation of this risk, but also the opportunity, the loss of species will be inevitable.

Take home messages

- Freshwater fishes are threatened; with small-bodied species particularly at risk
- Historical declines were compounded by the prolonged and extreme drought and anthropogenically exacerbated low flows
- Translocations are required to re-establish populations and, in some cases, species
- Critical complimentary management actions to support the small bodied fish translocation strategy are necessary

Section 2 PRESENT STATUS OF TARGET SPECIES

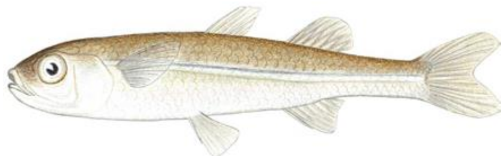
To inform the translocation strategy, the following section summarises the background and post-drought status of wild, captive and surrogate populations for each of the four target species in the SA MDB region.

2.1 Murray Hardyhead (*Craterocephalus fluviatilis*)

2.1.1 Conservation status

International: *Endangered* (IUCN)
National: *Endangered* (EPBC)
South Australia: *Critically Endangered* (Action Plan); *Protected* (Fisheries Management Act)
Rest of range: *Critically Endangered* (NSW); *Threatened* (Vic)

2.1.2 Identification guide



Murray Hardyhead have a small protruding mouth, large silvery eye; moderately rounded snout; two small and short-based dorsal fins; forked tail; and pectoral fins positioned high on the body (Lintermans 2007). The species is often confused with several species across its range, including Smallmouthed Hardyhead (*Atherinosoma microstoma*) and Unspecked Hardyhead (*Craterocephalus stercusmuscarum fulvus*).

Distinction is largely made on the basis of scales; the scales on the dorsal surface of Murray Hardyhead are generally roundish with pigment around the margin, while Unspecked Hardyhead and Smallmouthed Hardyhead scales appear diamond shaped and are arranged in uniform rows, with pigment through the scale as well as around the margin (Figure 2-1) (Ellis and Kavanagh 2014). The transverse series scale count for Murray Hardyhead is 9–12 (including 4–8 above the mid lateral band), whereas the other species have lower transverse scale counts (i.e. 7–8 larger scales). Additional identification features include: Unspecked Hardyhead has a pointed snout and a dusky stripe from the snout, through the eye and operculum, extending to the base of the caudal fin whereas Smallmouthed Hardyhead has a typically silver body colour and bright silver opercula.

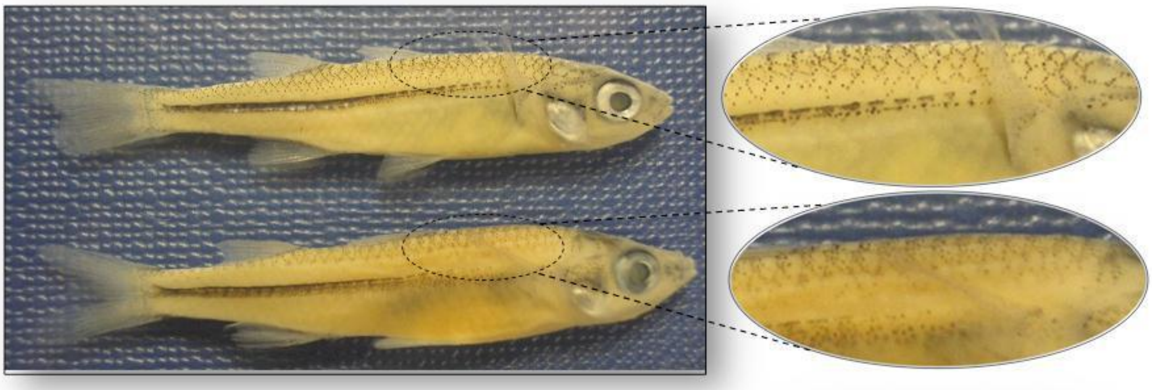


Figure 2-1. Identification of adult Murray Hardyhead (top) and Unspecked Hardyhead (bottom), with reference to scale pattern (Courtesy Iain Ellis, NSW DPI).

2.1.3 Background

The Murray Hardyhead is a small (<80mm) and short-lived species that is endemic to the lowland floodplains of the Murray and Murrumbidgee rivers where is was historically common (Ellis *et al.* 2013; Lintermans 2007). Presently, the species is managed as five subpopulations (i.e. management units, MUs) on the basis of genetic distinction (Adams *et al.* 2011; DELWP 2017; Ellis *et al.* 2013), these being the:

- Lower Murray: lower reaches of the Murray River and Lower Lakes;
- mid-Murray: subpopulations the Riverland and Sunraysia regions;
- Kerang Lakes: Round Lake and Lake Kelly);
- Woorinen north Lake: believed to be extinct; and
- Lake Elizabeth: believed to be extinct

Recent population genetic analyses identifies nine partially distinct subpopulations across two regional populations (i.e. Lower Murray and the mid-Murray) (Thiele 2018). There is a need for further resolution to guide this translocation strategy.

The species has experienced rapid and ongoing decline, attributed to multiple, compounding threats (DELWP 2017; Ellis *et al.* 2013; Hammer *et al.* 2013). Many of these threats relate to the deterioration and loss of the shallow saline, and vegetated (namely submerged

Myriophyllum and *Ruppia*) wetland habitats preferred by Murray Hardyhead (Wedderburn *et al.* 2007). These habitats have been impacted by river regulation for decades, but more recently habitat degradation increased during critical water shortages during the Millennium Drought. In fact, populations at many sites became extinct during the drought, while others experienced dramatic declines in abundance (DELWP 2017). The species has been lost from several sites (e.g. Lake Albert), but some key sites were maintained, including Berri Evaporation Basin and Disher Creek (mid-Murray) and Boggy Creek (Lower Murray), which ensured regional populations persisted through the drought and allowed for some recovery (Bice *et al.* 2014; Ellis *et al.* 2013; Wedderburn *et al.* 2014).

2.1.4 Post-drought status

Captive and surrogate populations

During the Millennium Drought, captive maintenance and breeding as well as surrogate populations were established (Ellis *et al.* 2013; Hammer *et al.* 2013). In 2007, emergency captive maintenance and breeding was prioritised and undertaken at the Murray-Darling Freshwater Research Centre (MDFRC) hatchery, with Murray Hardyhead sourced from nine sites across four of the regional populations (Ellis *et al.* 2013; Hammer *et al.* 2013). Fish were maintained at the hatchery until 2011, with wild and captive bred fish from this facility being used to establish a surrogate population in Munday Dam. Additionally, in 2011, a total of 300 fish from Boggy Creek (Lower Murray population) were used to establish a captive maintenance and breeding facility at Flinders University; these fish were bred over one season and utilised for wild release (to Hindmarsh and Mundoo islands) before closure of the facility. More recently in 2017, captive maintenance and breeding was established for the Lake Elizabeth population, which has enabled small-scale releases into sites across the lake (Dan Stoessel, Arthur Rylah Institute, unpublished data). Captive maintenance and breeding has been critical as an emergency measure to maintain populations, but the numbers of captive-reared Murray Hardyhead have been deemed insufficient to enable the establishment of self-sustaining populations when released to the wild (Ellis *et al.* 2013).

Consequently, attempts have been made to establish surrogate populations to increase production of the species. During 2010 and 2011, a total of 221 Murray Hardyhead from two sites in the Lower Murray population were released into the spring-fed Munday dam in the Mount Lofty Ranges (Figure 2-2).

Figure 2-2. The surrogate refuge (Munday Dam) established for Murray Hardyhead (left) and net full of fish (right).

The surrogate refuge quickly established a robust self-sustaining population (~10 000 fish), which has been maintained over time (Aquasave-NGT, unpublished data; Bice *et al.* 2014). Importantly, these surrogate populations have been used to reinforce and reestablish wild sites (23 120 fish to four sites). Whilst the surrogate refuge has been successful, efforts to establish a second surrogate refuge in [redacted] Wetlands, for the Lower Murray population have been challenged. During 2016, 600 Murray Hardyhead, sourced from Munday Dam, were released at [redacted] Wetlands and abundance increased over time, with more than 1000 fish sampled during February 2017. In 2018, the wetland dried to a level where it was thought the population was extirpated, but sampling in December 2018 revealed Murray Hardyhead were still present. There is now greater capacity to maintain water levels in this wetland and sampling in February 2019 showed that the population in this surrogate refuge had expanded considerably with over 3000 fish sampled.

The history and present status of each captive and surrogate population is detailed in Table 2.1.

Table 2-1. Summary of captive and surrogate populations established for Murray Hardyhead across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
Murray-Darling Freshwater Research Centre (MDFRC) 	MDFRC	Captive maintenance & breeding		2007–11	• Fish held at the MDFRC hatchery were from the following SA populations: Boggy Creek, Rocky Gully, Berri Evaporation Basin and Disher Creek. • Fish from MDFRC were used to establish MD.	0	Closed
Munday Dam 	MD	Surrogate refuge	221	2010–present	• 221 from captive (MDFRC, 55 fish originally from Boggy Creek, May 2011) and wild (Boggy Creek, 80 fish, May 2010; Rocky Gully Wetland, 86 fish, May 2011) populations. • Robust population maintained. • Dam has now changed ownership with supportive new owners.	10 000s	Stable
Flinders University 	FU	Captive maintenance & breeding	300	2011–2014	• Established with fish sourced from AQ. • Has not produced fish for release. • Closed in 2014.	0	Closed

Table 2-1 CONT'D. Summary of captive and surrogate populations established for Murray Hardyhead across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
[redacted] *Wetlands* 	BW	Surrogate refuge	900	2016–present	• 350 fish (100 fish between 25–70mm; 250 fish between 15–25mm) sourced from Munday Dam in Dec 2016. • Reinforced in December 2018 (300 fish). • Population thought lost during considerable wetland drawdown, but recent sampling indicates it persists.	1000s	Stable

Wild populations

The end of the Millennium Drought in 2010–2011 resulted in significant inflows of freshwater into the Murray Darling Basin. The return of water to the system saw water levels rise in most habitats to pre-drought levels and the reappearance of what was deemed as suitable levels of submerged and emergent vegetation throughout the system (Bice *et al.* 2014). Due to the improved water levels and return of habitats, the Critical Fish Habitat (CFH) project was developed, with the aim of reintroducing displaced native fish populations to wild sites. The first releases of Murray Hardyhead were during spring and autumn 2012 when 7000 fish were released into Mundoo Island channel and 520 fish released into Hunters Creek.

Post-release surveys have detected Murray Hardyhead at numerous sites across the lower reaches of the EMLR streams and Lake Alexandrina, with greatest numbers occurring at the Finniss Junction (Bice et al. 2014). Despite this, Murray Hardyhead have not been detected in Lake Albert since the drought period (Wedderburn 2014; Wedderburn et al. 2014). Considering their mobile nature, it is possible for the species to naturally colonize Lake Albert; however, given the relatively small connection between Lakes Alexandrina and Albert and that the nearest known population is 30 km of lake edge away from Lake Albert, it was unclear if the species could naturally recolonize the lake (Wedderburn 2014). Considering this, a total of 14 200 Murray Hardyhead was released to three sites across Lake Albert on four occasions between 2016 and 2019 (Figure 2-3) Continued monitoring, however, indicates that the species remains absent from Lake Albert.

Figure 2-3. One of the Murray Hardyhead reintroduction sites (left) and released fish (right) from Lake Albert.

In the mid-Murray, active management has helped to maintain Disher Creek and Berri Evaporation Basin populations since the drought, which are considered relatively stable even though they are exhibiting cyclic boom and bust fluctuations in abundance. The species was thought to be lost from the Gurra Gurra Wetland Complex, despite reintroductions (135 fish to Causeway Lagoon in 2010: Ellis *et al.* 2013; Suitor 2012), but in February 2019, a self-sustaining subpopulation was detected in Lyrup Lagoon in the northern section of the wetland complex (Whiterod and Gannon 2019). The species also persists in the isolated Noora Evaporation Basin. In November 2018, cross-border collaboration enabled reintroductions of the species back into Little Frenchmans Creek, New South Wales, with post-release monitoring (in March 2019) indicated signs of establishment (i.e. recruitment evident and numbers greater than were released) – representing the first record of the species in NSW for more than 20 years (Ellis *et al.* 2018; NSW DPI and Aquasave-NGT, unpublished data).

Overall summary

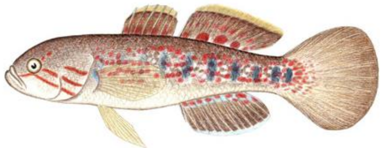
Murray Hardyhead is persisting in the wild with rediscovery and reintroductions improving regional status. In Lake Alexandrina, the species occurs at multiple locations, but has not been detected in Lake Albert since 2008 despite reintroductions. Across the mid-Murray population, the Berri and Disher Creek subpopulations appear secure although these population do exhibit variability in abundance. The rediscovery at Gurra Gurra Wetland Complex is important. The Munday Dam surrogate refuge is stable and new landowners are supportive of the conservation of this species. A recently established surrogate refuge at [redacted] Wetlands is variable but persisting. Future arrangements with the landowner may prevent the pond from drying, therefore showing potential for continuing use of the pond as a Murray Hardyhead surrogate refuge. Continued active management and reintroductions are required to continue regional recovery of the species.

2.2 Southern Purple-spotted Gudgeon (*Mogurnda adspersa*)

2.2.1 Conservation status

International: Not listed
National: Not listed
South Australia: *Critically Endangered* (Action Plan); *Protected* (Fisheries Management Act)
Rest of range: *Endangered* (NSW); *Threatened* (Vic)

2.2.2 Identification guide



Southern Purple-spotted Gudgeon has a rounded head, small mouth, rounded tail and two dorsal fins (Lintermans 2007). The species has several distinguishing markings; a row of darkish blotches present on the sides from the start of the second dorsal fin to the start of the caudal fin, surrounded by numerous red and white spot and, at times, series of iridescent blue blotches toward the tail. The species also has brown to purple facial strips (3–4 in males; two in females), which act as to differentiate it from other freshwater gudgeons, like Flathead Gudgeon (*Philypnodon grandiceps*) that it coexists with.

2.2.3 Background

Southern Purple-spotted Gudgeon (*Mogurnda adspersa*) is a benthic, and sedentary wetland specialist (maximum total length <150 mm; typically 60–120 mm), with a strong preference for dense physical (woody structure and rocks) and aquatic vegetation cover (Hammer *et al.* 2015; Lintermans 2007). Historically, the species was patchily distributed across the MDB, and was once widespread and common in wetland and fringing river habitats in the lower sections of the SA MDB. The species has declined profoundly due to intensive flow regulation and diversions resulting in habitat alteration and loss. In the SA MDB, the species was declared regionally extinct in the early 1990s; following

the last verified record of them in 1973. However, in 2002, the species was recorded from a single wetland, [redacted] Swamp near Murray Bridge, signaling its rediscovery after 30 years (Hammer *et al.* 2015). Just as the species was rediscovered, flows and water availability began to decline associated with the Millennium Drought. As conditions deteriorated, fish were rescued into three captive breeding facilities, with the view of establishing surrogate populations to help safeguard the species (Hammer 2007b). By spring 2009, [redacted] Swamp had completed dried, with presumed local, and regional extinction of the species (Hammer *et al.* 2015).

2.2.4 Post-drought status

Captive and surrogate populations

Fish rescued at the height of the Millennium Drought were used to establish a captive population in a private breeding facility, with a further two populations established at other facilities in 2011 (Figure 2-4). Attempts have also been made to establish two surrogate refuges, [redacted] Wetlands and Greensland Drive, both with mixed results. Only two of the captive breeding facilities have been successful, with regular, but low, numbers of fish produced. The Urrbrae Agricultural College (UC) hatchery was expanded in 2017 to include an outdoor pond, which is showing positive signs of producing more fish in a less intensive manner.

Figure 2-4. Habitat (left) and recaptured fish (right) from the [redacted] Wetlands surrogate refuge established for Southern Purple-spotted Gudgeon.

In terms of surrogate refuges, Greenlands Drive has failed to establish with fish not detected over the past two years, this is attributed to competition and predation with Flathead Gudgeon, which was previously stocked. In contrast, the [redacted] Wetlands have been very successful with regular high numbers caught (approx. 1000s of fish) with evidence of regular spawning and recruitment across. This strong self-sustaining population has also self-dispersed into two additional connected ponds, indicating that the population is expanding.

The history and present status of each captive and surrogate population of Southern Purple-spotted Gudgeon is detailed in Table 2.2.

Table 2-2. Summary of captive and surrogate populations established for Southern Purple-spotted Gudgeon across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
Aquasave Hatchery 	AQ	Captive maintenance & breeding	55	2007	• Wild fish sourced from [redacted] Swamp in 2007; moved to Berri in 2011; regular production.	100s	Stable
Alberton Primary School 	AB	Captive maintenance & breeding	300	2011–present	• Established with fish sourced from Aquasave Hatchery; breeding individuals (e.g. broodstock) replaced in 2016; has not produced fish for release.	10s	Non-functioning
Urrbrae Agricultural College (UC) 	UC	Captive maintenance & breeding	100	2011–present	• Fish sourced from Aquasave Hatchery; breeding individuals (e.g. broodstock) replaced in 2016; regular production; outdoor pond established in 2017.	100s	Stable

Table 2-2 CONT'D. Summary of captive and surrogate populations established for Southern Purple-spotted Gudgeon across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
[redacted] *Wetlands* 	BWP	Surrogate refuge	450	2013–present	• Three ponds established with Aquasave Hatchery and Urrbrae Agricultural College fish. • Robust populations, with evidence of colonisation of two other connected ponds (now present in four ponds).	10 000s	Stable

Wild populations

With the improvement in River Murray flows in 2010–11, the reestablishment of wild populations became a focus. Habitat in [redacted] Swamp, however, was unsuitable, so initial reintroductions occurred to the lower Finniss River site, which historically supported the species (Hammer 2004). Between spring 2011 and 2013, 1120 Southern Purple-spotted Gudgeon were reintroduced to the site (Bice *et al.* 2014). Recaptures (15 recaptures, six of which were observed in spring 2013) indicated short-term survival (6–18 months) but the ongoing status of the species at the sites was uncertain as no fish were detected in autumn 2014 (Bice *et al.* 2014). During the second half of 2014, the lower Finniss River site unexpectedly experienced declining water levels. At the time of monitoring in spring 2014, the site had dried to three disconnected and deteriorating pools with two fish detected in one of the pools. During summer 2014–15, the site dried completely and remained dry during monitoring in autumn 2015 with no fish detected. Whilst the site has maintained water since this time, no fish have been detected indicating that the species has been lost to the site.

Reintroductions to [redacted] Swamp were initiated in autumn 2014 as conditions had improved. With the loss of the lower Finniss River site, all releases over the past three years have occurred at [redacted] Swamp. Reintroductions continued between autumn 2015 and summer 2017–18, with an additional 522 fish reintroduced to the site (total=747 fish) and habitat improvements were made to restore flow path through the broader wetland (e.g. removal of *Typha*) (Kate Mason, Natural Resources, SA MDB, personal observation). In spring 2015, the first Southern Purple-spotted Gudgeon was detected, since the height of the Millennium Drought, further detections occurred in summer 2015–16 and summer 2016–17 (Figure 2-5). Most recently, during the 2017–18 and 2018–19 summers, 4216 fish were reintroduced to [redacted] Swamp, with the subsequent recapture of low numbers of the species (n = 6). The short-term persistence of the species is encouraging, but greater capacity for reintroductions as well as further habitat improvement, such as reintroducing submerged aquatic vegetation, is required. A single Southern Purple-spotted Gudgeon was detected during sampling in February 2019.

Figure 2-2. Southern purple-spotted gudgeon reintroductions in [redacted] Swamp: the first fish detected at the wetland since the Millennium Drought (left); dip netting for fish (right).

2.2.5 Overall summary

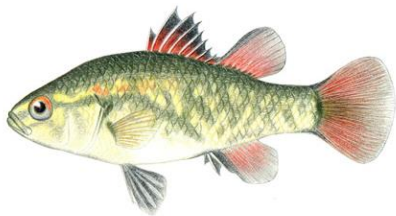
As of early 2019, there remains some encouraging signs for the species. Surrogate populations remain strong, which has allowed for greater numbers of fish to be reintroduced into [redacted] Swamp. This has resulted in the recapture of low numbers of fish in the wild, although the species has not been detected in the most recent monitoring. It is likely that an increase in both the frequency of releases and gross number of individuals released will aid in greater numbers of Southern Purple-spotted Gudgeon persisting in [redacted] Swamp. Habitat improvement with an increase in submerged aquatic vegetation is required to increase survival rate of released fish in [redacted] Swamp.

2.3 Southern Pygmy Perch (*Nannoperca australis*)

2.3.1 Conservation status

International: Not listed
National: Not listed
South Australia: *Critically Endangered* (Action Plan); *Protected* (Fisheries Management Act)
Rest of range: *Endangered* (NSW); *Threatened* (Vic)

2.3.2 Identification guide



Southern Pygmy Perch has a slightly rounded head, small mouth that extends to just in front of eye and a rounded tail (Lintermans 2007). The body colour is cream to gold to greenish-brown. These features, along with a round pupil, distinguish the species from the Yarra Pygmy Perch, with which it is often confused. Additionally, male Southern Pygmy Perch develop bright red fins during spawning, whereas the fins of a breeding male Yarra Pygmy Perch are black.

2.3.3 Background

Southern Pygmy Perch are a small freshwater perch attaining a maximum size of ~100 mm. In the MDB, Southern Pygmy Perch have a fragmented range extending from Yass (NSW) through parts of Victoria and to wetland and tributary streams of the SA MDB region (Lintermans 2007). Historical declines have acted to fragment the species into genetically distinct subpopulations (Cole *et al.* 2016; Hammer 2008a). In the SA MDB region, Southern Pygmy Perch once occurred more broadly across Lower Murray floodplain wetlands, the fringing habitats of the Lower Lakes and tributary streams of the eastern Mount Lofty Ranges (EMLR) (Hammer *et al.* 2009b). The species has now contracted to four genetically distinct subpopulations across the study region (Cole *et al.* 2016; Hammer 2008a):

- Angas River Catchment;
- Finniss River Catchment;

- Lake Alexandrina and surrounds: lower reaches of Tookayerta Creek, Turvey's Drain and Mundoo and Hindmarsh islands; and
- mid- to upper-reaches of Tookayerta Creek Catchment.

Each subpopulation was severely impacted, but did persist, during the Millennium Drought (Hammer *et al.* 2013; Wedderburn *et al.* 2014; Whiterod *et al.* 2015).

2.3.4 Post-drought status

Captive and surrogate populations

During the Millennium Drought, wild fish were collected from the Lake Alexandrina and surrounds subpopulation (Turvey's Drain and Mundoo Island) and held in a private hatchery before being used as brood stock to initiate a captive breeding program at Flinders University (see Attard *et al.* 2016b). The genetic differentiation between these populations from differing catchments has complicated the identification and location of suitable surrogate waterways. In 2014, 60 captive bred fish at Flinders University (i.e. Lake Alexandrina and surrounds subpopulation) were introduced to one of the semi-isolated ponds in the [redacted] Wetlands. Initially the new population thrived; however, Southern Purple-spotted Gudgeon have now colonised this site and recent sampling (February 2018) indicates that the numbers of Southern Pygmy Perch (n=52) are lower than Southern Purple-spotted Gudgeon (n=109) This indicates a vulnerability of the Southern Pygmy Perch population at this site, and the need for a new surrogate location for the remaining fish to be relocated into.

The history and present status of each captive and surrogate population of Southern Pygmy Perch is detailed in Table 2.3.

Table 2-3. Summary of captive and surrogate populations established for Southern Pygmy Perch across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
Aquasave Hatchery 	AQ	Captive maintenance & breeding	55	2007–2011	• A total of 30 wild fish from Turvey's Drain and Mundoo Island were maintained, and an additional 50 fish bred. • These fish were then incorporated into the Flinders University breeding program or released back to the wild.	0	Closed
Flinders University 	AB	Captive maintenance & breeding	300	2011–2014	• Established with breeding individuals (e.g. broodstock) that were offspring obtained from the Aquasave hatchery. Captive fish were then bred and maintained in outdoor ponds. • The facility has not produced fish for release.	0	Closed
[redacted] *Wetlands* 	BWP	Surrogate refuge	40	2014–present	• 60 fish (40–65 mm) were sourced from Flinders University's captive breeding program during October 2014 and 2015 and introduced to one of the semi-isolated ponds, initially a robust population. • Southern Purple-spotted Gudgeon have now colonised but Southern Pygmy Perch persists.	100s	Establishing

Wild populations

As flows returned to the lower MDB in 2010, water levels and native fish habitats fringing the Lower Lakes Region improved, and the Critical Fish Habitat (CFH) project focused on reintroducing fish back into Lake Alexandrina. Reintroductions of Southern Pygmy Perch focused on three sites around Lake Alexandrina (Turvey's Drain, Hindmarsh Island and Mundoo Island). During spring and autumn of 2011 and 2012 approximately 1350 individuals were released across the three sites. Post-release monitoring detected the species at all three sites, but only the Hindmarsh Island site has demonstrated persistence and recruitment in subsequent years. Additional monitoring has periodically detected the species at additional sites around Lake Alexandrina and indicated some recovery of EMLR populations (Wedderburn and Barnes 2012; Wedderburn and Barnes 2013; Wedderburn and Barnes 2014; Whiterod and Hammer 2014).

Wild populations of Southern Pygmy Perch within the EMLR exhibit patchy distribution, but the species remains locally abundant at some sites (in Tookayerta, Finniss and Angas catchments). As of autumn 2018, self-sustaining populations of the species were evident at two sites within Tookayerta Creek and three sites in the Finniss River (Whiterod 2018). The same survey also detected the first Southern Pygmy Perch in Turvey's Drain since 2012. In the Angas River, three individuals were recorded during the autumn 2018 surveys, this in contrast to the 84 individuals found in the 2013 survey. However, 68 adult Southern Pygmy Perch were sampled on the Angas River in one fyke net just a few months later during a community engagement day (S. Zukowski, Aquasave–NGT, unpublished data), indicating they are locally abundant in some areas and persisting in a patchy distribution. A recent survey targeting Pygmy Perch habitats (Yarra and Southern species) detected the species in significant numbers in a few isolated sites on Hindmarsh Island, including large numbers of young of year fish indicating successful reproduction.

2.3.5 Overall summary

The condition of wild populations of Southern Pygmy Perch appears to be highly variable between subpopulations. MDB. For example, populations in the Finniss River and Tookayerta Creek catchments show signs of persistence, whereas the species seems to be patchy in numbers in the Angas River Catchment. The surrogate and captive populations are limited, with previous efforts hampered by the fact that each catchment is a subpopulation, thus requiring separate management. There has been some improvement in the range and extent of the subpopulation in the Lake Alexandrina and surrounds.

2.3 Yarra Pygmy Perch (*Nannoperca obscura*)

2.3.1 Conservation status

International: *Vulnerable* (IUCN)
National: *Vulnerable* (EPBC)
South Australia: *Critically Endangered* (Action Plan); *Protected* (Fisheries Management Act)
Rest of range: *Endangered* (NSW); *Threatened* (Vic)

2.3.2 Identification guide

Yarra Pygmy Perch has a pointed head, small mouth (not reaching below the eye), slightly rounded tail and single deeply notched dorsal fin (Lintermans 2007). The body colour is gold to dusky brown with a pale belly and dark spots in a row along the midline. These features, along with an irregular shaped (imperfect circle) black pupil, distinguish the species from the Southern Pygmy Perch, which it is often confused with. Additionally, the fins of breeding males are black whereas male Southern Pygmy Perch develop bright red fins during spawning.

2.3.3 Background

Yarra Pygmy Perch is a small (~75mm) temperate species with a geographic range extending from Western Victoria through South Eastern South Australia to the SA MDB region, where the only MDB population occurs. Throughout its range, the species occurs in patchily and fragmented habitats. It prefers lower flow habitats within drainage channels and wetlands, preferably with an abundance of submerged aquatic vegetation. The MDB population, restricted to fringing habitats of the Lake Alexandrina, was only formally recognised within the MDB in 2001 and it has subsequently been shown to be genetically distinct from others across the range of the species (Brauer *et al.* 2013; Hammer *et al.* 2010). This population is restricted to fringing habitats of Lake Alexandrina, the lower reaches of the Mount Lofty Ranges tributary streams and waterways of Hindmarsh Island (Hammer 2004; Hammer *et al.* 2002; Wedderburn and Hammer 2003). During the period of critical water shortages associated with the Millennium Drought, there were dramatic declines in the availability and condition of these habitats and the species experienced declines in range and abundance (Hammer 2007a; Hammer 2008b; Wedderburn *et al.* 2012a). The species was last detected in February 2008 (Holmes Creek at Estick Creek mouth: Hammer 2008b), after which time it is considered to have become regionally extinct.

2.3.4 Post-drought status

Captive and surrogate populations

In 2007, a total of 200 wild Yarra Pygmy Perch were rescued from drying habitats at three sites to enable temporary captive maintenance and breeding (Aquasave Hatchery and Cleland Wildlife Park; see Table 2-). At the same time, a small number of wild Yarra Pygmy Perch from the three sites were released into a surrogate refuge (Pembroke School), which was maintained up until 2011 when monitoring ceased. From 2008 to 2010, offspring from the initial captively-bred fish were utilised to establish both additional captive (Flinders University) and surrogate (Crouch Dam, Harper (Oster) Dam and Tulepo Grove Nursery Dam) populations. The Aquasave Hatchery closed in 2010. In 2017, a small number of fish from Cleland Wildlife Park was sourced to establish an additional surrogate population at Urrbrae Agricultural College Hatchery (in outdoor ponds). Recent sampling in the outdoor ponds indicated broad length structure (including juveniles) suggesting an establishing population. Moderately abundant (n=100s) populations have been maintained at Cleland Wildlife Park and Flinders University, although low reproductive output in 2017–2018 in the Flinders University population was believed to be a consequence of genetic deterioration. This has prompted a proposal to undertake genetic rescue where 200 fish sourced from the South East genetic unit were transferred to Flinders University in September 2018 to increase genetic diversity. Additionally, small number of fish are maintained at two captive maintenance and breeding facility (Investigator College and Urrbrae). Genetic analyses is being undertaken on existing surrogate refuges to determine whether genetic rescue is warranted.

There has been variable success with the surrogate refuges. Undoubtedly, the most successful was Crouch Dam, where the population increased rapidly following the initial release of 90 fish. Biannual monitoring during the period 2011–2013 indicated populations in the 1000s to 10 000s with a broad length structure. However, water level dropped dramatically over the

2014–15 summer and the population collapsed – no fish have been recorded since March 2015 (Figure 2-5). The water level now drops each summer with the cause largely unknown, possibly due to alteration of catchment scale water availability or leakage of the dam wall.

Figure 2-5. The surrogate refuge (Crouch Dam) established for Yarra Pygmy Perch before (left) and after dramatic drop of the water level (right).

Small populations of Yarra Pygmy Perch (in their 100s) have been maintained in the Tupelo Grove Nursery and Harper (Oster) dam surrogate refuges, but these surrogate refuges have also experienced declines in fish numbers over recent years. The Tupelo Grove Nursery population suffered a large decline in numbers due to insufficient water quality (specifically low dissolved oxygen). The population of Yarra Pygmy Perch in Harper (Osters) Dam appears to be persisting, although abundance fluctuates over time. In September 2018, 200 fish (150 from Harper (Oster) Dam and 50 from Cleland Wildlife Park) were introduced into a new surrogate refuge (Price Dam). Post-release sampling in autumn 2019, indicated encouraging early signs with more fish sampled then were initially released indicating some recruitment has occurred. Ongoing monitoring and possibly further releases are required to ensure the establishment of this surrogate refuge.

The history and present status of each captive and surrogate population of Yarra Pygmy Perch is detailed in Table 2.4.

Table 2-4. Summary of surrogate populations established for Yarra Pygmy Perch (YPP) across the SA MDB region.

Location	Code	Type of facility	Initial population numbers	Years of operation	Details	Present indicative numbers	Present status
Aquasave Hatchery 	AQ	Captive maintenance & breeding	200	2007	• Wild fish sourced from three locations around Lake Alexandrina in 2007. • Fish transferred to establish three surrogate refuges (Crough Dam, Oster Dam, and Flinders University) then closed.	0	Closed
Pembroke (Blue Lagoon) 	PS	Surrogate refuge	20	2007-unknown	• Wild fish sourced from three locations around Lake Alexandrina in 2007. • Monitoring in 2018 detected no YPP, but alien species Eastern Gambusia were present.	0	Population lost
Crouch Dam 	CD	Surrogate refuge	90	2008–2014	• Established with offspring sourced from Aquasave Hatchery (20 fish) and Cleland Wildlife Park (70 fish). • Strong (1000s) population until refuge dried, summer 2013–14 – reasons unknown.	0	Population lost

Table 2-4 CONT'D. Summary of surrogate populations established for Yarra Pygmy Perch across the SA MDB region.

Location	Code	Type	Initial numbers	Years of operation	Details	Indicative numbers	Status
Harper (Oster) Dam 	OD	Surrogate refuge	70	2008–present	• Established with offspring sourced Aquasave Hatchery. • Stable population.	100s	Stable
Cleland Wildlife Park 	CWP	Captive maintenance & breeding	10s	2008–present	• Little maintenance/monitoring but 100s of fish.	100s	Stable
Flinders University 	FU	Captive maintenance & breeding	77	2010-present	• Established with offspring sourced Aquasave Hatchery. • Maintained in outdoor ponds since completion. • Recent breeding largely unsuccessful but 100s of fish maintained.	100s	Declining
Tupelo Grove Nursery 	TG	Surrogate refuge	300	2011–present	• Established with offspring sourced Aquasave Hatchery. • Reasonable numbers (100s) over time, but population has decreased due to changes in water regime (leading to poor water quality).	10s	Declining

Table 2-4 CONT'D. Summary of surrogate populations established for Yarra Pygmy Perch across the SA MDB region

Location	Code	Type	Initial numbers	Years of operation	Details	Indicative numbers	Status
Price Dam 	PD	Surrogate refuge	200	2018–present	• Fish sourced from two locations (Cleland Wildlife Park: 50 fish; Harper (Oster) Dam: 150 fish) in 2018. • Unsure of status, monitoring required in autumn 2019.	100s-	Establishing

Wild populations

With the return of post-drought flows to the lower Murray region in 2010–2011, the restoration of wild populations of Yarra Pygmy Perch within suitable habitats became a priority for the CFH project. As part of the CFH project, 5850 fish were reintroduced at five former sites and short-term survival (i.e. recapture) and wild recruitment was observed over 2013 to 2014 (Bice *et al.* 2014). Yet, in autumn 2014, only one individual was detected across the region (during targeted monitoring of the reintroduction sites) despite broader monitoring across its former range (Bice *et al.* 2014; Wedderburn 2014; Wedderburn and Barnes 2014). During spring 2015, 900 Yarra Pygmy Perch were reintroduced into three sites on Hindmarsh Island. Extensive post-release surveys detected Yarra Pygmy Perch for up to one month after release, these were the last records of the species in the wild release sites of the Lower Murray, and no Yarra Pygmy Perch have been detected within the lower Murray since December 2015 despite regular monitoring across the region. Most recently, an occupancy study across the lower Murray conducted in November to December 2018 failed to detect the species (Wedderburn *et al.* 2019). The study involved triplicate surveys, to increase probability of detection, at 32 sites where Yarra Pygmy Perch has been recorded historically (Bice *et al.* 2008; Higham *et al.* 2005; Wedderburn and Hammer 2003), at sites where the species was reintroduced in 2011, 2012 and 2015 (Bice *et al.* 2014; Wedderburn *et al.* 2016) and several other sites in the region that have suitable habitat.

2.3.5 Overall summary

Despite extensive monitoring, Yarra Pygmy Perch are suspected to now be extinct from the MDB (Wedderburn *et al.* 2019). The surrogate and captive breeding populations appear to also be in peril with potentially <1000 individuals in total remaining, although the early signs of a new surrogate refuge afford some hope. Critical actions and hard decisions (i.e. exploring genetic rescue) are required to increase production of the species to allow for the capacity to undertake translocations back into the MDB in the future. Without this response the first freshwater fish extinction from the MDB will be confirmed (Wedderburn *et al.* 2019).

Section 3 THE STRATEGY

3.1 Introduction

The strategy presented here (i.e. *a translocation strategy to ensure the long-term future of threatened small-bodied freshwater fishes in the South Australian section of the Murray-Darling Basin*) focuses on the role of translocations to promote the recovery and persistence of the four target species. This strategy is outlined in the following sections and provides a robust and logical framework to guide future translocations of each of the species.

3.2 Defining the objective and targets

The primary objective of translocating fish is to reestablish self-sustaining subpopulations to ensure the long-term persistence of each target species in the SA MDB region. Secondary objectives will be defined in terms of increasing the number and status of individual subpopulations that persist for each target species. In turn, the objective relates to increasing the geographic range (i.e. extent of occurrence and area of occupancy) and improving the trend in condition of the species to link with improving the conservation status of the four target species.

3.2.1 Framework to achieve objective

To achieve the translocation objectives for each of the four target species, a range of steps are required (Figure 3-1). These steps include not only those specifically related to translocation, but also consider the protection and maintenance of presently known subpopulations; identification of additional existing subpopulations; mitigation of threats, site and regional habitat and flow management. In terms of translocations, the step of reestablishing new subpopulations is paramount, which can be achieved through reintroductions and then reinforcement. Reinforcement may also be necessary to maintain known subpopulations. Consideration of site habitat and flow management, broader flow connectivity and the capacity to rapidly respond to emerging threats will assist with persistence of both known and new subpopulations.

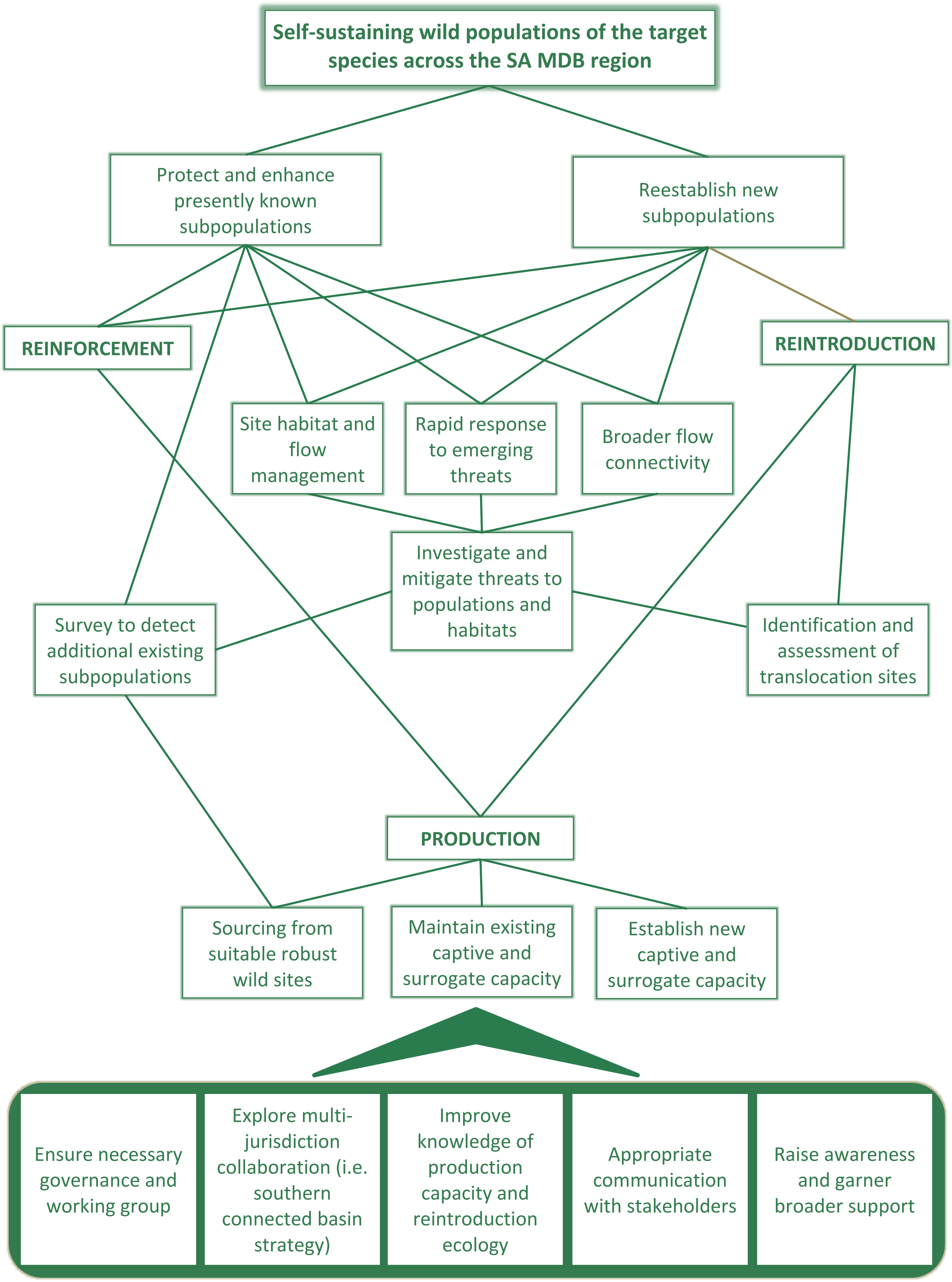


Figure 3-1. Conceptual summary of steps required to implement a translocation strategy for the target species in the SA section of the Murray-Darling Basin region.

The investigation of threats to populations and habitats will provide information for the management steps above. The identification and assessment of potential translocations will be necessary to enable the reestablishment of new subpopulations. The strategy will be underpinned by the capacity to produce sufficient numbers of fish for reintroduction and reinforcement.

Successful implementation of the translocation strategy will require appropriate governance and formalisation of a working group, exploration of multi-jurisdiction collaboration, improving knowledge of production capacity and reintroduction ecology through specific research and monitoring, ensuring appropriate communication amongst stakeholders and a willingness to raise awareness and garner broader support. There also needs to be a commitment of appropriate effort and investment into each step. For instance, it is recommended that the decision to initiate reinforcement or reestablishment of an individual subpopulation must be combined with, at least, a five-year commitment to ongoing fish releases in order to maximise the likelihood of successful establishments of populations. It will also be necessary for the maintenance of basic habitat and water flow, monitoring and evaluation of success of each subpopulation, and appropriate communication with stakeholders and wider community to achieve appropriate outcomes.

The following sections discuss the key steps of the translocation strategy.

3.3 Fish production

3.3.1 Background

The sustained translocations recommended in the present strategy will only be achieved through the secure production of sufficient numbers of healthy fish. To date, some fish for translocations were initially sourced from wild populations, but mostly captive maintenance and breeding and surrogate refuges have been used to produce fish. Fish initially rescued from deteriorating habitats were maintained in captivity with reproduction occurring naturally – without these actions, two of the target species (Southern Purple-spotted Gudgeon and Yarra Pygmy Perch) would have been lost in the region. Over time, captive breeding in intensively managed facilities was instigated for all four target species, which resulted in the production of 100s to 1000s of fish (Attard *et al.* 2016a; Ellis *et al.* 2013; Hammer *et al.* 2013). Presently, two of the target species are maintained in captivity, and in the case of Southern Purple-spotted Gudgeon 100s of fish are produced annually. Yet, captive maintenance is labor-intensive, has greater likelihood of biosecurity issues and greater attention to genetic management (given smaller population sizes). Surrogate refuges ameliorate some of these issues and have been critical to the ability to reintroduce each of the four target species. In fact, almost 70% of the fish reintroduced into the SA MDB region between 2011 and 2019 (and >95% of fish over the past three years) have been sourced from surrogate refuges. These surrogate refuges are established following selection on the basis of species-specific habitat and water quality requirements as well as the permanency of water and absence of predatory fish. A requirement of surrogate refuges is that they are not hydrologically connected to surrounding rivers or creeks to ensure fish are not introduced into areas they do not originate from. Once established, these sites have been able to maintain considerable populations (i.e. 10 000s of fish) for release. These surrogate refuges have been successful for three of the target species, but not Southern Pygmy Perch. Although less intensive, surrogate refuges do require ongoing management and assessment. As the network of surrogate refuges (coupled with captive facilities) has expanded, so has the management effort required to support them. Lastly, the collapse of two surrogate refuges (for Yarra Pygmy Perch) emphasise that they may not represent a long-term option.

Whilst these approaches have been adequate to meet the previous demand for fish for release, expanded fish production is necessary to meet the scope of translocations detailed in this strategy. Where 100s or 1000s of fish can be sourced from captive and surrogate populations, 10 000s to 100 000s of fish are anticipated to be required to reinforce or reintroduce the number of subpopulations of each target species detailed in Section 3.4. It is recommended that population modelling be employed to provide an indication of the numbers required. Regardless of the approach, the production of fish must consider biosecurity (i.e. disease and health) as well as genetic status.

3.3.2 Strategies to produce the fish

A staged approach is required to increase the production of fish for translocations. In the short-term, all existing captive and surrogate populations will need to be maintained. This maintenance should be accompanied by a review of the status of each captive population, in terms of biosecurity and genetic status along with re-evaluation of the aspects of the application of the original species-specific criteria. Specifically, the reevaluation should consider if original site suitability remains valid (considering long-term water security, commitment from landowners/stakeholders, etc), while prevailing water quality and composition of resident fish community should also be revisited. Most importantly, there is a need to undertake a genetic assessment of the status of all existing captive and surrogate populations to inform future management decisions. This review should also consider the factors that have contributed to the inability for a Southern Pygmy Perch surrogate refuge to be established. Following this review, there will be a need for consolidation of existing captive and surrogate populations as well as a plan to strategically expand existing populations.

The numbers of fish required to implement the present translocation strategy could potentially be achieved through the establishment of new surrogate populations to ensure ten surrogate populations are maintained for each target species over the next five years. These expanded networks, of potentially 40 surrogate populations, will require substantial management to ensure conditions are maintained, and landowners adequately engaged. There is also an opportunity to source individual fish directly from known robust wild subpopulations or through the utilisation of ephemeral wetlands as temporary *in situ* surrogate refuges. Direct sourcing from wild subpopulations is anticipated to eliminate biosecurity and genetic issues relating to maintenance of captive and surrogate individuals. Presently, the mid-Murray subpopulations of Murray Hardyhead represent the only feasible option for sourcing wild individuals for any of the target species. The use of temporary *in situ* surrogate refuges is a promising option but may require sustained releases to ensure establishment. As such, there would need to be a management commitment to ensure they are maintained for an appropriate and sufficient time period.

Realistically, the number of fish required is likely to only be achieved by concerted effort to increase the production of each of the four target species. This could be achieved by expanding the capacity of existing captive and surrogate populations, creating collaborations to allow the four target species to be produced at facilities already in existence in Victoria and/or New South Wales multi-species hatcheries or creating a new purpose-built facility in South Australia.

Each of these approaches have strength and weaknesses which will influence its feasibility. For instance, expanding the existing network of captive and surrogate populations would require little upfront investment but with each new location the management (and monitoring) burden would increase. Utilisation of an interstate hatchery will equally lessen upfront investment, but there would be less control (i.e. dependent on priorities of the hatchery) and the production of the four target species may be comprised. In contrast, the creation of a new purpose-built conservation facility would require substantial upfront investment as well as ongoing resources to operate, but would allow for greater control of operations, ensuring the focus remained on the four target species. Such a facility would maintain each of the target species in appropriately vegetated earthen ponds with regulation of water level and conditions (e.g. water quality) and allow for the efficient and secure production of 10,000s (or potentially 100,000s) of fish. A conservation facility would not only benefit the target species but also allow for greater community engagement, the creation of regional employment and specific partnerships with key stakeholders (i.e. traditional owners). The example provided by the Los Lunas Silvery Minnow Refugium, a purpose-built conservation facility, illustrates the potential (see insert above).

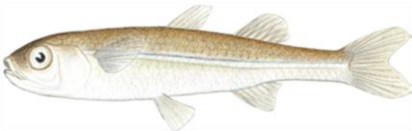
In summary, it is recommended to evaluate the potential to create a conservation facility. While such a facility might appear unrealistic to achieve, it will more than likely represent the only means to achieve the scope of the present conservation strategy for these species.

Purpose-built conservation facility

The globally *endangered* Rio Grande Silvery Minnow (*Hybognathus amarus*) is a small (<100mm) and short-lived species that was once abundant across more than 3800 river-kilometres of the Rio Grande Catchment (across New Mexico, Texas and Mexico).

Over the last 150 years, the species has declined with the species presently believed to only occupy 5% of its former range. Translocations are an important part of the recovery strategy for the species. Importantly, a purpose-built (US$ 2 million) conservation facility – the Los Lunas Silvery Minnow Refugium – which combines flowing stream habitat with a diversity of adjacent ponds to mimic Rio Grande habitats. The refugium has been able to produce substantial numbers of fish, as well as allowing for conservation education and ecological research.

3.4 Resilient, connected subpopulations

> ***Multi-jurisdiction* reintroduction**
>
> The globally *endangered* Murray Hardyhead (*Craterocephalus fluviatilis*), naturally occurred over three jurisdictions (New South Wales, South Australia, Victoria) across lowland floodplains of the MDB. It's a multi-jurisdiction range that has complicated conservation efforts in the past.
>
> 
>
> In acknowledgement of the need to reestablish connected subpopulations (regardless of state borders), efforts have recently focused on sourcing fish from SA sites for release into New South Wales, where the species has been absent for more than 20 years. Thus, a collaborative project involving national and state management agencies, NGOs and land managers, have navigated through multi-jurisdiction planning and implementation to release individuals into actively managed management floodplain wetland (Ellis et al. 2018).
>
> Continued management of the site, additional releases and population monitoring will help to reestablish the species.

Each of the four target species now persist as small, fragmented subpopulations with increased extinction risk across the SA MDB region. Whilst the exact number of subpopulations required to achieve long-term persistence is presently unknown, the present strategy relies on the assumption that considerably more (than present) resilient, connected subpopulations are required to reduce extinction risk. Thus, guided by objectives provided in the Basin-wide environmental watering strategy and relevant national recovery plans (DELWP 2017; MDBA 2014; Saddlier and Hammer 2010), the present strategy broadly recommends that 10 subpopulations should occur in each genetic management unit for each target species by at least 2033. To achieve this for each target species, there will be a requirement to expand the range of all known subpopulations (via reintroductions) as well as initiate the reestablishment of subpopulations to ensure that at least five subpopulations persist within each genetic management unit for each target species over the next five years with an additional five subpopulations over the next 10 years (to ensure that 10 subpopulations occur in each genetic management unit for each target species). Undoubtedly, this will require considerable expansion of the capacity of surrogate and captive populations.

This will require specific translocations for each target species based on the number and extent of known subpopulations and genetic management units. For instance, with one known subpopulation of Southern Purple-spotted Gudgeon, there will be a necessity to establish a further four subpopulations over the next five years. Southern Pygmy Perch subpopulations exist in three EMLR catchments (Tookayerta, Angas and Finniss) and in numerous sites within Lake Alexandrina, therefore translocations may be limited to reinforcement or reintroduction to key sites. In contrast, there are presently no known Yarra Pygmy Perch subpopulations, so it is critically important to initiate establishment of five subpopulations across the next five years and an additional five subpopulations over the next 10 years. Lastly, with 10 subpopulations recommended across each of the two genetic management units for Murray Hardyhead, the three known Lower Murray and three Mid-Murray subpopulations will need to be maintained whilst the establishment of two subpopulations in each management unit will need to be initiated over the next five years. For each genetic management unit, the initiation of the establishment of five additional subpopulations will be required over the next 10-years. By way of an example, Figure 3-2 provides visual representation of how the translocation strategy will seek to create connected subpopulations of Murray Hardyhead across both genetic management units, Lower Murray and mid-Murray, occurring in the SA MDB region.

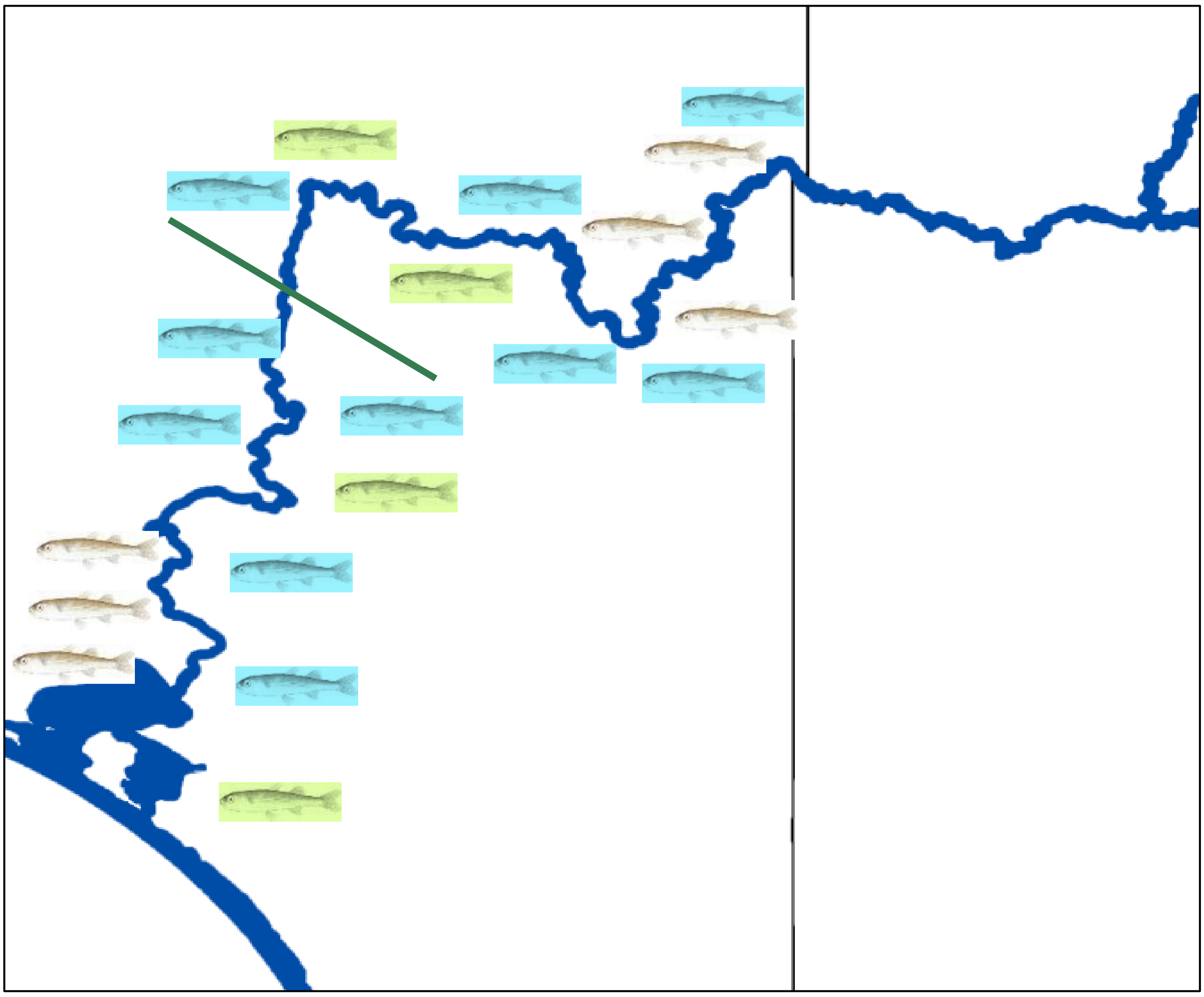


Figure 3-2. Visual representation of the translocation strategy for one of the target species, Murray Hardyhead. Existing subpopulations show as , with five years ( ) and 10-year ( ) targets for subpopulation establishment also illustrated.

3.5 Genetic management

3.5.1 Background

The preservation of gene flow amongst populations and genetic diversity is critical to adaptive potential and species viability (Frankham *et al.* 2010). Typically, species that maintain large populations across a broad range exhibit sufficient levels of gene flow and genetic diversity. Yet, for species that have declined to small and fragmented subpopulations, genetic differentiation amongst subpopulations and the loss of genetic variation and inbreeding is considered inevitable (Frankham *et al.* 2010; Smith *et al.* 2014). These subpopulations will have less ability to persist and adapt to environmental change and, are at greater risk of extinction, which in turn influences the viability of the species (Frankham 2005; Hoffmann and Parsons 1997). Translocations seek to redress genetic deterioration by mimicking gene flow by maintaining or enhancing genetic diversity, build adaptive potential and lessen extinction risk (Weeks *et al.* 2011).

Adaptive genetic management will be critical to the long-term survival of the target species in the SA MDB region. Whilst some effort has previously been directed to the genetic management of translocations of these species, it is pertinent to explore opportunities to enable more effective genetic management without the constraints of traditional approaches. By way of example, translocations traditionally act to maintain genetically differentiated populations separately, based on the distinction of genetic lineages (i.e. ESUs) and management units (MUs), but in some cases the mixing within and amongst these subpopulations (i.e. genetic rescue) may be warranted (Frankham 2015; Ralls *et al.* 2018; Whiteley *et al.* 2015). Specifically, the strategy warrants a commitment to a more coordinated and effective approach to genetic management. To this end, development of an adaptive genetic management framework to accompany the present translocation strategy is recommended (cf. Attard *et al.* 2016a; Flanagan *et al.* 2018).

The following sections detail genetic structuring and diversity of the target species along with insight into the post-drought status of captive and surrogate populations and wild subpopulations as well as providing key aspects of the required adaptive genetic management framework.

3.5.2 Genetic structuring

MDB populations of each target species represent distinct genetic lineages (i.e. evolutionary significant units, ESU) from other populations in the species range (Adams *et al.* 2011; Brauer *et al.* 2013; Faulks *et al.* 2008; Hammer *et al.* 2010; Unmack *et al.* 2013). Within the MDB, restrictions in contemporary gene flow ensure that the four target species persist as fragmented subpopulations that have been defined as separate management units (MUs). In the SA MDB region, Southern Pygmy Perch subpopulations occur across separate catchments (i.e. Angas, Finniss and Tookayerta) as well as within the Lake Alexandrina and surrounds (e.g. Hindmarsh and Mundoo islands) (Brauer *et al.* 2016; Cole *et al.* 2016). For Murray Hardyhead, two subpopulations have previously been identified in the SA MDB region (Adams *et al.* 2011; DELWP 2017; Ellis *et al.* 2013), but with recent genetic resolution indicating as many as four partially distinct subpopulations (i.e. Lower Lakes, Boggy Creek, Rocky Gully Wetland and the

Riverland) may exist across two regional populations (Thiele 2018). The remaining two species are presently represented by single MUs in the SA MDB region.

3.5.3 Genetic diversity

Levels of genetic diversity are typically low for subpopulations of each target species across the SA MDB region. Most obviously, the level of genetic variation – expressed as observed heterozygosity, H_O=0.30 and allelic richness, A_R=1.83 – for the MDB population of Yarra Pygmy Perch was the lowest reported amongst the target species (Brauer *et al.* 2013). For Southern Pygmy Perch, genetic diversity was variable, and typically low, amongst subpopulations (H_O=0.30–0.61; A_R=1.79–5.28) (Brauer *et al.* 2016; Cole *et al.* 2016). Equally, the known SA MDB subpopulation of Southern Purple-spotted Gudgeon showed moderately low genetic variation (H_O=0.41; A_R=1.88), which was considerably lower than populations outside the MDB (Hammer *et al.* 2015; Hughes *et al.* 2012; Sasaki *et al.* 2016). The genetic diversity of Murray Hardyhead subpopulations across the SA MDB region appears moderately high (H_O=0.45–0.75; A_R=3.64–4.78) (Thiele 2018).

3.5.4 Post-drought status

During fish rescues during the Millennium Drought only low numbers (10s to 100s) of each target species were able to be rescued. These formed the basis of all captive and surrogate populations later created, and at this stage there has not been any attempts to introduce new wild fish into these populations. Despite this, the rescued fish demonstrated sufficient levels of genetic diversity , at least based on the assessment of the two pygmy perch species (Attard *et al.* 2016a). Although maintained over one generation, genetic diversity in Southern Pygmy Perch declined substantially over the second generation of captive breeding (Attard *et al.* 2016b). This has emphasised the importance of surrogate refuges, which are capable of maintaining larger numbers of individuals, to help combat loss of genetic diversity. To date, specific genotyping of any surrogate populations is yet to take place. Equally, there has only been limited assessment of the present genetic status of wild subpopulations in the SA MDB region (Attard *et al.* 2016a).

3.5.5 Future considerations

The key recommendation of the present report is to develop an adaptive framework to guide the genetic management of the present translocation strategy (Attard *et al.* 2016a; Flanagan *et al.* 2018). This adaptive genetic management framework will be imperative to ensure genetically robust fish are produced and translocated into wild subpopulations to maintain and enhance the genetic status of the target species. Initially, it will be necessary to gain an updated understanding of the status of existing captive and surrogate populations as well as known wild subpopulations. This will guide the direction of the framework. It may be determined that some captive and surrogate populations, and in turn wild subpopulations, may have maintain enough genetic diversity for future population viability, whereas others will benefit from genetic rescue (Frankham 2015; Ralls *et al.* 2018; Whiteley *et al.* 2015). This genetic rescue should be used to maintain or enhance genetic diversity by introducing new genes from individuals within the same subpopulation, or amongst subpopulations .The latter is increasingly utilised for threatened species, but will require careful consideration (Weeks *et al.* 2011).

Effective genetic management is not possible without an understanding of how genetic status changes over time (Attard *et al.* 2016a; Flanagan *et al.* 2018). Thus, genetic monitoring is vital to adaptively implement and assess the present translocation strategy in combination with information provided by population monitoring. Specifically, genetic monitoring can be used not only for assessing genetic status (e.g. genetic diversity, relatedness, population connectivity) but can also provide an indication of survival, recruitment, and abundance within the population (Attard *et al.* 2016a). Genetic monitoring can be equally insightful for wild, captive or surrogate populations. Thus, we believe genetic monitoring must become routine as part of the implementation of the present strategy. The transition from genomic-based monitoring will be particularly useful to provide more powerful insight into genetic status and local adaptation (Allendorf *et al.* 2010; Flanagan *et al.* 2018).

3.6 Management in a time of drought and climate change

Future climates of the southern MDB are forecast to be warmer and drier with increased frequency and periods of extreme drought (Timbal *et al.* 2015). With reduced river flow volumes and less frequent flooding (Colloff *et al.* 2016; CSIRO 2008; Neave *et al.* 2015).

wetlands will experience longer dry periods or be lost completely (Colloff *et al.* 2016). Broadly, there is a need to adequately acknowledge the implications for future climates on water resources across the southern MDB (MDBA 2012). In some cases, this will require engineering solutions to optimise water delivery to wetlands. In the SA MDB region, initiatives such as the Riverine Recovery Project (RRP) as well as efforts by the Natural Resources, SA MDB are attempting to achieve effective wetland management under the constraints imposed by river regulation and future climates.

The implication of reduced water availability on freshwater fishes must be considered, particularly across the SA MDB region (Balcombe *et al.* 2011; Morrongiello *et al.* 2011). As evidenced during the Millennium Drought, the loss of wetland habitat profoundly impacted the four target species (Hammer *et al.* 2013). These species possess biological traits (including small body size) that make them some of the most vulnerable to drought impacts of the MDB fishes (Chessman 2013; Crook *et al.* 2010; McNeil *et al.* 2013). To combat the potential impacts imposed by climate change, the objectives of increasing the population resilience as well as enhancing wetland extent and suitability, and maintaining some drought refugia is essential (McNeil *et al.* 2013; Morrongiello *et al.* 2011). Practically, it will be necessary to ensure that knowledge of future inundation regimes is considered when deciding on potential translocation sites.

3.7 Conclusions

The present strategy introduces a framework that seeks to reestablish self-sustaining subpopulations to ensure the long-term persistence of each target species in the SA MDB region. To achieve this objective, sufficient numbers of healthy fish (i.e. 10 000 to 100 000s of each target species per year) is likely to be required. This will allow for suitable numbers of fish to be released over a sustained period at each translocation site. The strategy identifies the need to expand the range of all known subpopulations (via reintroductions) as well as initiating reinforcement and/or reestablishment to establish five subpopulations within each genetic management unit for each target species over the next five years. Once a translocation is initiated at least a five-year commitment to further releases and monitoring is strongly recommended to maximize the likelihood of establishing self-sustaining populations.

Take home messages

- Production capacity and scope of releases ((i.e. more fish, more often) is required to increase considerably
- A network of wild subpopulations (known and reestablished) is needed
- Translocations should be informed with an adaptive genetic management framework
- Consideration of drought and future climates is essential

Section 4 IMPLEMENTATION FRAMEWORK

4.1 Introduction

Where Section 3 provides the overarching strategy to guide translocations, this section concentrates on the implementation of the strategy. Building on previous work (Bice *et al.* 2014; Hammer *et al.* 2009a), the framework focuses on key aspect of implementation, such as site selection and preparation, release considerations, legislative requirements, requirements for managing sites and engaging stakeholders. The implementation framework will be broadly applicable to translocations, reinforcement and reintroduction of wild subpopulations, as well as captive and surrogate populations.

4.2 Identifying and assessing potential sites

4.2.1 Addressing underlying threats to the target species

The single most important consideration for translocations to any site is an understanding of the underlying drivers of local extirpation. Without mitigation of these drivers, translocations are unlikely to be successful in establishiUnderng self-sustaining populations. Broadly, each of the target species has been impacted by the consequences of river regulation through reduced overall flow volumes, altered flow regimes and frequency of flooding, as well as floodplain reclamation and levee construction. As such, many wetlands are nowadays permanently inundated, with others infrequently flooded, while others are permanently dry (Mallen-Cooper and Zampatti 2018; Walker 2006). This has led to a substantial reduction in wetland habitat diversity, which along with habitat degradation (which includes loss of aquatic vegetation, poor water quality, contamination and eutrophication) and the predation and competition influence of alien species have had dire impacts on native fish populations (DELWP 2017; Hammer *et al.* 2009b; Saddlier and Hammer 2010). In combination, these threats have acted to simplify the fish assemblage of the region, by creating conditions more conducive to ecological generalists and alien species with ecologist specialists such as the target species declining (Wedderburn *et al.* 2017). More recently during the Millennium Drought, critical water shortages and reduced freshwater flows resulted in significant water level recession, habitat loss (i.e. submerged vegetation) and habitat fragmentation, which profoundly impacted the target species (Hammer *et al.* 2013). Some of these threats have ceased (e.g. Millennium Drought) but others endure (e.g. river regulation, alien species, habitat degradation).

4.2.2 Identifying potential sites

Presently, potential surrogate and wild translocation sites for the target species are identified predominately through knowledge of former habitats that supported the target species immediately prior to the Millennium Drought. This approach has been logical as post-drought reestablishment was deemed most likely at these former habitats. Expert opinion has also been useful to identify additional sites that may be suitable for each of the target species. Ellis and Kavanagh (2014), for instance, utilised an expert workshop to identify potential translocations sites for Murray Hardyhead across the range of the species.

Whilst this approach will be utilised here, it is acknowledged that a more quantitative approach is required to identify the number of sites required for the scale of translocations proposed under the present strategy. By way of an example, species distribution models (SDMs) can help to derive spatially explicit predictions of environmental suitability as to guide translocation strategies (Guisan *et al.* 2013; Malone *et al.* 2018). SDMs are developed using knowledge of fish distribution and environmental predictors such as landscape and river character and water quality. They allow comparison of the availability of suitable habitat under current and future climates that can inform assessment of wild populations as well as the source populations and potential release sites for translocations. Relevantly, SDMs that were developed for threatened fish species in New South Wales (Riches *et al.* 2016) could be modified to apply to the target species across the SA MDB region. This would allow for a systematic evaluation of suitable habitats across the region.

4.2.3 Site suitability criteria

A semi-quantitative (i.e. expert opinion and on-ground data collection) two-stage site suitability criteria can be employed to assess potential translocation sites (Table 4-1) (Bice *et al.* 2014; Ellis and Kavanagh 2014; Hammer *et al.* 2009a). Initially, pre-assessment (stage 1) of general site suitability is made in the context of the long-term suitability of the site. This is predominately achieved as a desktop pre-assessment, which draws on the expertise of relevant stakeholders, although some of the considerations can be assessed through preliminary site inspection. Secondly, for each site differential habitat and water quality requirements of each target species is assessed (Table 4-1). Equally, the criteria are relevant to both surrogate and wild sites.

Table 4-1. Two-stage criteria for assessing suitability of surrogate and wild translocation sites in the SA MDB region.

Stage	Considerations	Requirements
Stage 1: General site suitability	• Hydrology • Site management • Location • Habitat suitability • Water Quality • Fishes	• Water level variability • History of water permanency (preference for long history, e.g. 5–10 years) • Landowner/stakeholder commitment to target species conservation? • Under appropriate management regime? • Within natural range of the species (wild) or isolated (surrogate refuge)? • Nearby potentially suitable habitats? • Suitable access to site? • Good levels of habitat cover (e.g. submerged and emergent vegetation, woody structure)? • Suitable water quality for target species (see Table 4-3)? • Prior knowledge of prevailing fish species?
Stage 2: Specific site suitability	• Hydrology • Site management • Location • Habitat cover • Water quality • Food resources • Fish survey	• Confirm stage 1 assessment via ground truthing • Confirm stage 1 assessment via ground truthing • Under appropriate management regime • High stable cover and submerged plants linked to species-specific requirements (see Table 4-3)? • More detailed assessment at number of locations, linked to criteria in Table 4-3. • Adequate availability of macroinvertebrates • Prevailing fish species, with large-bodied predators as well as small-bodied competitors (see Table 4-3).

Prevailing hydrology is the predominant criterion, with assessment relating to water permanency at the site. In acknowledging the benefit of variable water levels, the criteria are linked to the persistence of refuge pools (that could support the target species) at the site as opposed to the maintenance of stable water levels. Whilst preference is given to sites that exhibit a long history of some water permanency (5–10 years) it is acknowledged that shorter periods may be suitable, particularly if suitable habitats occur nearby.

Appropriate site management is equally important, in terms of landowners and stakeholder commitment to conservation of the target species, and a willingness to manage the site in a manner that predominately benefits the target species; this commitment would ideally be articulated in a wetland management plan for the site. In terms of location, wild sites must be in the natural range of the species, with additional preference given to sites where the species had previously been abundant rather than present in low numbers. For surrogate sites, the location can be outside the natural range of the species, but it must be deemed as isolated from the catchment. General assessment of likely habitat suitability, water quality and prevailing fish species is made at this stage.

If the pre-assessment of general site suitability is favourable, assessment moves to specific site suitability achieved through field assessment (stage 2). The assessment of overall site suitability is achieved through on-site evaluation of habitat cover, water quality parameters, food resources and prevailing fish species as well as confirmation of criteria relating to hydrology, site management and location. Habitat cover is described (by visual estimation) as the percentage of aquatic habitat cover (i.e. below the water surface) comprised of submerged vegetation, emergent vegetation, other physical structure (e.g. woody debris, rock) and open water. Water quality parameters, including water temperature, pH, dissolved oxygen concentration, electrical conductivity and water transparency, are assessed. Assessment of macroinvertebrate diversity and abundance is undertaken to investigate the presence of adequate food resources. Importantly, prevailing fish species are evaluated through targeted fish sampling, using appropriate sampling gear (e.g. fyke and seine netting) with specific focus on the presence of large-bodied predators (such as Redfin Perch) and small-bodied competitors (e.g. Eastern Gambusia *Gambusia holbrooki*) that would act to lessen the likelihood of establishment of the target species.

In combination, these criteria are evaluated against the species-specific tolerances and habitat preferences (Table 4-2) to provide the final assessment of overall site suitability. At this stage, a site can be recommended or rejected as a translocation site, but also identified as requiring potential management actions (e.g. habitat improvement) to improve site suitability.

Table 4-2. Summary of species-specific tolerances and preferences including percentage preferred habitat cover, key habitat preferred, water quality requirements, food resources and prevailing fish species (competitors and predators) preferences for assessing translocation sites in the SA MDB region. EC= Electrical conductivity, DO= Dissolved oxygen.

Target species	**Habitat cover**		**Water quality**			**Food resources**	**Prevailing fish species**	
	Percentage (%) physical habitat	Key habitat	EC (μScm^{-1})	DO (mgL^{-1})	pH		Competitors	Predators
Murray Hardyhead	>30%	Submerged *(Ruppia, Myriophyllum, Potamogeton,* and *Vallisneria)* and emergent *(Paspalum)* vegetation	400–~85,000	>2.0	4–10	Microcrustaceans (cladocerans, copepods, ostracods) and insect larvae (chironomids, mayflies, mosquito larvae mosquio	Juvenile Common Carp (<100mm): <30 fish per net Eastern Gambusia: <100 fish per net Freshwater Generalists: <100 fish per net	Redfin Perch and trout species (>90mm): <15 fish per net Adult Common Carp (>250mm): <20 fish per net
Southern Purple-spotted Gudgeon	>30%	Submerged *(Myriophyllum, Ceratophyllum* and *Vallisneria)* and emergent *(Schoenoplectus)* vegetation	800–5,000	>3.0	7–10			
Southern Pygmy Perch	>50%	Submerged *(Myriophyllum, Ceratophyllum and Vallisneria)* and emergent *(Schoenoplectus, Triglogchin, Typha)* vegetation as well as physical (rock, woody structure)	<3000	>2.0	4–10			
Yarra Pygmy Perch	>50%	Submerged *(Myriophyllum, Ceratophyllum* and *Vallisneria)* and emergent *(Schoenoplectus)* vegetation	<3000	>2.0	4–10			

4.3 Site enhancement

Where potential surrogate and wild sites are deemed as requiring management actions to bring them to a suitable state for translocation, certain objectives should be addressed. This can include enhancing water quality, emergent and submerged vegetation, presence of macroinvertebrates and absence of introduced or other predatory fish species. Water quality in translocation sites need to meet criteria outlined in Table 4-2.

The target species need to have suitable habitat with physical opportunities to lay eggs and have refuge from predators as well as providing a food source from both the plants and microinvertebrates that reside in them. Habitat at a site can be improved encouraging the growth (potentially by targeted establishment) of native submerged vegetation (such as *Myriophyllum, Ceratophyllum* and *Vallisneria*) and emergent vegetation (for example *Schoenoplectus, Triglogchin and Typha*) and through the addition of substrate such as rock and woody structure (Figure 4-1).

Figure 4-1. Examples of site enhancement: (a) transplanted Vallisneria at Greenslands Drive surrogate refuge, and (b) constructed habitat at [redacted] *Wetlands.*

4.4 Release considerations

The practical release considerations are a critical aspect of the translocation process (Moehrenschlager and Lloyd 2016). Undoubtedly, the ability to collect, transport and then release healthy fish will influence post-release survival and thus the successful establishment of translocated populations. As such, efforts should be made to minimise the stress experienced by fish during the translocation process (Sampaio and Freire 2016). In the following section, key considerations are discussed in the context of the translocations and release of the target species

4.4.1 Minimising transport-related stress

Transport-related stress during live fish transport adversely impacts fish health and post-release survival (Brown and Day 2002; Sampaio and Freire 2016). Through past experience, two of the target species (Murray Hardyhead and Yarra Pygmy Perch) are particularly susceptible to transport-related stress (Bice *et al.* 2014). Paramount to stress reduction during the transportation of fish is the maintenance of water quality parameters, as well as accounting for the accumulation of metabolic wastes (Sampaio and Freire 2016). Table 4-3 provides guiding principles to minimize transport-related stress. To minimise transport stress: 1) pure oxygen should be released into transport tanks, 2) water temperature should be maintained below species tolerances, and 3) fish should be transported in near-isosmotic water to minimise the metabolic cost of osmoregulation, thus lessening oxygen demand and waste production.

Table 4-3. Concern and suggested solutions for managing fish stress during transportation.

Aspect	Concern for fish stress	Solution
Dissolved oxygen	• Low dissolved oxygen (hypoxia) conditions increase stress	• Ensure adequate oxygen supply (preferably pure O_2) to meet oxygen demand of fish
Temperature	• Higher temperatures lead to greater oxygen demand and water production	• Transport in well-insulated tanks • Transport fish during cooler periods
Electrical conductivity	• Departure from the isosmotic point results in greater metabolic demand of osmoregulation (thus greater oxygen demand and waste production)	• Maintain transport water near isosmotic point for the target species
Metabolic waste (carbon dioxide and ammonia)	• Accumulation of metabolic wastes • Waste build-up can pose increased stress	• Utilise ammonia-reducing agents, such as Stress Coat, to mitigate the build-up of ammonia • Utilise pH buffer to achieve optimal pH
Suspended solids	• The build-up of suspended solids can influence fish stress	• Avoid feeding for 24–48 h prior to transportation • Source clean water to fill transport tanks
General	• All aspects of the transportation process can promote stress in fish	• Minimise transport time • Fish are handled as little as possible as it increases stress and oxygen demand • Avoid turbulent mixing of the transport water (from air stone or water movement) through the use of baffles and filling transport tank up completely • Use appropriately-sized transport tanks • Avoid high fish densities to avoid overcrowding • Regularly check fish and oxygen supply during transport • Monitoring stress responses of fish

Besides these water quality parameters, the complex interaction between pH and the build-up of metabolic wastes (carbon dioxide and ammonia) needs to be considered (Sampaio and Freire 2016). The accumulation of ammonia is considered a major concern, which can be ameliorated through the addition of commercial-available ammonia-reducing agents or fasting prior to transportation. Fish (and bacterial) metabolism produces carbon dioxide, which can directly impact fish by reducing the oxygen-carrying capacity of fish blood and making them more prone to low dissolved oxygen concentrations. Carbon dioxide can also indirectly impact fish by acidifying transport water so that pH levels become lethal. During fish transportation, the build-up of carbon dioxide is typically gradual, but pH decline can be rapid. To combat carbon dioxide build-up, a combination of adequate oxygen supply and ventilation (to allow carbon dioxide to dissipate) is needed. Buffers can be used to control pH levels in the transport water. Lastly, in acknowledgement that fish transport is an inherently stressful process, a range of general solutions, such as minimizing overall transport time and handling, is recommended.

In the past, multiple small tanks (60 and 120L) have been used to transport fish, but the expanded releases proposed in the present strategy, warrant exploration of larger transportation tanks to avoid overcrowding (Figure 4-2).

Figure 4-2. Various scales of fish transport options that be explored for transportation of fish as part of the present strategy.

The mitigation of transport-related stress will require ongoing review and evaluation of the translocation process. This will be achieved through trial-and-error, discussion with colleagues and periodic review of the scientific literature. It will also require a greater understanding of changes in water quality and metabolic wastes as well as physiological stress in transported fish. As such, it is recommended that comprehensive monitoring of water quality and stress responses becomes routine during the transportation of fish. This should incorporate real-time monitoring of key water quality (dissolved oxygen, temperature, pH) and metabolic waste parameters. Equally, thresholds for physiological markers of stress, such as cortisol and blood glucose, should be established for each target species, which can allow for assessment of release considerations that act to lessen transport-related stress.

4.4.2 Releasing fish

Upon arrival at translocation site, transport water should be gradually mixed with water from the translocation site to equilibrate water quality (namely water temperature and electrical conductivity). Once satisfied with water quality equilibration, the condition of fish should be assessed (with release ceased if fish considered unhealthy), and then fish released in a manner appropriate for each targeted species. While release of fish in larger groups is appropriate for a schooling species such as Murray Hardyhead, release in small groups is more effective for other species, such as Southern Purple-spotted Gudgeon (Figure 4-3).

Figure 4-3. Fish release approaches for Purple-spotted Gudgeon (left) and Murray Hardyhead (right).

A combination of direct release and soft release methods can be utilised. Direct release simply involves the direct liberation of fish at the release site following a period of onsite acclimation (to prevailing water). In contrast, soft release allows for a period of acclimatisation to the prevailing conditions, so that fish become accustomed to the prevailing conditions and develop accompanying natural behaviour that are likely to elicit a greater survival rate. Soft-release enclosures have been utilised successfully in previous reintroductions in the Lower Lakes; they should be sufficiently large (>1m x 1m), clad with small mesh (4mm) (Figure 4-4) (Bice et al. 2014). Prior to releases, all soft release enclosures should be sampled by dip net to eliminate other fish species allowing a subsequent recovery period from netting disturbance (i.e. disturbed sediment/silt). A period of 24 hours has been chosen to allow for adequate recovery from transportation and acclimation, whilst limiting density-dependent negative impacts from holding fish for longer periods (e.g. aggression and limited dispersal) (Brown and Day 2002).

Figure 4-4. Utilisation of soft-release enclosures for the translocation of the target species.

4.4.3 Biosecurity and disease

Disease is an important consideration when reintroducing endangered species back into the wild. Not only is disease capable of nullifying the potential benefits of captive breeding programs, it can also have deleterious effects on wild populations (Viggers *et al.* 1993). Ongoing inspection of fish to be released is required and fish presenting poor health should be quarantined and treated. Previously, fish were taken from captive and surrogate populations, held for up to three weeks to monitor health before being transported and released at the translocation site. Over time, this approach was streamlined to reduce holding and transport time (and stress) whilst permitting a greater number of translocations to take place. This approach should continue in the future as it is deemed most appropriate.

4.4.4 Timing

Generally, translocations should be undertaken in (1) spring/early summer and (2) late summer/autumn to maximise the number of fish released and account for the greatest range of conditions that will be experienced. During spring to early summer, increased food abundance and habitat availability (e.g. growth of aquatic plants) will allow fish to establish before summer, whereas individuals released in early autumn will have sufficient time to establish at the site prior to winter. Typically, releasing fish in winter or mid-summer is not recommended due to the likelihood of extreme conditions (e.g. flooding and high flows, low water levels) although may be appropriate in certain situations.

4.5 Legislation and policy

In order to minimise any impacts to wild populations through the translocation of the target species, this translocation strategy aligns with relevant biosecurity legislation and guidelines. Broadly, translocations will adhere to the *National Policy for the Translocation of Live Aquatic Organisms (1999*) (MCFFA 1999), which is implemented in each state under separate policy. In South Australia, the *Policy for the release of aquatic resources* provides guideline on the *implementation of the national policy* (PIRSA 2015). Broadly, the management of fish translocations (and fish species in general) is governed under *Fisheries Management Act 2007*, which states that an 'ecologically sustainable development' approach is employed to minimise aquatic impacts; the benefits of a proposed translocation must outweigh any associated risks. Thus, a PIRSA Application for Aquaculture Stock Translocation permit is required for the movement of aquatic animals, which should be applied for well in advance of translocations. As part of the two-stage application process, the merit of the translocation is made. Central to this assessment, is the identification and evaluation of ecological and socio-economic risk (in terms of negligible, low, moderate, high and extreme risk). Ecological risk relates to environmental/ecosystem level, abundance/behaviour responses, genetics and disease whereas socio-economic risk is associated with variables (e.g. impact to commercial fisheries, community dependent on local environmental and major industries), which are not particularly relevant to conservation translocations. Presently, assessment is made on a case-by-case basis but there is an opportunity for a renewed collaboration between PIRSA and key stakeholders (e.g. NRM, researchers and practitioners) to ensure a more calculated and streamlined assessment of the conservation translocations proposed in the present strategy.

4.6 Engaging stakeholders

The present strategy will require a long-term commitment to planning, implementation, review and engagement. This commitment is the responsibility of a range of stakeholders on different levels. First and foremost, it is worth emphasising that the conservation of the target species is a shared responsibility and strong working relationships between these stakeholders are critically important. In Table 4-4, a recommended frequency of contact and communication approach for key stakeholders is articulated that seeks to achieve effective communication and engagement which will be necessary to maintain collaborative effort.

Table 4-4. Recommended frequency of contact and communication approach for key stakeholders in the translocation strategy.

Stakeholder	Recommended frequency (but also as required)	Communication approach
Big Little Four working group	• Quarterly	• Review implementation of strategy • Discuss management issues • Explore collaborative research projects
Regional and national management agencies (Natural Resources, SA MDB; SA DEW; MDBA; CEWO)	• Weekly/monthly	• Discuss relevant aspects of strategy • Report on success of the implementation of strategy • Explore complimentary actions
Fisheries managers (PIRSA)	• Biannually	• Coordination of permit application • Reporting on translocation actions • Collaboration on fisheries-related management issues
Wild site custodians (various)	• Quarterly	• Provide input into site management and environmental watering • Coordinate fish releases and organise monitoring • Assist with community events
Captive and surrogate population managers	• Bi-monthly or monthly	• Provide support and address logistical questions • Discuss site management • Anticipate, and hopefully advert, any threats to the population • Coordinate fish transfer
Wider community	• Biannually	• Provide regular updates (social media, radio interviews and newspaper articles) • Participate in community events
Interstate stakeholders	• As required	• Explore collaborative opportunities • Discuss implementation of strategy

4.7 Conclusions

Section 4 provides guidance on the implementation of the proposed translocation strategy. It presents practical approaches relevant to identification and assessment of potential translocation sites, preparing sites, release considerations, legislative and policy requirements. It should be considered an adaptive framework, which is informed by new knowledge and understanding as implementation occurs. This continued refinement, along with the translocation strategy more broadly, will require the effective collaboration of a range of stakeholders.

Take home messages

- Underlying threats must be addressed at potential translocation sites
- Two-stage site suitability criteria are used for assessment of sites, with more robust assessment warranted in the future
- Effective release considerations will strongly influence post-release survival
- The long-term commitment of stakeholders to appropriate site management and species conservation is necessary; this should be facilitated through wetland management plans

Section 5 MONITORING AND EVALUATION

This section was prepared with the assistance of Scotte Wedderburn (University of Adelaide)

5.3 Introduction

Monitoring is imperative to evaluate the success of a species' reintroduction (Fischer and Lindenmayer 2000; IUCN/SSC 2013; Sheean *et al.* 2012). Indeed, the failure of many programs is attributed to inadequate monitoring that impedes robust evaluation and adaptation of the reintroduction strategy over time (Ewen and Armstrong 2007), and this is the case for freshwater fish reintroductions in Australia (Lintermans *et al.* 2015). Monitoring should be linked to the translocation strategy's objective of reestablishing resilient, connected populations that ensure the long-term persistence of the target species. Monitoring data provides the ability to evaluate the success of the strategy using varying parameters at different temporal and spatial scales across a timeframe linked to the life history of the target species.

Monitoring and research is critical to evaluate the success of meeting the objective of the present translocation strategy, especially regarding population status and improved knowledge of biological and ecological aspects of the four species. The following sections provide guidance to inform development of monitoring and research to accompany the present strategy.

5.4 General considerations

Fish reintroductions are fraught with uncertainties that may impact on the success of a translocation strategy. Further, fish are inherently difficult animals to examine in the wild. Therefore, evaluating success of the present translocation strategy requires well considered and comprehensive monitoring and research to allow for meaningful assessment. In this regard, several key factors should be considered when evaluating the strategy. First, sampling methods and devices should be selected to target the fish species. In this case, the more mobile, schooling Murray Hardyhead differs from the pygmy perches and gudgeon (see below). Second, the spatial extent of each species should be considered, especially with regards to the potential range a species could achieve over several years (e.g. natural recolonisation of new sites, connectivity of populations). Third, given that the four target species are currently considered rare, sampling should account for false absences (cf. Mackenzie *et al.* 2018). Finally, detecting real changes in the fish populations over longer time periods must consider statistical power to avoid false impressions of the data (cf. Barata *et al.* 2017).

The method of analysing data should also be considered when assessing the strategy's objective, and several approaches are available depending on the level of monitoring and the fish species of concern. Three general approaches should be considered. First, relative abundance of a fish species, as related to a baseline value (e.g. from the first survey after reintroductions at a site), should be measured. Second, levels of recruitment should be examined or measured at each site, either using length-frequency analysis or through established indices (e.g. proportion of young-of-the-year fish in the catch). Third, occupancy (proportion of sites detected) should be estimated for each fish species in their total potential range. The spatial extent to estimate occupancy may be subject to definition based on regional presence of some fish species. For example, Southern Pygmy Perch can be assessed in three groups – Tookayerta-Finniss, Angas-Bremer and Lake Alexandrina. Similarly, Murray Hardyhead and River Murray Purple-spotted Gudgeon have more than one group, but Yarra Pygmy Perch is confined only to the south-west of Lake Alexandrina.

5.5 Scales of monitoring

Ongoing monitoring of the translocated populations of the target species is critical to document presence, distribution and abundance, and to examine population demographics to allow for regular status assessments (Bice *et al.* 2014; Saddlier *et al.* 2013). As has occurred previously, it is important to conduct monitoring both at the release sites and at several of the originally selected reintroduction sites to detect any recolonisation occurring as a result of the dispersal of released individuals (Bice *et al.* 2014). In this approach, three monitoring levels are proposed. Seasonal monitoring at reintroduction sites is necessary over the duration of the translocation strategy (i.e. repeat translocations over several years) to confirm short-term survival (Level 1; see below). Once fish are established, monitoring can subsequently become annual to assess ongoing survival and recruitment as part of broader condition monitoring across the region (Level 2). Statistically robust pre-translocation baselines and repeat monitoring every 5 years can determine the long-term success of the strategy for each species as related to the objective (Level 3).

Monitoring outcomes will provide an improved understanding of the factors driving the presence, abundance and recolonisation of the threatened fishes. Consequently, monitoring will improve the opportunities to successfully establish populations through translocations by better understanding the needs of each fish species. For example, monitoring may identify the factors that were responsible for failure of a fish to establish at a site. Therefore, findings from the monitoring may also trigger targeted actions at reintroductions sites to assist population that have been translocated (e.g. environmental watering, predator removal, habitat enhancement). The long term monitoring (Level 3), using replicate surveys at multiple sites, will be ideal for inferring patterns and dynamics of threatened fish occurrences related to environmental variables, including water levels, water quality, and predator abundances (Mackenzie *et al.* 2018). There may be an opportunity to combine the strategy's monitoring with other long-term monitoring (e.g. The Living Murray condition monitoring; EMLR monitoring), should they continue in the future, so methods must be consistent.

5.5.1 Level 1: Site-based seasonal monitoring

Aim: Determine the immediate success or failure of reintroductions and understand the factors that cause discrepancies.

Seasonal monitoring conducted at the reintroduction site will confirm the short-term survival of reintroduced fish by measuring abundance (total number in catch), breeding condition, general health (e.g. parasites visible) and conditions that may affect fish numbers (e.g. water quality parameters, water depth, predator abundances). The findings will determine if there are any continuing or new threats to the fish that may be addressed. The seasonal monitoring will also determine if follow up reintroductions are required in the same season (i.e. if initial reintroduction appears unsuccessful and cause is abated). This approach will contribute to the medium- to long-term success of the translocation strategy.

5.5.2 Level 2: Site-based annual monitoring

Aim: Determine if the fish species has established a self-sustaining population at the reintroduction sites.

Apart from measuring the same factors in level 1 monitoring, the annual monitoring approach will determine if released individuals have bred at the reintroduction sites and, if so, assess recruitment based on population size structure by measuring the total length of all threatened fish. Therefore, the annual monitoring should be conducted between February and April, at the end of the breeding–recruitment period, for each of the four fishes. Annual monitoring conducted at the reintroduction sites will also assess the ongoing survival of reintroduced fish (possibly excluding Murray Hardyhead which lives for only 12–18 months). Other current, ongoing monitoring programs may cover some of the future reintroduction sites in this manner (e.g. Wedderburn and Barnes 2018), so data sharing may be applicable in some cases.

5.5.3 Level 3: Regional occupancy estimation (long-term)

Aim: Determine changes in occupancy and range of the fish species to examine the overall success of the translocation strategy over a decade (resilient, connected populations).

Broader spatial scales surveys are required to determine the long-term success of the translocation strategy at 5-year intervals for at least a decade. These surveys will provide an estimate of occupancy, which is the proportion of habitat (sites) occupied within the species potential range. The broad surveys, covering reintroduction sites and other sites that the species could potentially colonise naturally, must be replicated within a short period of time during the monitoring to account for false absences (probability of detection: Mackenzie *et al.* 2018). Based on a previous study of three of the target species, imperfect detection may be accounted for by conducting three replicate surveys (fyke nets: see below) for Yarra Pygmy Perch, Southern Pygmy Perch, and four replicate surveys for Murray Hardyhead (seine, or fyke nets and seine) (Wedderburn 2018). Data for River Murray Purple-spotted Gudgeon is lacking. Initially, three replicate surveys using fyke nets would provide adequate information, and the method could be modified if necessary.

Ideally, this level of monitoring would include a comprehensive baseline survey prior to the commencement of the translocation strategy so that the objective can be assessed by tracking the extent of occupancy for each species from the beginning of the program. In this regard, for example, there was sampling in November–December 2018 targeting Yarra Pygmy Perch whereby three replicate surveys were conducted at 32 sites within its entire previously known range, although the species was undetected (Wedderburn *et al.* 2019). This approach, using a baseline survey, provides a statistically robust method of determining any long-term changes in occupancy of the fish species and, just importantly, the reasons for any changes. For example, an increase in occupancy (i.e. establishment at reintroduction sites and additional sites) may be significantly related to rates of river or stream flows, or water levels or quality. The assessment may also be used to determine the success of habitat enhancement efforts.

5.6 Monitoring methods

5.6.1 Fish surveys

There are a number of methods and devices for sampling small-bodied fish. Passive devices are set in place for a period of time to trap fish. Passive gear types include fyke nets, gill nets and box traps. Gill nets are highly size selective and ineffective for catching small-bodied fishes and are therefore unsuitable for monitoring during the translocation strategy. Fyke nets provide the ideal passive sampling technique, where they can be set overnight, and are recommended as the predominant sampling method in all levels of monitoring. For seasonal and annual monitoring, single surveys using three or four fyke nets at each site are suitable. For long-term regional monitoring, based on data for Southern Pygmy Perch (Wedderburn 2018), three replicate fyke surveys are necessary to accurately estimate occupancy. This same approach should be used for Yarra Pygmy Perch and Southern Purple-spotted Gudgeon in the initial level 3 monitoring surveys, where data can later be analysed to determine the optimal study design for each species (Guillera-Arroita *et al.* 2010). The dimensions of fyke nets and the number of nets per site should correspond to complimentary, ongoing monitoring programs (e.g. Wedderburn and Barnes 2018; Whiterod 2018)

Active gear types include seine, dab net and electrofishing. Seining is generally ineffective in the well-vegetated habitats suitable for the pygmy perches and River Murray Purple-spotted Gudgeon, but is more effective than fyke nets for detecting Murray Hardyhead in its preferred habitats (Wedderburn 2018). For long-term monitoring (e.g. level 3), a combination of two seine surveys and two fyke net surveys (i.e. modelled as four surveys) provides an adequate probability of detection for Murray Hardyhead. Alternatively, four replicate seine or fyke surveys would be adequate.

Other fish sampling methods and devices have been considered but lack usefulness for monitoring in the translocation strategy. Notably, environmental DNA is a passive method to determine the presence of fish species (Shaw *et al.* 2016), but currently lacks the ability to gather demographic data – the method may be useful in future monitoring once the technique is refined. Electrofishing may be useful in stream habitats, but is unsuitable for targeting the four threatened species in the translocation strategy due to inoperability at the high turbidity and salinities at most potential reintroduction and colonisation sites. Dab netting may be useful in situations where there is insufficient open water habitat to set fyke nets or to seine, but this is likely to be infrequent.

5.6.2 Habitat surveys

Monitoring of habitat should be conducted to determine suitable reintroduction sites and, then in concert with fish surveys, to determine prevailing conditions. Several water quality variables that are influential on fish should be measured, including salinity (or electrical conductivity), water transparency, temperature, pH and dissolved oxygen. Aquatic macrophytes should be identified and their density (proportion of site) should be visually estimated to record the amount of suitable habitat for the target species.

Data from the habitat monitoring may be used to select reintroduction sites, and to determine if habitat suitability and availability change over time. It is envisaged that on some occasions the habitat assessments will inform the success, or otherwise, of habitat enhancement efforts. Many of the measured habitat variables (covariates) can also be used in analyses of the level 3 fish monitoring data to determine their significance in influencing changes in occupancy of the fishes over time and, therefore, their contribution to meeting or failing the translocation strategy objective.

5.7 Evaluating overall reintroduction success

The expected outcomes for the four target species are framed in terms of restoring distribution and abundance to levels recorded prior to 2007, before major population declines and extirpations were caused by extreme drought. This includes the expansion of existing populations (e.g. range extension) and/or the establishment of new populations (e.g. additional populations), which may be facilitated through translocations. Over a decade, this is articulated as expanding the range of each species and establishing 3–4 additional locations (sites) for each of the four target species, which can be evaluated from the level 3 monitoring data (i.e. occupancy estimation).

In broader terms, the national recovery plans for Murray Hardyhead and Yarra Pygmy Perch detail recovery objectives relating to the protection and maintenance of key presently known populations (i.e. primary populations) as well as identifying and undertaking translocations to establish secondary populations to increase area of occupancy (DELWP 2017; MDBA 2014; Saddlier and Hammer 2010). For Murray Hardyhead, it is recommended to establish three secondary populations (one for each genetic management unit) whereas at least one new population (in the lower Murray) is recommended for Yarra Pygmy Perch. Both recovery plans emphasise the importance of surrogate and captive populations. The findings of monitoring may also be used to evaluate state and federal government objectives within the Murray–Darling Basin. For example, assuring that key species show improved length structure and movement, and expanded distribution – an objective of the Basin Plan and associated Basin-wide environmental watering strategy (MDBA 2014).

5.8 Research opportunities

5.8.1 Reintroduction ecology

The data gained from level 1 and 2 monitoring will generate knowledge regarding reintroduction ecology for the threatened fish and other related species. Initially the monitoring will determine levels of short-term, post-release survival. There would also be an opportunity to conduct genomic analyses (e.g. local adaptation, parentage) if fin clips are collected during monitoring. An important overall benefit of examining reintroduction ecology will be to answer questions regarding the number of fish required to be stocked and the frequency of reintroductions (i.e. how many, how often?). This will establish the 'optimal stocking strategy' (Lintermans *et al.* 2015) for each species to meet the translocation strategy objective.

5.8.2 Ecological and biological understanding

There are many questions surrounding the ecological and biological understanding of the four target species where the answers may assist population management and, therefore, assist in meeting the translocation strategy objective of species recovery. A primary research gap is the relationship between hydrological factors and the responses of threatened fish populations. For example, water level management in Lake Alexandrina impacts on fringing wetlands inhabited by some of the target species but currently the population responses are untested. Further, the relationship between water level management and other biological factors that influence threatened fish recruitment (e.g. food availability, macrophytes, Redfin Perch and Eastern Gambusia abundances) are untested. Combined, the three levels of monitoring in the translocation strategy will provide robust data to determine the major manageable influences on threatened fish populations. Additionally, but outside the scope of the translocation strategy, the comprehensive data generated through monitoring may be useful to evaluate the future impacts of climate change on the target species and their habitats using predictive models.

Section 6 IDENTIFYING AND ASSESSING POTENTIAL SITES

This section was prepared with the assistance of Kate Mason (Natural Resources, SA Murray-Darling Basin)

6.1 Summary

Historically, there were more than 1100 floodplain wetlands across the SA MDB region (Pressey 1986). Yet, river regulation has altered the hydrologic character of many of these wetlands; over 75% are now permanently inundated whilst others are infrequently flooded (Walker and Thoms 1993). This has acted to reduce local and regional habitat heterogeneity, which has contributed to a simplification of the regional fish community and lessen suitability for the target species (Wedderburn *et al.* 2017). Against this decline in regional habitat suitability, a considerable number of suitable wild translocation sites are necessary to fulfil the objectives of the present strategy. Ideally, these sites would be specifically managed for the target species, but the reality is that a broader range of objectives sees present management focus on reinstating more variable water regimes that include dry periods. Wetlands that experience a two-year period of connection to the river following this managed drying period may provide a suitable window of opportunity for reintroduction of the target species. Sites that had variable water regimes but maintained permanent water (periods without managed fluctuations in water levels and maintained connectivity for 24 months) were identified. The primary focus of the preliminary site identification and assessment presented here was to demonstrate application of the existing site suitability criteria against these constraints.

6.2 Preliminary identification and assessment of site suitability

In total, 89 potential translocation sites across the SA MDB region were initially short-listed during preliminary site identification (Figure 6-1). These included sites currently managed by Riverine Recovery Project and Natural Resources, SA MDB as well as some that have been identified previously (e.g. Ellis and Kavanagh 2014). During stage 1 assessment, the general site suitability of 69 of the sites was deemed not suitable for further assessment. The exclusion of sites was primarily based on insufficient water permanency (i.e. less than a two-year period of river connection) under the existing management regime (note: for these sites only, the criteria that deems them unsuitable is shown). Several sites were eliminated due to the maintenance of permanent connection with the river and/or the lack of suitable habitat or unfavourable prevailing fish species. Further, seven managed wetlands (Brenda Park, Hart Lagoon, Loveday Lagoon, Martin’s Bend, Morgan's Lagoon/Yarramundi North, Sugar Shack Complex - Wetland 10) were deemed to have the requisite minimum two-year period of river connection but were not assessed at this stage. Equally, nine sites (Causeway Lagoon, Col Col Lagoon, Col Col Outlet, Devon Downs South, Eckerts-Wide Waters, Mundic Creek, Rocky Gully, Paringa Paddock-Goat Island and Bookmark Creek) were deemed to warrant future assessment but were not visited as part of the present project due to infrastructure construction preventing site access and time constraints.

As such, only five sites – representing one sixth of those initially short-listed through this preliminary identification – were assessed as requiring specific survey and assessment at this stage (Table 6-1 to Table 6-5). During the specific site survey and assessment, only one site (Ramco Lagoon) was considered as a high priority for reintroduction of one of the target species (specifically, this site was deemed suitable for Murray Hardyhead as elevated electrical conductivity will act to provide the species with a competitive advantage over freshwater generalists and introduced species). The following tables provide justification of the final assessment of each site considered during specific site survey and assessment (Table 6-1 to Table 6-5). As the sites that were deemed to require future assessment demonstrate, the identification and assessment is an iterative process where timely review of (a) newly identified sites and (b) sites presently not deemed suitable as new knowledge becomes available. It is evident from the present process that the majority of managed wetlands across the SA MDB region maintain water permanency and management regimes that are incongruent with the requirements of the target species.

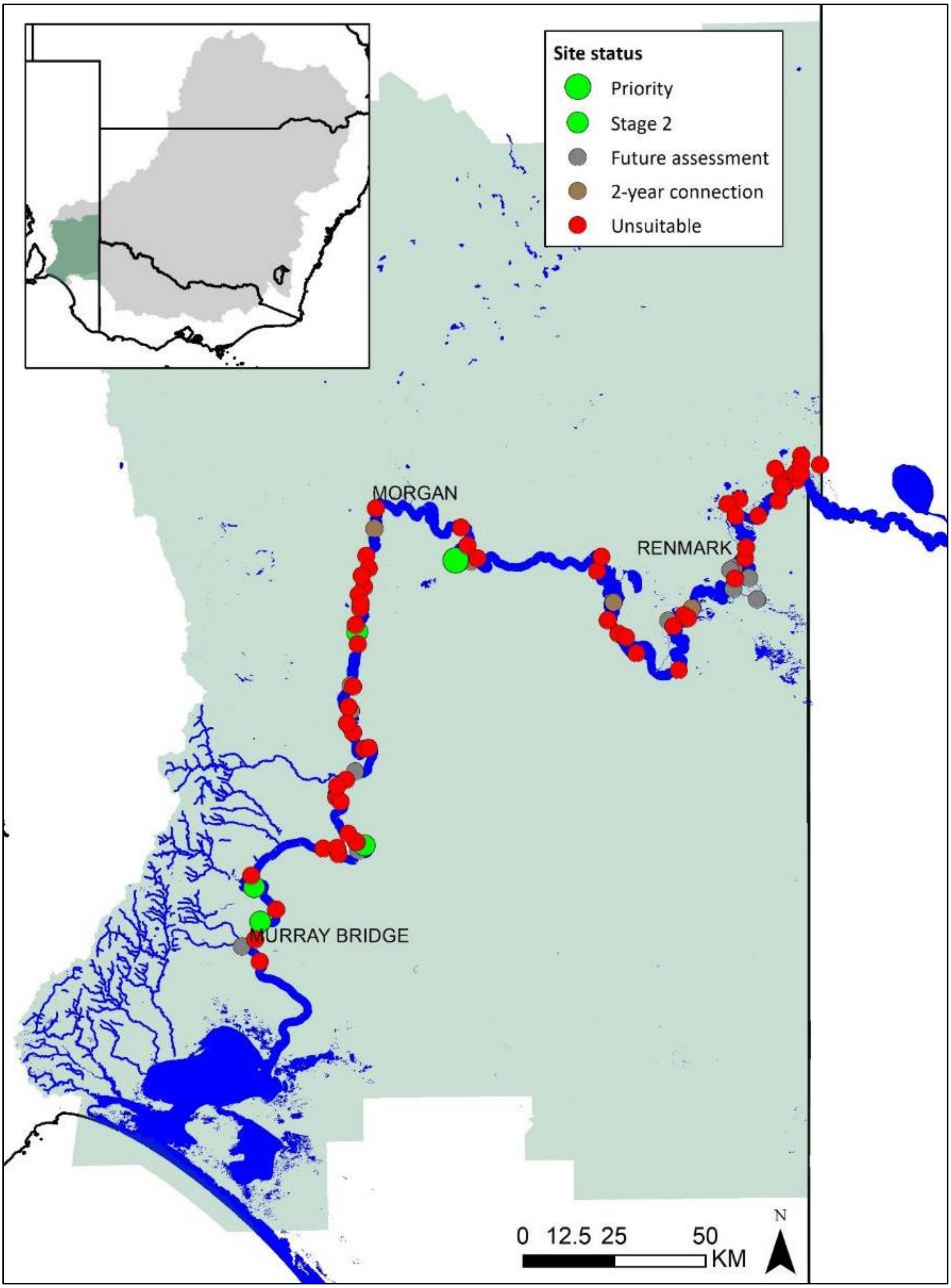


Figure 6-1. Preliminary identified potential translocation sites across the SA MDB region, indicating sites eliminated during stage 1 (•), sites requiring future assessment (•) and those subjected to stage 2 (•) assessment (site considered high priority for translocation (•)).

Table 6-1. Site suitability assessment of high priority translocations sites: [redacted] Swamp (outer wetland).

Translocation site assessment

REINTRODUCTION/REINFORCEMENT/SURROGATE

[redacted] Swamp (outer)

TARGET SPECIES

Southern Purple-spotted Gudgeon

Background: [redacted] Swamp (outer) is a shallow, wetland of the lower Murray River near the township of Mypolonga. Well connected to the main river channel, Jury Swamp largely has a permanent supply of water and is largely inundated, although may dry in periods of drought. Parts of Jury Swamp are subject to potential translocations and this assessment was focusing on the larger outer wetland.

Pre-assessment

Water permanency: Being well connected to the main river channel, [redacted] Swamp is largely inundated. Historically [redacted] Swamp has dried during periods of extreme drought.

Location: Within the Lower Murray management unit; easily accessible.

Site management: Managed by private body corporate and Natural Resources, SA MDB; strong working relationship and support for broader species conservation.

Specific site survey & assessment

Habitat suitability: At the time of assessment (December 2018), the wetland was exhibited relatively good habitat with reasonably high amounts of submerged aquatic (*Myriophyllum sp*.) and emergent vegetation (*Typha sp*.). Low amounts of structural habitat in the form of snags or rocks etc. were observed.

Water quality: At the time of assessment, water quality was suitable for the species, namely electrical conductivity (600µScm^{-1}), dissolved oxygen (8.93mgL^{-1}), pH (8.21) and water temperature (24.46°C).

Food resources: Low to moderate levels of macroinvertebrates (predominately *Notonectidae* and *Ephemeroptera)*.

Prevailing fish species: The observed fish assemblage included diadromous species, freshwater generalists and alien species. Ten species were detected during the recent assessment, with Unspecked Hardyhead and Carp Gudgeon recorded in relatively high numbers. Large Freshwater Catfish and Golden Perch were also amongst the native fish species recorded. Introduced species observed were: Eastern Gambusia and Common Carp, with both species recorded in relatively low numbers (although numerous free swimming large Common Carp were also observed).

Final assessment

UNSUITABLE

Justification: The outcomes of the assessment indicate that the site is presently unsuitable for the reintroduction of the target species, despite reintroductions occurring nearby. Although the water quality and habitat are adequate for the species, the combined number of large Common Carp, Freshwater Catfish and Golden Perch is likely to result in high level of predation of Purple-spotted Gudgeon adults, fry and eggs.

Table 6-2. Site suitability assessment of high priority translocations sites: Paisley Creek.

Translocation site assessment

REINTRODUCTION/REINFORCEMENT/SURROGATE

Paisley Creek

TARGET SPECIES

Southern Purple-spotted Gudgeon

Background: Located near Blanchetown SA, Paisley Creek Wetland is an anabranch of the River Murray located upstream of the Blanchetown Bridge in the Lower Murray Region. Paisley Creek is permanently inundated and is connected to the main river channel through Ryans Lagoon, Paisley Creek inlet and Siphon Creek inlet (Ecological Associates 2006).

Pre-assessment

Water permanency: Paisley Creek is permanently inundated and is connected to the main river channel through Ryan's Lagoon, Paisley Creek inlet and Siphon Creek inlet (Ecological Associates 2006).

Location: Within Lower Murray genetic management unit; easily accessible.

Site management: Paisley Creek wetland is positioned on both private with nearby land uses being a caravan park on one side, a vineyard on the other and a major road bridge at the southern end of the wetland. The creek is permanently inundated.

Specific site survey & assessment

Habitat suitability: At the time of assessment (December 2018), there was low abundance of aquatic vegetation (*Azolla* sp., some *Myriophyllum* sp.) but high abundance of emergent vegetation (*Typha* sp., *Ludwigia* sp.). Some further habitat cover was provided by snags.

Water quality: At the time of assessment, water quality was suitable for the species, namely electrical conductivity (386µScm^{-1}), dissolved oxygen (5.87mgL^{-1}), pH (6.96) and water temperature (23.92°C).

Food resources: Low to moderate levels of macroinvertebrates (predominately *Notonectidae*).

Prevailing fish species: Twelve species have been previously recorded (six of which were detected during the present assessment). Species detected at Paisley Creek included freshwater generalists and alien species including Eastern Gambusia and Common Carp, previous surveys have also detected Redfin Perch and Goldfish. The most abundant species recorded in the current survey was the Carp Gudgeon (native freshwater generalist), this species was recorded in very high abundance.

Final assessment

UNSUITABLE

Justification: The outcomes of the assessment indicate that the site is currently unsuitable for the reintroduction of Southern Purple-spotted Gudgeon, this is largely due to the likely high degree of competition for habitat and food resources from abundance of other fish species.

Table 6-3. Site suitability assessment of high priority translocations sites: Ramco Lagoon.

Translocation site assessment
REINTRODUCTION/REINFORCEMENT/SURROGATE

Ramco Lagoon

TARGET SPECIES
Murray Hardyhead

Background: Ramco Lagoon is a shallow, 99.7-hectare wetland (Wegener 2012) in the Gorge Tract of the SA MDB region. Naturally experiencing a temporary water regime, it is now permanently inundated under regulated conditions. The wetland has a long history of saline drainage disposal, but with recent management focusing on reducing prevailing salinity. Yet, the wetland continues to maintain salinity levels above that of nearby wetlands.

Pre-assessment

Water permanency: Although management aims for a variable water regime, the wetland artificially maintains water permanency.

Location: Within mid-Murray genetic management unit; easily accessible.

Site management: Prevailing management regime ensures that areas of permanent water are maintained. The landowners (Loxton-Waikerie District Council and G. Ziegler) and local (Riverland West Landcare) and regional (Natural Resources, SA MDB) management organisations need to be consulted.

Specific site survey & assessment

Habitat suitability: At the time of assessment (December 2018), the wetland was relatively turbid and no aquatic vegetation was detected. Some habitat cover was provided by dead *Eucalyptus* sp.

Water quality: At the time of assessment, water quality was suitable for the species, namely electrical conductivity (2286µScm^{-1}), dissolved oxygen (9.55mgL^{-1}), pH (8.67) and water temperature (28.54°C). Additionally, the summer drawdown will promote increasing electrical conductivity, which will suit the target species whilst reducing suitability for other fish species. It is recommended to reassess water quality at the end of summer to confirm that water quality prevailing at that time is suitable for the species.

Food resources: Low to moderate levels of macroinvertebrates (predominately *Chironominae*).

Prevailing fish species: Ten species have been previously recorded (five of which were detected during the present assessment, all in low abundance). This included freshwater generalists and alien species – previously Redfin Perch (not recorded since 2006) and low abundance of introduced Eastern Gambusia and Common Carp, with the latter believed to typically die-off in late summer.

Final assessment

PRIORITY FOR REINTRODUCTION

Justification: The outcomes of the assessment indicate that the site is presently managed in a manner that provides conditions suitable for the target species. Specifically, the elevated salinity (electrical conductivity), which act to reduce predation and competition, strongly enhances site suitability. As such, following confirmation of suitable conditions at the end of summer and endorsement from stakeholders, this site is recommended as a priority for reintroduction.

Table 6-4. Site suitability assessment of high priority translocations sites Saltbush Flat.

Translocation site assessment

REINTRODUCTION/REINFORCEMENT/SURROGATE

Saltbush Flat

TARGET SPECIES

Murray Hardyhead

Background: Saltbush Flat is a large shallow wetland near Bowhill in the Murray Gorge region SA. Saltbush Flat is approximately 2.5 km long and a maximum width of 500 m (Smith and Fleer 2007). The wetland is connected to the main river via two narrow channels and is considered to have a permanent water source.

Pre-assessment

Water permanency: Water permanent due to inlets from the main river channel at the northern and southern ends of the wetland. Excavation of the northern inlet in 2006–2007 has increased connectivity of water between the wetland and the main river channel (Smith and Fleer 2007).

Location: Within mid-Murray genetic management unit; easily accessible.

Site management: Management of flow regimes throughout the Murray River ensures that areas of permanent water are maintained. The inlet at the north of the lagoon was excavated in 2006–2007 to increase flow from the main channel.

Specific site survey & assessment

Habitat suitability: At the time of assessment (December 2018), much of the wetland was shallow, turbid and little or no aquatic vegetation present. Some habitat cover was provided by *Typha sp.* and *Eucalyptus* sp.. Sampling took place near the north inlet where emergent vegetation and snags were more abundant.

Water quality: At the area and time of sampling, most hydrological variables were suitable for the species, namely electrical conductivity (412µScm^{-1}), pH (7.31) and water temperature (21.37°C). However dissolved oxygen was low at (1.92mgL^{-1}).

Food resources: Low to moderate levels of macroinvertebrates (predominately *Notonectidae, Odonata*).

Prevailing fish species: Twelve species have been previously recorded (seven of which were detected during the present assessment). This included freshwater generalists and alien species. Most species recorded in the current survey were in relatively low numbers with the exception of Carp Gudgeon. Previously Smith and Fleer (2007) recorded four introduced species at Saltbush Flat including Redfin Perch, Eastern Gambusia, Common Carp and Goldfish. The current survey did not detect Redfin Perch however a single Oriental Weather Loach was recorded.

Final assessment

UNSUITABLE

Justification: The outcomes of the assessment indicate that the site is currently unsuitable for the reintroduction of Murray Hardyhead, this is largely due to the likely high degree of competition for habitat and food resources from abundance of Carp Gudgeon and the observed low dissolved oxygen levels.

Table 6-5. Site suitability assessment of high priority translocations sites Walt Flat.

Translocation site assessment

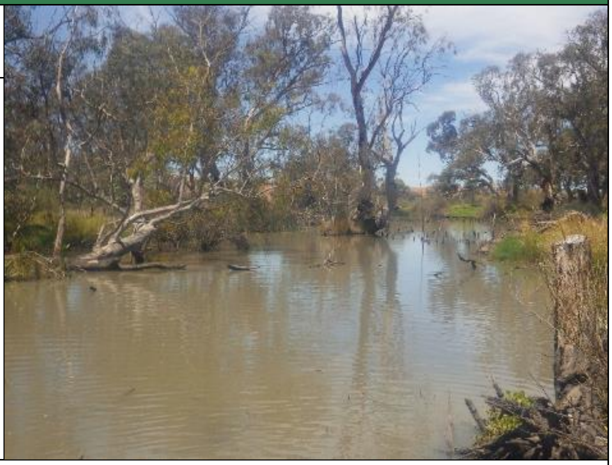
REINTRODUCTION/REINFORCEMENT/SURROGATE

Wall Flat

TARGET SPECIES

Southern Purple-spotted Gudgeon

Background: Wall Flat is a shallow wetland located directly across the main river channel from Ponde SA. Wall Flat wetland it is now permanently inundated under regulated conditions. The wetland has connection with the main river channel through a number of small inlets.



Pre-assessment

Water permanency: Although management aims for a variable water regime, the wetland artificially maintains water permanency.

Location: Within the single management unit.

Site management: Wall Flat wetland is located on Private land and water levels are maintained through river flow management ensuring that areas of permanent water are maintained.

Specific site survey & assessment

Habitat suitability: At the time of assessment (December 2018), the wetland was shallow turbid and no submergent aquatic vegetation was detected but good levels of emergent vegetation were present and some additional structurally complex habitat in the form of dead trees.

Water quality: At the time of assessment, hydrological variables were suitable for the species, namely, dissolved oxygen (8.81mgL^{-1}), pH (7.59) and water temperature (28.40°C), however, the electrical conductivity (461μScm^{-1}) may be too fresh for Murray Hardyhead to flourish.

Food resources: Low to moderate levels of macroinvertebrates (predominately *Notonectidae*).

Prevailing fish species: Nine species were recorded in the recent survey. This included freshwater generalists, diadromous species and alien species. The most abundant species were the native Unspecked Hardyhead and Carp Gudgeons. Three introduced species were recorded in low abundance, these species were: Redfin Perch, Eastern Gambusia and Common Carp

Final assessment

UNSUITABLE

Justification: The outcomes of the assessment indicate that the site is currently unsuitable for the reintroduction of Murray Hardyhead, this is largely due to the likely high degree of competition for habitat and food resources from high abundance Unspecked Hardyhead and Carp Gudgeon.

6.3 Next steps

The present report provided preliminary site identification and assessment, which leads to a number of priority and subsequent actions (Table 6-6). For the priority site (Ramco Lagoon) there is a requirement to confirm the suitability of habitat and water quality and support of land managers before reintroductions of Murray Hardyhead can be initiated. For the sites requiring future assessment the priority action is to determine the appropriate timing of this assessment to allow confirmation of general and specific site suitability as well exploring complementary actions to enhance habitat and water quality suitability. Lastly, the broad requirement for a more strategic evaluation of sites potentially suitable for the target species will require stakeholder engagement and species-specific habitat suitability modelling before sites can be identified to be subjected to the two-stage criteria of assessment.

Table 6-6. Recommended priority and subsequent actions for potential translocation sites across the SA MDB region.

Sites	Priority actions	Subsequent actions
Priority site: Ramco Lagoon	• Confirm suitable habitat and water quality at end of summer • Obtain support from land managers	• Initiate reintroductions of Murray Hardyhead to site
Sites requiring future assessment	• Determine appropriate timing of stage 2 assessment • Explore complimentary actions to enhance habitat and water quality	• Confirm stage 1 suitability • If warranted, undertake stage 2 assessment and make recommendations
All sites across SA MDB region (including those previously deemed unsuitable)	• Conduct expert workshop to discuss broader site identification and assessment • Undertake comprehensive site evaluation employing species-specific habitat suitability modelling	• Identify sites to assessed

6.4 Conclusions and recommendations

A single site (Ramco Lagoon) appears suitable for the translocation of any of the target species. Depending approval from site managers and confirmation of suitable condition toward the end of the summer drawdown period, it is recommended to initiate reintroduction of the species to the site. From the present process, however, it is evident that the majority of managed wetlands across the SA MDB region maintain water permanency and management regimes that are incongruent with the requirements of the target species. This emphasises that identification of priority translocation sites can be problematic where management focuses on reinstating drying periods as part of reinstating variable water levels.

To identify the number of sites recommended in the present strategy, more comprehensive site evaluation employing species-specific habitat suitability modelling is warranted. Equally, at strategic sites there will need to be greater commitment to conservation of the target species. The successful implement of the present translocation strategy will depend on exploring the potential of these opportunities.

Section 7 GENERAL DISCUSSION

7.1 A critical moment in time

The target threatened small-bodied freshwater fishes – Murray Hardyhead, Southern Pygmy Perch, Southern Purple-spotted Gudgeon and Yarra Pygmy Perch – face an uncertain future in the SA MDB region. Having experienced historical declines, these species were profoundly impacted by the Millennium Drought, which led to declines in known range and abundance, and threatened regional persistence. In fact, Southern Purple-spotted Gudgeon and Yarra Pygmy Perch were believed to have become extinct regionally at this time (Hammer *et al.* 2013; Hammer *et al.* 2015; Wedderburn *et al.* 2014). Yet, the foresight of a few researchers and managers allowed fish to be rescued, which in turn allowed captive and surrogate populations to be established and enabled a series of small-scale and short duration reintroductions into former habitats to take place. Whilst there were short- to medium-term signs of success (persistence for up to 18 months; wild recruitment), the reintroductions failed to reestablish self-sufficient populations. The scale of previous efforts did not match the severity of the problem and a clear understanding of the magnitude of what is required in an attempt to reestablish self-sustaining populations of the four target species was lacking.

Thus, we now reach a critical point in time; where sustained translocations are required to lessen the risk of regional extinction of each target species as well as allowing for the ability to capitalise on the opportunities provided by other interventions.

7.2 An appreciation of what is required; is it realistic?

The present report articulates a translocation strategy deemed necessary to attempt to reestablish resilient, connected populations to help secure the long-term survival of each target species in the SA MDB region. The strategy is predicated on two assumptions; (a) that a greater scope for releases (numbers, duration) will increase the likelihood of establishment at a wild site, and (b) considerably more (than present) resilient, connected subpopulations are required to reduce extinction risk. Accordingly, the strategy requires substantially expanded fish production to allow for the release of much greater numbers of fish over more years across more sites (five sites in five years; 10 sites in 10 years). Insight into the scope of fish production could be gained through population modelling of reintroduction scenarios (see Todd *et al.* 2017).

This will be confronting as it will require considerably greater effort and investment; but, what of the alternatives? Table 7-1 provides some guidance of the anticipated outcomes under three scenarios: 1) do nothing, 2) continue existing effort, or 3) the translocation strategy is implemented.

Table 7-1. Anticipated outcome of 'doing nothing', 'continue existing effort' and 'implement the translocation strategy' scenarios relevant to the present strategy (timeframe is 10 years).

Scenario	Species	Anticipated outcome
Doing nothing	MHH	• Lower Murray management unit: gradual (natural) increase in range across Lake Alexandrina/Goolwa Channel/lower reaches of EMLR but still absent from former habitats (Lake Albert) • Mid-Murray management unit: persisting at known managed sites
	SPP	• Persisting in Lake Alexandrina/Hindmarsh Island and some streams of EMLR, but susceptible to disturbance events
	SPSG	• Regionally extinct
	YPP	• Regionally extinct
	All	• Loss of most captive and surrogate populations
Continue existing effort	MHH	• Lower Murray management unit: greater expansion of range across Lake Alexandrina/Goolwa Channel/lower reaches of EMLR) and possible reestablishment in Lake Albert • Mid-Murray management unit: persisting at known managed sites and reintroductions underway at additional sites
	SPP	• Overall persistence, with the loss of some sites (likely EMLR) but recolonsation of others
	SPSG	• Possibly reestablished at one wild site
	YPP	• Regionally extinct
	All	• Maintenance of some captive and surrogate populations
Implement the translocation strategy	MHH	• Lower Murray: Persistence three known sites; reestablished at seven additional sites • Mid-Murray: Persistence two known sites; reestablished at eight additional sites
	SPP	• Persistence of known sites
	SPSG	• Persistence at known site; reestablished at nine additional wild sites
	YPP	• Reestablished at 10 wild sites
	All	• 10 captive and surrogate population for each target species

Under the 'doing nothing' scenario, it is anticipated that both Southern Purple-spotted Gudgeon and Yarra Pygmy Perch will be lost to the SA MDB region, whereas Murray Hardyhead and Southern Pygmy Perch will have gradual natural expansion across their former range (although remaining absent from other areas). Importantly, the 'continued existing effort' scenario will allow for the persistence of Southern Purple-spotted Gudgeon, but possibly only at one site, and the reestablishment of Murray Hardyhead in areas (i.e. Lake Albert and additional sites in mid-Murray) where natural recolonisation is not likely, although the regional extinction of Yarra Pygmy Perch is not everted. Lastly, with successful implementation of the translocation strategy it is anticipated that 10 wild sites (in each management unit) will be reestablished for each target species. This translocation strategy highlights the intensity of the situation at hand. Without appreciation of this risk, but also the opportunity, the loss of species will be inevitable.

7.3 Implications across the southern MDB

Each of the target species, with the exception of Yarra Pygmy Perch, historically occurred more broadly across the southern MDB. However, across other areas of the southern MDB, Murray Hardyhead, Southern Purple-spotted Gudgeon and Southern Pygmy Perch have equally experienced the loss of subpopulations, which has placed regional populations at risk. With this recognition, the present strategy was developed in a manner where it could be applicable to the translocation of the target species across the southern MDB. Further, to be able to achieve the objectives for the reestablishment of subpopulations outlined in the strategy (i.e. at least five subpopulations in five years; 10 subpopulations in 10 years), it may be necessary to undertake translocations into Victoria and NSW. This is emphasised by the yielding of only a handful of suitable translocation sites during preliminary identification and assessment as part of the present report. Clearly, additional SA MDB region priority translocation sites may be revealed in the future, particularly through systematic evaluation of suitable habitats (see Section 4), but expanded consideration will remain warranted. In the case of Murray Hardyhead, the initiation of the reestablishment of recent Victorian and NSW subpopulations may act to offset the requirement of identifying additional SA MDB region priority sites. In reality, broader translocation may represent the only way that the objectives relating to geographic range (i.e. extent of occurrence and area of occupancy) and improving the conservation status of each target species can be realised.

The cross-border movement of threatened fish creates administrative and implementation complexity. Strong multi-jurisdiction collaboration is critical to overcome potential problems associated with legislation, communication, efficiency and effectiveness. Encouragingly, recent translocation of Murray Hardyhead from SA to both Victorian and NSW wetlands demonstrated the potential, but also highlighted aspects that need to be streamlined. Moving forward, development of, and commitment to, a multi-jurisdiction strategy will help translocations such as these to become more routine. Lastly, it is hoped that multi-jurisdiction collaboration will promote a heightened level of interest and attention in the conservation of threatened small-bodied freshwater fishes.

7.4 Conclusions and recommendations

Small-bodied freshwater fishes, including the four target species of the present strategy, are particularly threatened across the Murray-Darling Basin. These species have experienced historical declines, which were compounded most recently by the prolonged and extreme Millennium Drought. The SA MDB region – representing a hotspot for small fishes – was profoundly impacted by the drought, with the significant deterioration and loss of aquatic habitat. In turn, populations of four target species were lost and regional extinction of two small fish species was believed to have occurred. The foresight of certain researchers to rescue fish from deteriorating habitats at this time, has allowed translocations aimed at returning fish (and species) to former habitats.

Thus, a critical moment in time has been reached where concerted actions are required to exert species loss. The present report represents an important step forward in that is articulates a strategy of sustained translocations to reestablish resilient, connected populations to help secure the long-term survival of each target species in the SA MDB region. This will require expanded fish production to fulfil the greater numbers of fish required to be released over a longer duration, at each translocation site (i.e. more fish, more often). In time, a network of wild subpopulations (known and reestablished) are needed to reduce the risk of regional extinction of the targeted species. Appropriate genetic management and monitoring and evaluation is critical, as will be consideration of drought and future climates. Equally important will be the identification of high priority translocation sites, which maintain abiotic and biotic conditions, as well as appropriate management. In summary, the present translocation strategy highlights the intensity of the situation at hand. Without appreciation of this risk, and a long-term commitment by a range of stakeholders, the loss of species will be inevitable. This strategy could be considered a working document that can be amended as new knowledge is gained.

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