Inland Waters & Catchment Ecology

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The Critical Fish Habitat Project: Reintroductions of threatened fish species in the Coorong, Lower Lakes and Murray Mouth region in 2011/12

C. Bice, N. Whiterod, P. Wilson, B. Zampatti and M. Hammer

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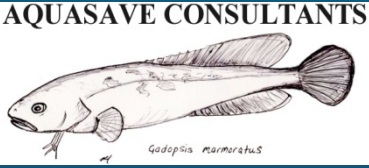

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Executive summary

Dramatic water level recession and habitat degradation (e.g. elevated salinity, loss of submerged macrophytes) in the Lower Lakes over the period 2007 – 2010 placed several species of threatened fish under risk of extirpation. Thus the South Australian Drought Action Plan (DAP) for Murray-Darling Basin (MDB) Threatened Freshwater Fish Populations was initiated with the objective of conserving threatened fish species during this period. In some cases, this necessitated removal of individuals from the wild, captive maintenance and breeding, with the objective of re-introducing fish to wild habitats upon the return of favourable conditions.

In 2010/11, broad-scale rainfall and significant inflows in the MDB resulted in increased flows to South Australia and improved flow and habitat availability in local stream tributaries. As such, by spring 2011 water levels in Lake Alexandrina had returned to typical regulated levels and aquatic habitat (i.e. submerged and emergent vegetation) was beginning to show signs of recovery. Thus, it was deemed there was the potential for reintroduction of fish captively maintained and bred since 2007.

The Critical Fish Habitat (CFH) project was developed to provide a framework to guide and undertake reintroductions of threatened fish species to the Coorong, Lower Lakes and Murray Mouth (CLLMM) region, namely Yarra pygmy perch (*Nannoperca obscura*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*) and Murray hardyhead (*Craterocephalus fluviatilis*). The CFH project is projected to run until 2013 and ultimately aims to restore wild self-sustaining populations of these species in the region.

More specifically, the CFH project aims to increase the likelihood for successful reintroductions by (1) identifying potential receiving sites, (2) developing and undertaking a screening process to assess the suitability of receiving sites (e.g. presence of favourable habitat, prey resources and water quality), (3) determining a method for fish release (i.e. matching the scale of captive outputs to release site number and spatial extent, transport, acclimatisation, hard vs. soft release), (4) undertaking fish releases, and (5) developing and conducting a monitoring and evaluation program to assess the success of the reintroduction.

A total of 20 sites were deemed generally suitable for reintroductions. These sites then underwent screening to further determine their suitability, based on a series of predetermined species-specific criteria (e.g. defined levels of habitat cover). Fish, macroinvertebrate, habitat and water quality monitoring was undertaken at these sites in spring 2011 and summer/autumn 2012, prior to reintroductions. In spring 2011, two sites were deemed suitable for reintroductions of Yarra pygmy perch, two for southern pygmy perch and one for southern purple-spotted gudgeon. In

summer/autumn 2012, a further two sites were deemed suitable for releases of Yarra pygmy perch, one further site for southern pygmy perch, one for Murray hardyhead and one for southern purple-spotted gudgeon.

Two rounds of reintroductions have now been completed, in November 2011 and March 2012. Individuals were sourced from various locations including three different hatcheries (Aquasave – Native Fish Australia (Todd Goodman), Alberton Primary School and the Flinders University threatened fish ARC Linkage grant genetics project) and three different surrogate dams (Table 1). A total of about 10,300 individuals were released into the CLLMM region in 2011/12 across the four species at a total of nine sites (Table 1). All fish were marked with calcein prior to release to allow for differentiation of reintroduced and wild fish recaptured during the subsequent monitoring program.

Table 1. Summary of sites and numbers of Yarra pygmy perch, southern pygmy perch, southern purple-spotted gudgeon and Murray hardyhead released during spring 2011 and autumn 2012 reintroductions. The source of reintroduced fish is coded as either (1) surrogate dams (Crouch Dam (CD), Oster Dam (OD) or Munday Dam (MD)), (2) Flinders University (FU) either equal (EC) or unequal (UC) contribution from broodstock, (3) the Aquasave Hatchery (AQ), (4) Alberton Primary Hatchery (AP) or (5) wild individuals that were maintained in captivity (Wild).

Site name	Species released	Numbers released (approx.)	Source	Release date
Spring 2011				
Natural channel connected to Hunters Creek	Southern pygmy perch	770	FU (EC)	2 Nov 2011
Turvey's drain	Southern pygmy perch	300	Wild, FU	9 Nov 2011
Blue Lagoon	Yarra pygmy perch	400	CD	8 Nov 2011
Finniss River junction	Yarra pygmy perch	800	CD	8 Nov 2011
Finniss at Winery Road	Southern purple-spotted gudgeon	200	AQ	9 Nov 2011
Autumn 2012				
Mundoo Island Channel east 2	Southern pygmy perch	280	FU (UC)	29 Mar 2012
Streamer Drain	Yarra pygmy perch	2200	FU (EC)	27 Mar 2012
Shadows Lagoon	Yarra pygmy perch	1500	CD, OD, FU	29 Mar 2012
Finniss at Winery Road	Southern purple-spotted gudgeon	400	AQ, AP	29 Mar 2012
Mundoo Island Channel east 1	Murray hardyhead	3500	MD	28 Mar 2012

Fish monitoring conducted for site assessments in summer/autumn 2012 fulfilled the complementary role of post-reintroduction monitoring for the spring 2011 releases. Including data from other monitoring in the region, a total of 10 southern pygmy perch have been recaptured and there was evidence of wild recruitment (most likely progeny of reintroduced individuals). Additionally, there have been three recaptures of southern purple-spotted gudgeon. No Yarra pygmy perch have been recaptured since reintroduction and post-reintroduction monitoring has yet to be conducted for the Murray hardyhead releases.

The reintroduction of fish into wild habitats and restoration of viable, self-sustaining populations is a difficult task. Nonetheless, the initial results from the current project are encouraging. Two of the reintroduced species had survived in the wild for approximately four months and an indication of recruitment for southern pygmy perch following the initial release suggest that reintroductions have a high likelihood of success for this species. Further releases of all species are planned for 2012/13, with follow-up monitoring to determine the success of these actions.

1. Introduction

River regulation and a history of over-abstraction have greatly reduced freshwater flows throughout the Murray-Darling Basin (MDB) (Kingsford 2000). The situation was exacerbated over the period 1997 – 2010 when the most severe drought in recorded history was experienced in the MDB (Murphy and Timbal 2008), resulting in significantly diminished freshwater flows to South Australia. The impact was perhaps greatest in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region at the terminal end of the MDB, where the water level in Lake Alexandrina fell below sea level for the first time in recorded history, accompanied by significant reductions in submerged aquatic vegetation cover, disconnection of fringing vegetation habitats and elevated salinity (Kingsford *et al.* 2011). This in turn resulted in substantial declines in threatened freshwater fish species, several of which were exposed to extreme risk of local extinction (Wedderburn *et al.* 2012). Subsequently, measures were taken to prevent the extirpation of select threatened species in the CLLMM region through the South Australian Drought Action Plan (DAP) for Murray-Darling Basin Threatened Freshwater Fish Populations (Hall *et al.* 2009). In several instances this necessitated removal of individuals from the wild, captive maintenance and breeding, with the objective of re-introducing fish to wild habitats upon the return of favourable conditions (see Hammer 2008).

Captive breeding programs were established for at least one population of all five threatened species investigated under the DAP; namely Yarra pygmy perch (*Nannoperca obscura*), southern pygmy perch (*Nannoperca australis*), southern purple-spotted gudgeon (*Mogurnda adspersa*), Murray hardyhead (*Craterocephalus fluviatilis*) and river blackfish (*Gadopsis marmoratus*) (Table 2).

Table 2. Summary of key threatened fish species in the CLLMM region and their conservation status. Conservation status is coded as Critically Endangered (CR); Endangered (E); Vulnerable (VU); Rare (R); and Protected (P) at national (*Environment Protection and Biodiversity Conservation Act 1999*), state (*Fisheries Management Act 2007*) and interim state listings (Hammer *et al.* 2009c).

Species	**International** (IUCN)	**National** (EPBC Act)	**State Fisheries**	**Action Plan 09**	**Local significance**
Yarra pygmy perch	VU	VU	P	CR	A genetically distinct population of this species. Lake Alexandrina represents the only known MDB population.
Southern pygmy perch	-	-	P	E	SA MDB fish are genetically distinct and diverse (populations are found only in the Lower Lakes and their tributaries)
River blackfish	-	-	P	E	Relict lower Murray population
Murray hardyhead	E	CR	P	CR	Endemic species, few populations remain (two genetically different populations in SA, one of which is present in the lower lakes)
Southern purple-spotted gudgeon	-	-	P	CR	Only known southern MDB population (present in the Lower Murray region, below Lock 1, historical records in CLLMM site)

Captive maintenance and breeding programs utilised various 'housing' and rearing techniques including aquaria, pond and surrogate (dam) population establishment, and programs for different species met with varying success (Hammer 2008; Hammer *et al.* 2009a; Hammer *et al.* 2009b; Westergaard and Ye 2010). Concurrently, Flinders University, together with several other industry partners, initiated a project with the objective of enhancing the captive breeding programs by determining breeding pair choices for optimal offspring fitness for each species (Carvalho *et al.* 2011; Carvalho *et al.* 2012a; Carvalho *et al.* 2012b). Captive maintenance and breeding programs involved collaboration between many different agencies including Aquasave, Native Fish Australia (SA), the Department of Environment Water and Natural Resources (DEWNR; formerly DENR), Flinders University, SARDI, the Murray-Darling Freshwater Research Centre (Mildura), Alberton Primary School and Urrbrae Agricultural College.

Multiple and consecutive years of below average inflows were followed in 2010/11 by broad-scale rainfall and significant inflows in the MDB. This resulted in increased flows to South Australia and improved flow and habitat availability in local stream tributaries. As such, favourable hydrology was restored to most catchments and therefore to sites where threatened fish species were deemed at risk of extirpation between 2007 and 2010. The water level in Lake Alexandrina increased rapidly in 2010, rising above sea level and reaching typical regulated levels (~0.75 m AHD, Australian Height Datum) by September 2010 (DEWNR 2012). Increased inflows and water level restoration in Lake Alexandrina resulted in decreased salinities (DEWNR 2012) and the reconnection of formerly isolated habitats, with submerged and fringing emergent vegetation communities exhibiting signs of recovery (Gehrig *et al.* 2011). Thus, there was potential for threatened species, maintained and bred as part of the various captive maintenance/breeding programs, to be reintroduced into former wild habitats.

In order to maximise the benefit of the surrogate refuge and captive maintenance, and breeding programs undertaken or facilitated through the DAP, the Critical Fish Habitat (CFH) Project was developed to provide a scientifically rigorous framework to guide and undertake re-introductions of threatened fish into the CLLMM region. The CFH project is anticipated to run until 2013 and ultimately aims to restore self-sustaining populations of threatened fish species through specific inter-annual objectives. Due to difficulties with captive rearing and improvement in known wild populations, it was determined to not reintroduce river blackfish as part of the CFH project. Thus in 2011/12, the primary objectives of the CFH project were to re-establish self-sustaining wild populations of:

- **Yarra pygmy perch** at 3 or more sites within the species' previous area of occupancy (as of 2005) in the CLLMM region. This encompasses an area from the railway bridge on the Finniss River (below Winery Road) through Wally's Wharf and Goolwa channel to the eastern side of Mundoo Island.

- **Southern pygmy perch** at 3 or more sites within the species' previous area of occupancy (as of 2005) in the CLLMM region. This encompasses an area from Pelican Lagoon in the north, near the confluence of the River Murray and Lake Alexandrina, to Hindmarsh Island in the south and Wally's Wharf on the Finniss River in the west.
- **Murray hardyhead** at 3 or more sites within the species' previous area of occupancy (as of 2005) in the CLLMM region. This encompasses Lakes Alexandrina and Albert and previous core habitat such as Hindmarsh Island, Dunns Lagoon and Waltowa.
- **Southern purple-spotted gudgeon** at 1 or more sites within the species' previous area of occupancy (as of 1960) in the CLLMM region. This encompasses the lowland braided channel and wetlands of the Finniss River from the railway bridge through to Wally's Wharf.

To meet these objectives, however, a holistic approach was required, which considered many factors including knowledge and status of threatening processes, past and current environmental conditions, and species' former range and biology, among others. As such, the CFH reintroduction framework was developed (see Watt *et al.* 2011) based upon the framework of Hammer *et al.* (2009a) and a review by George *et al.* (2009). This framework aims to increase the likelihood of success of the current reintroductions by (1) identifying potential receiving sites, (2) developing and undertaking a screening process to assess the suitability of receiving sites, (3) determining a method for fish release (i.e. matching the scale of captive outputs to release site number and spatial extent, fish training, transport, acclimatisation, hard vs. soft release), (4) undertaking fish releases and (5) developing and conducting a monitoring and evaluation program to assess the success of the reintroductions (Hammer *et al.* 2009a; Watt *et al.* 2011). The present report summarises the implementation of this framework - identification of potential reintroduction site selection, assessment of site suitability and reintroductions of fish species - in the CLLMM region in spring 2011 and autumn 2012, and assesses the success of these actions.

2. Methods

2.1 Selection of potential reintroduction sites

A total of 19 sites across the CLLMM region were selected as potential reintroduction sites for target species in 2011/12 (Table 3; Figure 1). These sites were selected based upon knowledge of the previous presence and abundance of these species, with particular consideration of these population metrics in, or prior to 2005. Several sources of information are available on the pre-2005 distribution and abundance of Yarra pygmy perch, southern pygmy perch and Murray hardyhead, including Hammer *et al.* (2002), Wedderburn and Hammer (2003), Higham *et al.* (2005) and Bice and Ye (2006). Potential site selection was limited to sites where these species were previously abundant, rather than present in low numbers, to enable thorough assessment of sites with the greatest likelihood of successful reintroduction. Additionally, certain sites are notable for the former co-occurrence of these species and thus, some sites are candidates for reintroductions of multiple species (Table 3).

The selection of potential receiving sites for southern purple-spotted gudgeon followed a different approach due to the likely long-term absence (since the 1960s) of the species from the CLLMM region (Hammer *et al.* 2009a). As such, there is no contemporary data and little historical data on the distribution and abundance of this species in the CLLMM region. However Hammer *et al.* (2009a) documented records of the species from the lower Finniss River as recently as the late 1960s adding to earlier observations from the 1920s (Nettlebeck 1926; Rutherford 1991). Thus potential reintroduction for this species was limited to one site (Table 3).

Table 3. List of proposed receiving sites for reintroductions of southern purple-spotted gudgeon (SPSG), Yarra pygmy perch (YPP), southern pygmy perch (SPP) and Murray hardyhead (MHH) in 2011/12.

Site name	Site #	Sub-region	Proposed species	Latitude	Longitude	Site assessment sampling		Reference
						Spring 2011	Autumn 2012	
Finniss above Winery Road	1	Lower Finniss	SPSG, YPP	35.396269 S	138.826406 E	Y	Y	(Hammer *et al.* 2009a)
Blue Lagoon	2	Lower Finniss	YPP	35.429166 S	138.859059 E	Y	Y	(Wedderburn and Hammer 2003)
Finniss River junction	3	Goolwa Channel	YPP, SPP	35.486760 S	138.893200 E	Y	Y	(Hammer 2008)
Hunters Creek (upstream of Denver Rd causeway)	4	Hindmarsh Island	YPP, SPP, MHH	35.527571 S	138.897927 E	Y	Y	(Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007)
Hunters Creek (downstream of Denver Rd causeway)	5	Hindmarsh Island	YPP, SPP, MHH	35.527021 S	138.893191 E	Y	Y	(Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007)
Eastick Creek	6	Hindmarsh Island	YPP, SPP, MHH	35.536366 S	138.921670 E	Y	N	
Drain behind Wyndgate	7	Hindmarsh Island	YPP, SPP	35.527249 S	138.904974 E	N	Y	(Bice and Ye 2006)
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	8	Hindmarsh Island	YPP, SPP, MHH	35.525690 S	138.898997 E	Y	Y	(Higham *et al.* 2005; Bice and Ye 2006; Bice and Ye 2007)
Steamer drain	9	Hindmarsh Island	YPP, SPP	35.53146 S	138.90810 E	Y	Y	(Bice *et al.* 2011)
Holmes Creek at Eastick Creek mouth	10	Hindmarsh Island	YPP	35.53778 S	138.92175 E	Y	Y	(Bice and Ye 2007; Hammer 2007a; Hammer 2008)
Turvey's drain	11	Milang	SPP	35.39472 S	139.00804 E	Y	Y	(Bice *et al.* 2009; Hammer 2009b; Bice *et al.* 2010)
Currency Creek Game Reserve	12	Goolwa Channel	YPP	35.49335 S	138.82333 E	Y	Y	(Hammer 2008)
Black Swamp	13	Lower Finniss	YPP	35.43119 S	138.84875 E	Y	Y	(Hammer 2009b)
Mundoo Island Channel east*	14	Mundoo Island	MHH	35.54765 S	138.91821 E	N	Y	(Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010)
Mundoo Island Channel west*	15	Mundoo island	SPP, MHH	35.54848 S	138.91566 E	N	Y	(Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010)
Boundary Creek drain*	16	Mundoo Island	MHH	35.55242 S	138.94520 E	N	Y	(Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010)
Boggy Creek*	17	Hindmarsh Island	MHH	35.52107 S	138.92888 E	N	Y	(Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010)
Dunn's Lagoon*	18	Clayton	MHH	35.50246 S	138.93180 E	N	Y	(Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007; Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010)
Shadows Lagoon*	19	Hindmarsh Island	YPP	35.51738 S	138.91756 E	N	Y	(Wedderburn and Barnes 2011; Kevin Wells Pers. Comm.)

Denotes sites monitored by the University of Adelaide as part of the Murray-Darling Basin Authority's 'The Living Murray' Program.

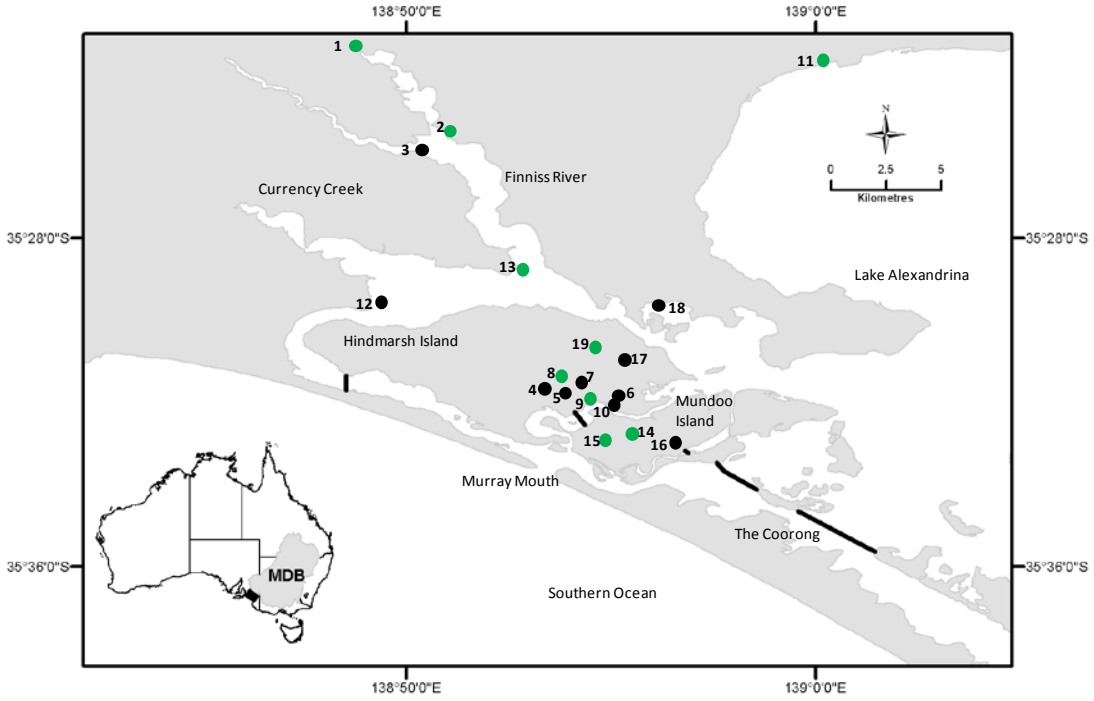

Figure 1. Summary of potential (black) and actual (green) reintroduction sites for southern purple-spotted gudgeon, Yarra pygmy perch, southern pygmy perch and Murray hardyhead in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region in 2011/12. Murray Barrages are indicated by bold lines. Site numbers are cross referenced in Table 3.

2.2 Suitability of potential reintroduction sites

Criteria

The suitability of the potential reintroduction sites listed in Table 3 was assessed against a range of general criteria using a two-stage framework (Hammer *et al.* 2009a; Watt *et al.* 2011) (Table 4). The initial step was to assess the general site suitability (stage 1), most importantly by ensuring that the key threatening process leading to the risk of extirpation was alleviated. In regards to the potential reintroduction sites across the CLLMM region and the target species in the current project, the key threatening process was reduced freshwater inflows leading to significant water level recession, habitat loss (i.e. submerged vegetation) and habitat fragmentation (Kingsford *et al.* 2011; Wedderburn *et al.* 2012). Thus, water security must be favourable, particularly during seasonal dry or low-flow periods (e.g. late summer – autumn) but also over longer time scales, in order for reintroduction to occur at any given site. Other important preliminary criteria relate to the feasibility of management intervention and the commitment of site stakeholders to species recovery and site management. If the site is deemed to be generally suitable for reintroduction, a specific site assessment is necessary.

Table 4. Summary of criteria in the reintroduction framework for CLLMM region threatened species (modified from Hammer *et al.* 2009a).

Site name	Considerations	Criteria to move to next stage
General site suitability (stage 1)	Key threatening process	Key threatening process alleviated?
	Hydrology/water security	Broad-scale hydrology and water security?
	Management feasibility	Ability for individual site management intervention?
	Stakeholders	Commitment to species recovery/restoration?
Specific site assessment (stage 2)	Hydrology	Adequate water levels over the next 1-2 years?
	Fish community	Reintroduction unwarranted, if target species present? No/few introduced (namely predators) species?
	Physico-chemistry	Salinity below tolerance/within preferred range? Dissolved oxygen above tolerance? pH within suitable range?
	Habitat	Suitable composition and proportion of habitat cover for target species?

The stage 2 assessment aimed to evaluate the present suitability of sites in terms of a range of species-specific biotic and abiotic parameters. Criteria are set to ensure fish are returned to habitats that are favourable in regards to water quality, provision of resources (e.g. prey abundance), shelter and spawning habitat, whilst not placing individuals into situations of intense competition or predation; thus maximising the likelihood of success from reintroductions. For each target species, specific physico-chemical and habitat criteria, based upon published data and from local sources (where possible), were evaluated to assess site suitability (Table 5). Nonetheless, expert opinion also played a significant role in the selection of reintroduction sites.

Table 5. Species-specific criteria for reintroduction of CLLMM region threatened fish species.

Target species	Physico-chemical parameters			Aquatic habitat			Food resources	Introduced predators/competitors abundance				References
	Salinity (μScm^{-1})	Dissolved oxygen (mgL^{-1})	pH	Species composition (submerged)	Species composition (emergent)	Percentage (%) physical habitat	Presence of prey resources of varying sizes (Y/N)	Redfin perch (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Yarra pygmy perch	<3000	>2.0	4-10	*Myriophyllum* sp, *Ceratophyllum demersum*, *Vallisneria australis*	*Schoenoplectus validus*	>50%	Y/N	<15 per 4 nets	<30 per net	<20 caught or observed	<100 per net	(Roberts *et al.* 1995; Mittlebach and Persson 1998; Wedderburn and Hammer 2003; Bice and Ye 2006; Hammer 2007b)
Southern pygmy perch	<3000	>2.0	4-10	*Myriophyllum* spp, *Ceratophyllum demersum*, *Vallisneria australis*	*Typha* spp and overhanging and fringing grasses	>50%	Y/N	<15 per 4 nets	<30 per net	<20 caught or observed	<100 per net	(Roberts *et al.* 1995; Mittlebach and Persson 1998; Hammer 2004; Hammer 2005; McNeil and Closs 2007)
Murray hardyhead	800-25,000	>2.0	4-10	*Myriophyllum* spp, *Potamogetan pecinatus*, *Ruppia* spp., *Vallisneria australis*	*Paspalum*, cooch, other	>30%	Y/N	<15 per 4 nets	<30 per net	<20 caught or observed	<100 per net	(Mittlebach and Persson 1998; Wedderburn and Hammer 2003; Bice and Ye 2006; Bice and Ye 2007; Hammer and Wedderburn 2008; Wedderburn *et al.* 2008; Hammer *et al.* 2009c; Bice *et al.* 2011)
Southern purple-spotted gudgon	800-5,000	>3.0	7-10	*Myriophyllum* spp, *Ceratophyllum demersum*, *Vallisneria australis*	*Schoenoplectus validus*, *Triglochin procerum*	>30% (includes other phys habitat e.g. woody debris)	Y/N	<15 per 4 nets	<30 per net	<20 caught or observed	<100 per net	(Nettlebeck 1926; Roberts *et al.* 1995; Mittlebach and Persson 1998; Llewellyn 2006; Hammer *et al.* 2009a)

2.3 Specific site assessment

Fish monitoring

To assess potential reintroduction sites against fish related criteria, monitoring of fish assemblages was carried out prior to reintroductions in spring (10/10/2011 – 14/10/2011) and summer/autumn (27/02/2012 – 23/03/2012). Sampling methods and effort matched prevailing environmental conditions at each site, with five single-winged fyke nets (four 6 m wing length, 0.6 m entry diameter and 0.003 m mesh; one 3 m wing length, 0.6 m entry diameter and 0.004 m mesh; Figure 2) set overnight at all sites, except the Finniss River at Winery Road. Fyke nets were set perpendicular to the bank, where possible, in habitat that was representative of the site being sampled. The Finniss River at Winery Road was sampled using a Smith-Root model LR-24 backpack electrofisher and a series of 20 box traps (0.4 m length x 0.24 m width x 0.24 m height, 0.03 m opening). This site was sampled with this technique due to its differing physical characteristics and also the potential ineffectiveness of fyke nets for sampling southern purple-spotted gudgeon in complex habitat. Some sites are monitored by the University of Adelaide as part of the Murray-Darling Basin Authority's (MDBA) *The Living Murray Program* and data are shared between these projects (Table 3).

Figure 2. Fish sampling in the Natural Drain connected to Hunters Creek (behind DENR-Wyndgate).

All fish sampled were indentified to species and enumerated. All threatened and non-native species sampled were measured for length (mm, total length (TL) or fork length (FL) depending on tail morphology) for up to 50 individuals per species per site. Select individuals were photographed at each site as identification vouchers. Sampling was conducted under a *Section 115 permit* in accordance with the *Fisheries Management Act 2007* and PIRSA Animal Ethics Committee standards.

Macroinvertebrate monitoring

A simple assessment of macroinvertebrate diversity and abundance accompanied fish monitoring to investigate the presence of adequate food resources for reintroduced fish. This involved the sampling of all major habitats at a site, using a 250 µm mesh dip net, for a total of 30 seconds. The contents were emptied onto a white tray, and where possible, debris and leaf litter were discarded after dislodging any attached macroinvertebrates. Macroinvertebrates were recorded to the family level using a modified 'Waterwatch' catalogue. A subjective abundance score (rare, uncommon, common, abundant, and very abundant) was assigned to macroinvertebrate taxa.

Environmental descriptors

To assess potential reintroduction sites against criteria related to habitat and water quality, the composition of physical habitat available was evaluated and water physico-chemical parameters described. Physical habitat cover was described (by visual estimation) as the proportion of aquatic habitat area (i.e. below the water surface) comprised of submerged vegetation, emergent vegetation, other physical structure (e.g. woody debris, rock) and open water. A series of random depth measures were also taken to determine mean depth at the site and a maximum depth was also determined by attempting to locate the deepest point at the site.

Various physico-chemical parameters were measured at each site. Turbidity was measured as secchi depth (m) using a secchi disk, whilst the following parameters were measured with a TPS 90-FLT water quality meter: conductivity ($\mu S.cm^{-1}$), pH, dissolved oxygen (ppm, readings at surface and at depth) and temperature (˚C).

2.4 Reintroduction methodology

Fish maintenance

Reintroductions of threatened fish were undertaken during late spring (02/11/2011 – 09/11/2011) and early autumn (26/03/2012 – 30/03/2012) following site assessment monitoring. All fish were transported from the various hatcheries (i.e. Flinders University, Aquasave Hatchery) and surrogate refuges to SARDI Aquatic Sciences approximately three weeks prior to release in order to undertake calcein staining (see below) and veterinary checks. Fish were held in a series of 5000 L (x 2) and 1000 L (x 12) aerated aquaculture pools. Temperatures were maintained between 15 and 22˚C and salinities for southern pygmy perch, Yarra pygmy perch and southern purple-spotted gudgeon maintained at approximately 1500 $\mu S.cm^{-1}$. Murray hardyhead were held at a salinity of approximately 5000 $\mu S.cm^{-1}$.

The aquaculture pools were supplied with artificial plants to provide physical structure. Fish were fed daily, either early in the morning or late in the afternoon, on a mixed diet of live and dead foods including artemia, daphnia, copepods, chironomid larvae and black worms.

Soft release enclosures

An increasingly common practise in fish reintroductions is defined as 'soft release', which refers primarily to providing fish with an acclimatisation period at the release site prior to liberation. Transportation may elevate stress and commonly results in disorientation, which may increase predation risk (Brown and Day 2002). As such allowing fish to become accustomed to the prevailing conditions and develop accompanying natural behaviours is likely to elicit a greater survival rate. Further steps in this process may include increasing the suitability of the receiving environment through local predator removal.

All fish reintroduced into the Lower Lakes under the current project were initially released into 'soft release enclosures' (Figure 3). The enclosures were triangular in shape (~2 m x 2 m x 2 m) and clad with 6 mm stretched mesh. Prior to releases, all soft release enclosures were sampled with a Smith-Root model LR-24 backpack electrofisher, to ensure the enclosures were predator free. Following release into the enclosures, a lid of shade cloth was fastened to the top of the enclosures to minimise predation by avian and mammalian predators. Fish were maintained in the enclosures overnight and released from the enclosures in the early morning. A period of 24 hours was chosen to allow for adequate recovery from transportation and acclimation whilst limiting density-dependent negative impacts from holding fish for longer periods (i.e. aggression and limited dispersal) (Brown and Day 2002).

Figure 3. Soft release enclosures (prior to fish releases) in the Steamer Drain.

Assessment of reintroduction success

An important component of the current project was to assess the success of reintroductions. Post reintroduction monitoring is necessary to document (a) the presence and abundance, (b) distribution and (c) population demographics of reintroduced species. Additionally, the ability to differentiate between wild produced and reintroduced fish is imperative; therefore all fish reintroduced under the current project were marked with calcein prior to reintroduction.

Calcein marking

Calcein is a chemical dye, which has been shown to be effective on a wide range of fish species and when applied through the process of osmotic induction, produces an external and thus non-lethal detectable mark (Mohler 2003; Crook *et al.* 2009; Smith *et al.* 2010). Osmotic induction involves immersing fish in a salt bath prior to immersion in the fluorescent dye solution, allowing for more efficient dye uptake (Figure 4a). The 'calcein mark' may then be visible upon the fish under an ultraviolet light (Figure 4b) or may be detected with the use of a fluorometer.

The method of calcein marking utilised (i.e. salt bath concentrations) differed between species (Table 6). The salt concentrations used for southern purple-spotted gudgeon and Yarra pygmy perch were determined from quantitative laboratory trials (SARDI unpublished data; Simon Westergaard *Pers. Comm.*), whilst the concentration used for southern pygmy perch was based on that of the congeneric Yarra pygmy perch. The concentration used for Murray hardyhead was determined from a pilot study (~30 individuals). The calcein marking process was successful with limited mortality (associated with handling stress) and high calcein retention (e.g. high fluorometer readings detected for select individuals post-processing).

Table 6. Summary of calcein marking process for each target species.

Species	**Salt bath** (concentration, immersion period)	**Calcein** (concentration, immersion period)
Yarra pygmy perch	25 $g.L^{-1}$, 5 min	5 $g.L^{-1}$, 10 min
Southern pygmy perch	25 $g.L^{-1}$, 5 min	5 $g.L^{-1}$, 10 min
Murray hardyhead	50 $g.L^{-1}$, 5 min	5 $g.L^{-1}$, 10 min
Southern purple-spotted gudgeon	Spring: 70 $g.L^{-1}$, 5 min; *Autumn: 50 $g.L^{-1}$, 5 min	5 $g.L^{-1}$, 10 min

**Due to southern purple-spotted gudgeon in autumn being of a small size, salt bath concentration was reduced.*

a) b)

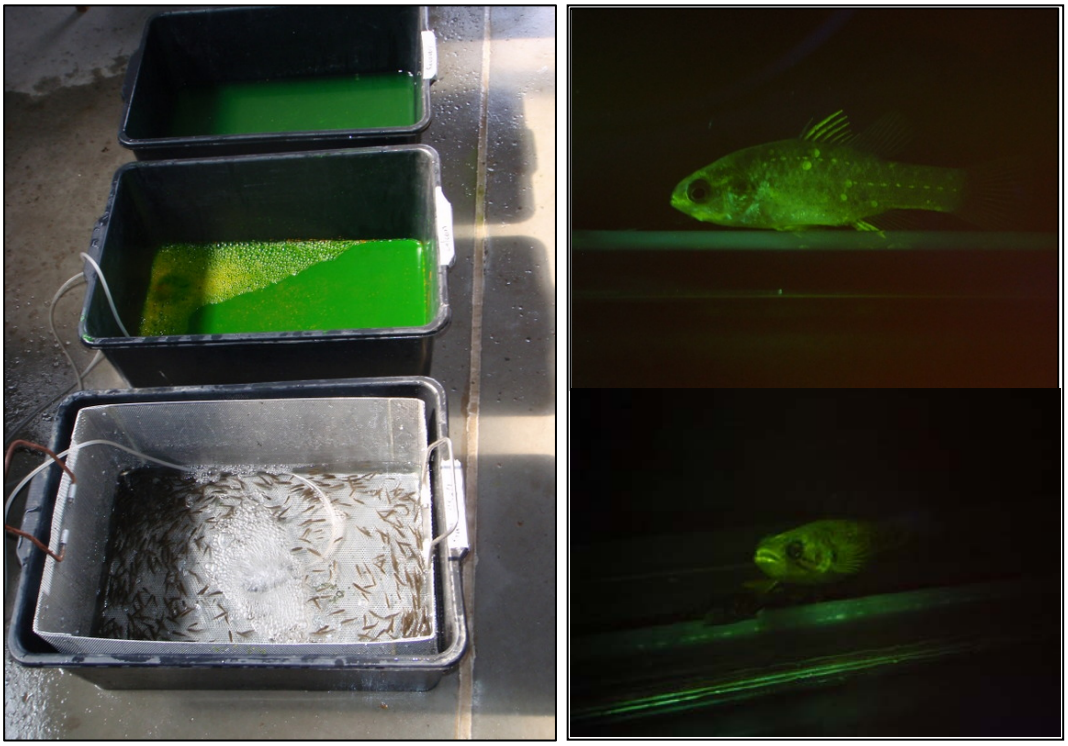

Figure 4. a) Southern pygmy perch undergoing calcein marking. Fish are in the salt bath prior to immersion in the calcein solution (next tub up) and finally bathing in a recovery tub, and b) southern pygmy perch (top) and southern purple-spotted gudgeon (bottom) as viewed under ultraviolet light 1 day post-staining.

Post reintroduction fish monitoring

Site assessment monitoring undertaken in summer/autumn 2012 fulfilled the complimentary role of post-reintroduction monitoring (see section 2.3 for detailed methods). Subsequent site assessment monitoring for future reintroductions is planned for spring 2012 and autumn 2013. Data from additional monitoring undertaken in the region (e.g. the University of Adelaide) is included where possible.

3. Results

3.1 Site assessment

Each of the 20 sites were deemed as generally suitable for reintroductions following stage 1 assessments, as the key threatening process - reduced freshwater inflows - had been largely alleviated and favourable hydrology, and water security is anticipated across much of the CLLMM region in the foreseeable future. As such stage 2 assessments were undertaken for all sites. Tables 7-9 present the outcomes of specific site assessments in relation to the criteria established for each target species. Detailed fish, macroinvertebrate and habitat monitoring data are presented in Appendix 1 and 2.

Following site assessment in spring 2011, one site was deemed suitable for the reintroduction of southern purple-spotted gudgeon, two for southern pygmy perch and two for Yarra pygmy perch (Tables 7 – 9). In autumn 2012, one site was again deemed suitable for the reintroduction of southern purple-spotted gudgeon, one for southern pygmy perch, one for Murray hardyhead and two for Yarra pygmy perch (Tables 7 – 9).

Table 7. Summary of site assessments relevant to Yarra pygmy perch (YPP) and southern pygmy perch (SPP) in spring 2011 and autumn 2012. Cells coloured in green indicate criteria were met, whilst red cells indicate criteria were not met.

Sites	Target species	Native species		Water quality			Food	Aquatic habitat			Introduced predators/competitors				Assessment/ comments
		Target species ?	Native spp	EC (<3,000 µS.cm^{-1})	DO (>2.0 ppm)	pH	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) physical habitat	Redfin perch (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Spring 2011															
Blue Lagoon	YPP	NO	9	1401	8.44		Y	*Myriophyllum*	*Schoenoplectus*	40-65	1	11	0	0	Diversity of sites, and some look favourable (further out from main site) **YPP release recommended**
Finniss River junction	YPP	NO	12	789	5.75	8.1	Y	*Myriophyllum*	*Schoenoplectus, Typha, Phragmites*	85	0	4 (12 >100 mm)	1	1	Recovered well (good veg, diversity of fish & prey) **YPP release recommended**
	SPP														
u/s Hunters Creek	YPP,	NO	4	660	5.41	5.7	Y	*Myriophyllum*, algae	No *Schoenoplectus*	45	1	16	0	3	Water is turbid and seems nutrient rich – high levels of filamentous algae. **No release**
	SPP								*Typha*						
d/s Hunters Creek	YPP	NO	8	669	5.94	5.4	Y	*Myriophyllum*	No *Schoenoplectus*	73	2	147	0	0	Abundant common carp. Only low levels of submerged vegetation. **No release**
	SPP								*Typha*						
Steamer Drain	YPP	NO	3	360	3.48	7.1	Y	*Myriophyllum*	*Schoenoplectus*	50	0	50 + 54 goldfish	0	1	High numbers of introduced species. **No release at this time**
	SPP								*Typha*						

Table 7 continued.

Sites	Target species	Native species		Water quality			Food	Aquatic habitat			Introduced predators/competitors				Assessment
		Target species ?	Native spp	EC (<3,000 µS.cm^{-1})	DO (>2.0 ppm)	pH	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) vegetated habitat	Redfin perch (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Spring 2011															
Natural channel north of Hunters Creek	YPP	NO	4	860	4.76	6.1	Y	*Myriophyllum, Ruppia*	No *Schoenplectus.*	50	0	1	<5	3	Good submerged & emergent vegetation. Looks similar to when SPP abundant (pre-2007). **SPP release recommended**
	SPP								*Typha*						
Eastick Creek (new site)	SPP	NO	4	2590	2.99	7.3	Y	0	*Typha, Triglochin, Bolboschoenus, Juncus*	35	0	129	0	2	Abundant common carp. **No release**
Holmes Creek at Eastick Creek mouth	YPP	NO	7	349	8.38	7.3	Y	0	*Schoenoplectus*	40	7	36	0	0	No submerged vegetation. **No release**
Turvey's drain	SPP	Yes, 1	4	1478	2.13	7.2	Y	*Myriophyllum, Ceratophyllum*	*Typha, phragmites*	85	1	18	0	1	Habitat favourable, SPP present. **SPP release recommended**
Currency Creek Game Reserve	YPP	No	12	450	10.2	7.4	Y	*Myriophyllum*	No *Schoenoplectus, but Typha, phragmites*	50	3	1 (but 37 100-250 mm)	4	17	Abundant common carp. **No release**
Black Swamp	YPP	NO	4	1047	3.76	7.1	N	0	No *Schoenoplectus but Typha, Phragmites*	50	4	3	0	0	Little regeneration of submerged vegetation. **No release**

Table 7 continued.

Sites	Target species	Native species		Water quality			Food	Aquatic habitat			Introduced predators/competitors				Assessment
		Target species ?	Native spp	EC (<3,000 µS.cm^{-1})	DO (>2.0 ppm)	pH	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) vegetated habitat	Redfin perch (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Autumn 2012															
Blue Lagoon	YPP	NO	11	2004	6.51	7.52	Y	*Myriophyllum*	*Schoenoplectus*	30%	19	0 (but 20 100-250 mm)	1	0	Not adequate vegetation cover and was a previous release site. Abundant redfin. **No release**
Finniss River junction	YPP SPP	12 MHH	9	708	6.32	8.1	Y	*Myriophyllum*	*Schoenoplectus* *Typha, Phragmites*	60%	3	17	2	27	Was YPP release site. Whilst site appears favourable other sites prioritised. **No release**
u/s Hunters Creek	YPP SPP	NO	5	788	4.4	7.66	Y	*Myriophyllum*	No *Schoenoplectus* *Typha*	20%	6	66	0	0	Low habitat cover, abundant common carp. **No release**
d/s Hunters Creek	YPP, SPP	NO	6	779	6.25	7.18	Y	*Myriophyllum*	No *Schoenoplectus* *Typha*	30%	7	29	3	9	Low habitat cover, abundant common carp. **No release**
Steamer Drain	YPP, SPP	NO	3	360	3.48	7.14	Y	*Myriophyllum*	*Schoenoplectus* *Typha*	50%	12	9 + 10 goldfish	0	1	Favourable habitat, low abundance of introduced species. **YPP release recommended**
Natural channel north of Hunters Creek	YPP SPP	YES (3 SPP)	2	1351	1.6	7.77	Y	*Myriophyllum,*	No *Schoenoplectus* *Typha*	95%	0	11	0	12	Was SPP release site, with recaptures. **No further release at this stage**
Holmes Creek at Eastick Creek mouth	YPP	NO	7	566	9.63	7.98	N	0	*No Schoenoplectus*	50%	8	12	7	0	No submerged vegetation, poor prey resources. **No release**

Table 7 continued.

Sites	Target species	Native species		Water quality			Food	Aquatic habitat			Introduced predators/competitors				Assessment
		Target species ?	Native spp	EC (<3,000 µS.cm^{-1})	DO (>2.0 ppm)	pH	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) vegetated habitat	Redfin perch (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Autumn 2012															
Turvey's drain	SPP	YES (1 SPP)	5	1478	2.13	7.18	Diverse & abundant	*Myriophyllum, Ceratophyllum*	*Typha, phragmites*	85	0	1	0	214	Site favourable but was previous SPP release site, with recapture. **No release**
Currency Creek Game Reserve	YPP	NO	4	678	4.77	8.64		*Myriophyllum*	*Schoenoplectus*	40%	7	25	3	0	Limited submerged vegetation. **No release**
Black Swamp	YPP	NO	4	1047	3.76	7.13	No	0	*Typha, Phragmites*	50%	9	8	2	0	No submerged vegetation, poor prey resources. **No release**
Shadows Lagoon	YPP	NO	6	956	-	8.04		*Myriophyllum, Vallisneria*	*Typha, Phragmites*	46%	10	27		0	Favourable vegetation, good connectivity with broader area, favourable landholder. **YPP release recommended**
Mundoo drain west	SPP	NO		723	1.44	7.44	Y	*Azolla*	Grasses, Typha	10%	2	3		0	Vegetation cover low. Site found nearby with better vegetation cover (Wedderburn Pers. Comm.) **SPP release recommended**
Boundary Creek drain	SPP	NO		713	-	7.85	-	-	-	25%	125	43		2	Abundant common carp and redfin perch. **No release**

Table 8. Summary of site assessments relevant to Murray Hardhead (MHH) in autumn 2012. Cells coloured in green indicate criteria were met, whilst red cells indicate criteria were not met.

Sites	Native species		Water quality			Food	Aquatic habitat			Introduced predators/competitors				Assessment
	Target species	Native diversity	EC (800-25000 µS.cm^{-1})	DO (>2.0 mg.L^{-1})	pH (4-10)	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) vegetated habitat	Redfin (>120 mm)	Juvenile common carp (<100 mm)	Adult common carp (>250mm)	SMHH (<100 per net)	
Autumn 2012														
Boggy Creek	NO	2	592	4.8	7.92	Y	*No submeged*	No grasses but typha	40%	0	4		0	Low salinity, no submerged vegetation. **No release**
Mundoo Drain East	NO		1211	9.66	7.95	Y	*Azolla*	*Typha, grasses*	10%	1	1		4	Low vegetation cover, however few other species and favourable salinity. **Release recommended**
Mundoo Drain West	NO		723	2.98	7.44	Y	*Only azolla*	Grasses, Typha	10%	2	3		0	Low salinity, low vegetation cover. **No release**
Dunn's Lagoon	NO		613	-	7.46	Y	-	-	78%	21	3		0	Low salinity. Abundant redfin perch. **No release**
u/s Hunters Creek	NO	4	788	5.75	7.66	Y	*Myriophyllum*	No *Schoenoplectus*	20%	6	66	0	788	Low habitat cover, low salinity, abundant common carp. **No release**
d/s Hunters Creek	NO	8	779	8.4		Y	*Myriophyllum*	*Typha*, no grasses	30%	7	29	3	9	Low salinity, low habitat cover. **No release**
Natural channel north of Hunters Creek	NO	2	1350	7.9	7.77	Y	*Myriophyllum*	Grasses	95%	0	11	0	12	Good submerged & emergent gestationon. Was a SPP release site. **No release**

Table 9. Summary of site assessments relevant to southern purple-spotted gudgeon (SPSG) in spring 2011 and autumn 2012. Cells coloured in green indicate criteria were met, whilst red cells indicate criteria were not met.

Sites	Native species		Water quality			Food resources	Aquatic habitat			Introduced predators/competitors				Assessment
	Target species?	Native diversity	EC (<3,000 µS.cm^{-1})	DO (>2.0 mg.L^{-1})	pH	Abundant (Y/N)	Species composition (submerged)	Species composition (emergent)	Percent (%) vegetated habitat	Redfin (>120mm)	Juvenile common carp (<100mm)	Adult common carp (>250mm)	Gambusia	
Spring 2011														
Finniss at Winery Road (Loveday)	NO	2	1342	7.6	7.8	Y	No *Myriophyllum or Vallisneria*	No *Schoenoplectus.* but *Triglochin, Phragmites, Berula* and grasses	40-80%	29	3	0	1	Generally looks good. Broad range of sub-sites, some highly vegetated. Need to consider impact of grazing. **Release recommended**
Autumn 2012														
Finniss at Winery Road (Loveday)	YES (3 recaptures)	3	2700	3.6	8.3	Y	No *Myriophyllum or Vallisneria*. *Lemna* and *Lemna*	*No Scheonoplectus* but *Triglochin, Phragmites, Typha, Berula, Rumex*	50%	0	0	0	0	Generally still looks good. Recaptures indicate site is favourable. **Releases recommended**

3.2 Reintroduction summary

In total, approximately 10,300 individual fish, including ~1350 southern pygmy perch, ~4900 Yarra pygmy perch, ~600 southern purple-spotted gudgeon and ~3500 Murray hardyhead were released across nine sites in the CLLMM region during spring 2011 and summer/autumn 2012 (Table 10). All reintroduction sites had responded positively to the return of favourable hydrological conditions to the region and habitat at many sites resembled that of pre-2007. Figure 5 presents some of the reintroduction sites and habitats now present.

Table 10. Summary of sites and numbers of Yarra pygmy perch (YPP), southern pygmy perch (SPP), southern purple-spotted gudgeon (SPSG) and Murray hardyhead (MHH) released and rationale for selection of sites for both spring 2011 and autumn 2012 reintroductions. The source of reintroduced fish is coded as either (1) surrogate dams (Crouch Dam (CD), Oster Dam (OD) or Munday Dam (MD)), (2) Flinders University (FU, either equal contribution from broodstock (EC) or unequal contribution from broodstock (UC)), (3) the Aquasave Hatchery (AQ), (4) Alberton Primary (AP) or (5) wild individuals that were maintained in captivity (Wild).

Site name	Species released	Numbers released (approx.)	Source	Release date	Justification for reintroduction
Spring 2011					
Natural channel connected to Hunters Creek	SPP	770	FU (EC)	2 Nov 2011	Good submerged & emergent veg. Looks similar to when SPP abundant
Turvey's drain	SPP	300	Wild, FU (UC)	9 Nov 2011	Habitat good, SPP present
Blue Lagoon	YPP	400	CD	8 Nov 2011	Site suitable for release (moderate vegetation); looks similar to when species were present.
Finniss River junction	YPP	800	CD	8 Nov 2011	Site recovered well (good veg, diversity of fish & prey)
Finniss at Winery Road	SPSG	200	AQ	9 Nov 2011	Diversity of sites that are highly vegetated, whilst others look fairly impacted by grazing. Overall, suitable for SPSG release
Autumn 2012					
Mundoo Island Channel east 2	SPP	280	FU (UC)	29 Mar 2012	New site between Mundoo Channel east and west. Habitat appeared favourable.
Streamer Drain	YPP	2200	FU (EC)	27 Mar 2012	Vegetation and water quality favourable – looks similar to when species present
Shadows Lagoon	YPP	1500	CD, OD, FU (UC)	29 Mar 2012	Good submerged vegetation, favourable salinity, anecdotal records of past abundance
Finniss at Winery Road	SPSG	400	AQ, AP	29 Mar 2012	Favourable habitat and water quality. Recaptures indicate site favourable
Mundoo Island Channel east 1	MHH	3500	MD	28 Mar 2012	Favourable salinity. Species previously abundant only 2 years ago

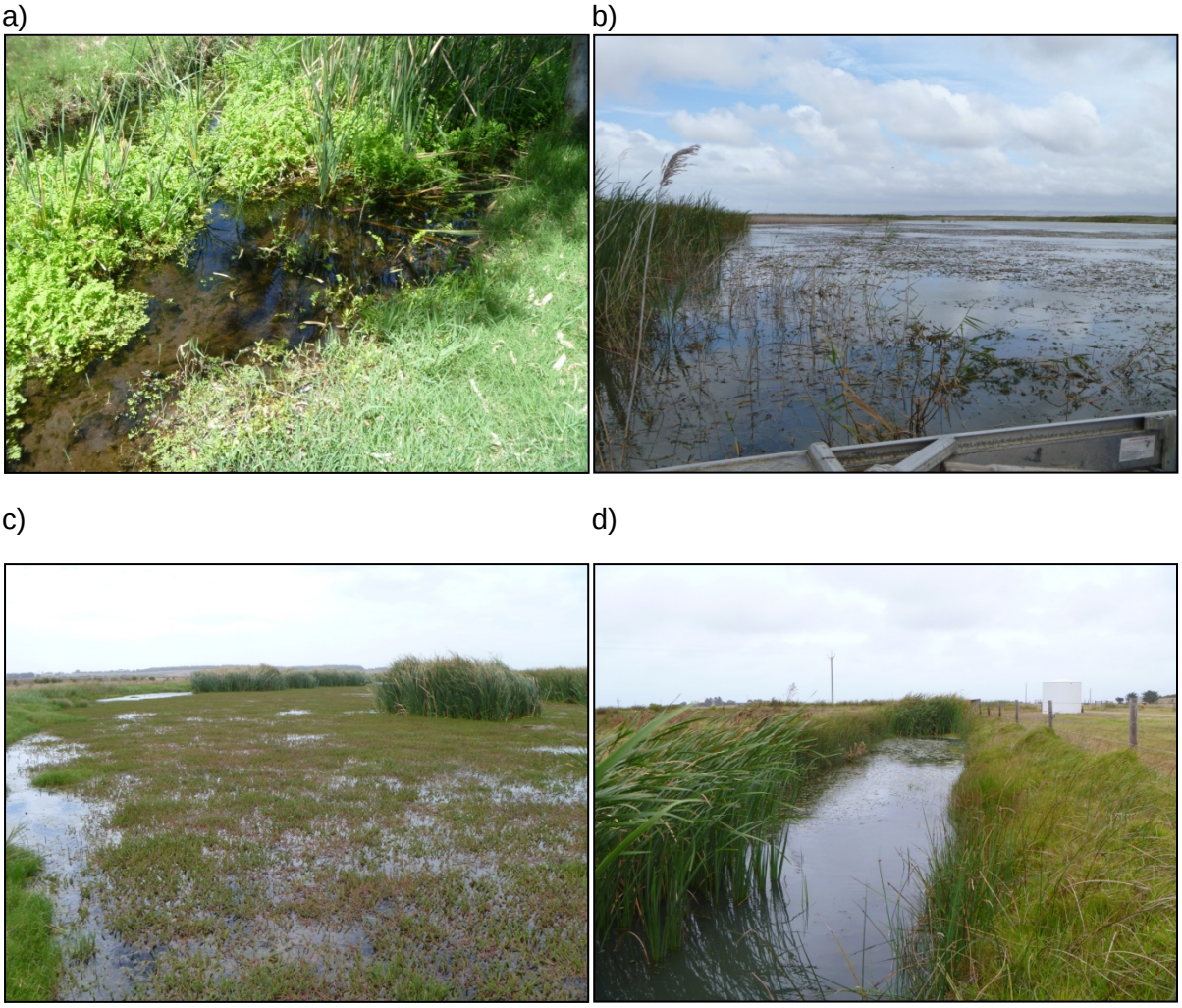

Figure 5. a) Emergent vegetation (*Berula erecta*) at the Finniss River southern purple-spotted gudgeon reintroduction site, b) extensive beds of *Myriophyllum* and emergent vegetation at the Finniss River Junction, c) southern pygmy perch reintroduction site at the natural channel connected to Hunters Creek and d) Steamer Drain – Yarra pygmy perch reintroduction site.

Fish were sourced from six locations (e.g. Flinders University, Aquasave Hatchery, Alberton Primary School and three surrogate dams) and required housing (and feeding), veterinary checks and calcein marking prior to reintroduction. Fish mortality was greatest during transport of surrogate dam fish to the SARDI holding facilities, although refinement to the process (e.g. limited handling when transferring from sampling nets to transport tubs and transporting fish at lower densities) improved survival rates during the second reintroduction period. Over the holding period, salinities were transitioned from those of the source water to known salinity of the reintroduction site. Both the veterinary checks and calcein marking were conducted in a manner to limit handling and stress, and few post-process mortalities were noted.

Soft-release enclosures were constructed and put in place days (i.e. 1 – 3 days) prior to fish release. The daily process of reintroductions involved the collection of fish from SARDI holding facilities

during the morning and release into soft-release enclosures in the afternoon with the soft-release enclosures opened (and removed) the following morning after an overnight acclimation period.

a) b)

Figure 6. a) Members of the Ngarrendjerri Regional Authority assisting with soft-release enclosure construction, and b) release of southern purple-spotted gudgeon into a soft release enclosure at the Finniss River site.

3.3 Post reintroduction monitoring/recaptures

All reintroduction sites were monitored during February/March 2012 to assess the success of reintroductions undertaken in spring 2011. Despite releases of significant numbers of individuals at two sites in spring 2011, no Yarra pygmy perch were recaptured in autumn 2012. Nonetheless, both southern pygmy perch and southern purple-spotted gudgeon were recaptured in autumn 2012. No Murray hardyhead were released in spring 2011 but future sampling in spring 2012 will provide insight on the survival of Murray hardyhead from the release in autumn 2012. A summary of recaptured fish caught as part of the 2012 post reintroduction monitoring is presented in Table 11.

Southern pygmy perch

In addition to monitoring as part of this project, a site within the vicinity of the 'natural channel connected to Hunters Creek' reintroduction site was sampled by Wedderburn *et al.* (2012) in spring 2011 (~three weeks post reintroduction) and autumn 2012. In spring 2011, during their monitoring, Wedderburn *et al.* (2012) detected two southern pygmy perch, which both exhibited signs of calcein marking (i.e. fluorescence under UV light) indicating they were reintroduced individuals. In autumn 2012, post reintroduction monitoring of the site under the current project yielded three southern pygmy perch. Additional monitoring was undertaken at the site the following week (~20 fyke nets set overnight) in an effort to capture a greater number of individuals for the Flinders University ARC Linkage Project, which yielded another six individuals. Fish sampled in autumn 2012 ranged from 32 – 53 mm TL and all but one exhibited signs of calcein marking (mean fluorometer reading ranged 504

– 1400 (signal overload)) indicating they were reintroduced individuals (Figure 7 and Figure 8). The one individual that did not exhibit signs of calcein marking was a likely young-of-year (32 mm TL) potentially indicating that recruitment had occurred following reintroduction (Figure 7).

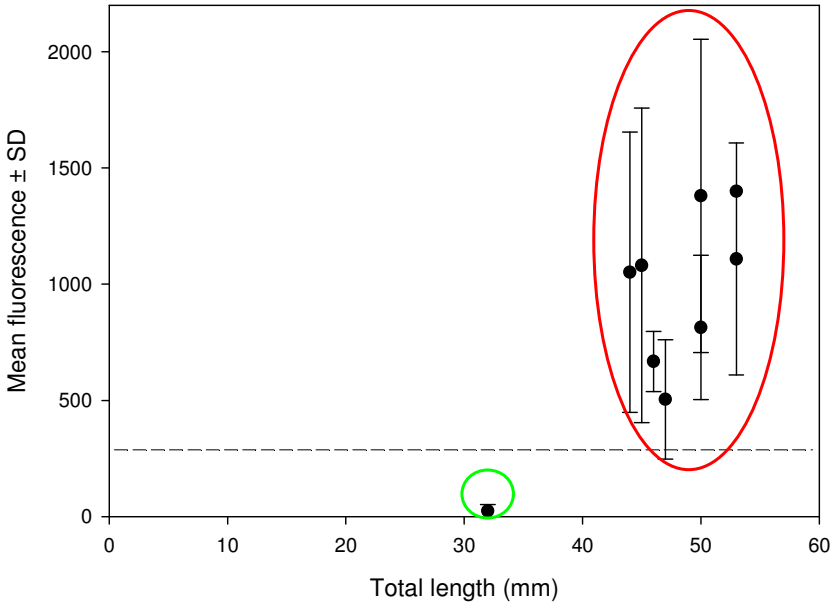

Figure 7. Mean fluorescence reading (± standard deviation (SD)) against total length (mm) for all southern pygmy perch sampled from the natural channel connected to Hunters Creek in March 2012. Red ellipse indicates reintroduced individuals and the green ellipse indicates the likely newly recruited young-of-year. The dashed line represents the fluorescence level deemed to indicate a calcein mark.

Figure 8. Likely newly recruited young-of-year southern pygmy perch sampled from the natural channel connected to Hunters Creek in March 2012.

One southern pygmy perch (41 mm TL) was also sampled from the Turvey's Drain site in March 2012, a location that historically harboured a strong population of the species. This individual exhibited signs of calcein marking (mean fluorescence ± SD = 407 ± 67) indicating it was a reintroduced fish.

Southern purple-spotted gudgeon

Post-reintroduction monitoring of the lower Finniss River site (Winery Road) detected three southern purple spotted gudgeon (64 – 72 mm TL). These fish exhibited varying levels of fluorescence with one individual giving a reading consistent with a calcein mark, whereas the remaining two fish exhibited fluorescence inconsistent with a mark (Figure 9 and Figure 10). It thus appears that either tissue growth has covered previously fluorescent structures or that exposure to ultraviolet light may have resulted in decreased fluorescence. Subsequent monitoring by Aquasave (Eastern Mt Lofty Ranges condition monitoring, April 2012) at sites within the vicinity of the reintroduction site (i.e. ~1 km upstream and downstream) failed to detect any southern purple-spotted gudgeon, suggesting that the population remains confined to the reintroduction site.

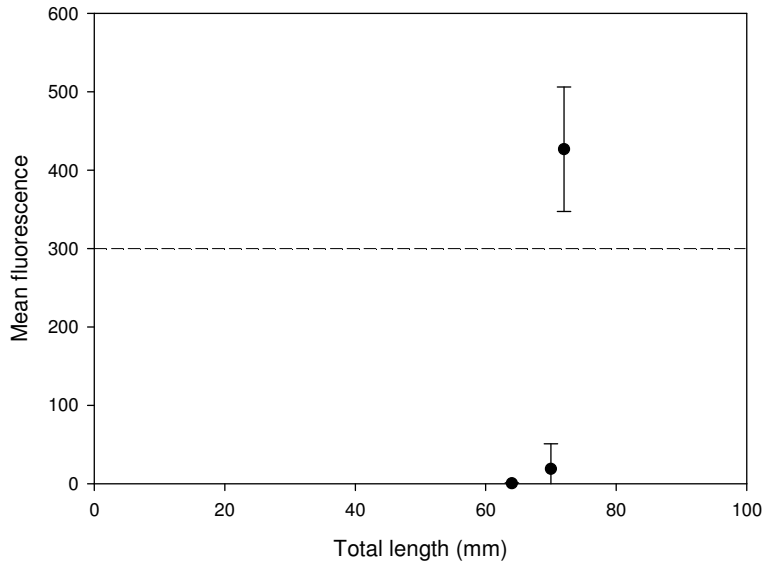

Figure 9. Mean fluorescence reading (± standard deviation (SD)) against total length (mm) for all southern purple-spotted gudgeon sampled from the Finniss River Winery Rd site. The dashed line represents the fluorescence level deemed to indicate a calcein mark.

Figure 10. Southern purple-spotted gudgeon recaptured from the Finniss River Winery Rd site in March 2012, following release in November 2011.

Table 11. Summary of recaptured individuals during post-reintroduction monitoring in March 2012.

Species	Site name	Monitoring details	No. recaptured	Recaptured details
Southern pygmy perch	Natural channel connected to Hunters Creek	The University of Adelaide Living Murray condition monitoring, October 2011	2 (36 & 45 mm)	Both exhibited signs of calcein marking.
		Post-reintroduction monitoring, March 2012	3 (44 – 53 mm)	All exhibited signs of calcein marking.
		Flinders University monitoring, March 2012	6 (32 – 53 mm)	All but one exhibited signs of calcein marking (45 – 53 mm TL). One fish (32 mm TL) exhibited no sign of marking.
	Turvey's drain	Post-monitoring, March 2012	1 (41 mm)	Exhibited sign of calcein marking.
Southern purple-spotted gudgeon	Finniss above Winery Road	Post-reintroduction monitoring, March 2012	3 (64 – 72 mm)	One fish exhibited definite signs of calcein mark. Remaining fish inconclusive.
		Aquasave, Eastern Mt Lofty Ranges (EMLR) condition monitoring, April 2012	0	Monitoring 1km upstream and downstream of release site was unable to detect species.
Yarra pygmy perch	Finniss Junction	Post-reintroduction monitoring, March 2012	0	No fish detected. Site is large and open, and thus detectability likely low.
	Blue lagoon	Post-reintroduction monitoring, March 2012	0	Same as above

4. Discussion

Unprecedented drought and continued over-abstraction from the MDB over the period 2007 – 2010 placed the CLLMM region on the point of ecological collapse (Kingsford *et al*. 2011; Wedderburn *et al*. 2012). The Lower Lakes fell below sea level for the first time in recorded history, accompanied by significant reductions in submerged aquatic vegetation cover, disconnection of fringing vegetation habitats and elevated salinity, resulting in substantial declines and potential extirpation of threatened freshwater fish species (Wedderburn *et al.* 2012). In response, measures were taken to prevent the extirpation of selected threatened species with the removal of individuals from the wild and captive maintenance, and breeding, with the view of reintroduction to wild habitats when favourable conditions returned. Drought conditions across the Murray-Darling Basin lessened in 2010/11 with broad-scale rainfall and significant inflows leading to improved water availability and flow to the CLLMM region. In turn, salinities declined, formerly isolated habitats were reconnected, and submerged and fringing emergent vegetation communities exhibited signs of recovery (Gehrig *et al.* 2011; DEWNR 2012). Thus there was potential for threatened fish species, maintained and produced as part of the various captive maintenance/breeding programs facilitated through the DAP, to be reintroduced into former wild habitats.

In the CLLMM region, the conservation of threatened fish is now managed in a coordinated and collaborative manner through the DAP, and now CFH, projects. The present document described the reintroduction (and monitoring) phase of this process, which has included the release of more than 10,300 individuals from four different species across nine different sites. Specifically, ~4900 Yarra pygmy perch were released at four sites, ~1350 southern pygmy perch at three sites and ~600 southern purple-spotted gudgeon and ~3500 Murray hardyhead at one site, within their previous areas of occupancy (prior to 2005). Importantly, there were recaptures of both southern pygmy perch and southern purple-spotted gudgeon, indicating survival of these species for at least four months post reintroduction. Indeed, the survival and recapture of reintroduced southern purple-spotted gudgeon represent the first records of the species in the region in 50 years. Additionally, an indication of recruitment for southern pygmy perch is particularly encouraging, suggesting that reintroductions for this species have a high likelihood of success.

The southern purple-spotted gudgeon recaptured exhibited variable levels of fluorescence and thus inconsistent indications of calcein marking. One individual exhibited fluorescence consistent with a calcein mark, whilst the other two did not. Nonetheless, their size (> 60 mm TL) and the fact that the species has not been detected at the site since the 1960s despite regular sampling (Hammer 2009a),

suggests they were reintroduced fish. A similar result of variable mark retention was detected for marked southern purple-spotted gudgeon reintroduced at Paiwalla (Bice *et al.* 2011). Contrastingly, all southern pygmy perch sampled during this project, except for a likely young-of-year individual, exhibited excellent mark retention. This suggests that behavioural differences between species, and even within species, and varying environmental conditions across sites may influence mark retention. Relative somatic growth of southern purple-spotted gudgeon is greater than that for southern pygmy perch and thus greater amounts of tissue may be laid on top of fluorescent structures. Additionally, the Finniss River release site is characterised by water of a higher transparency than the southern pygmy perch release sites, and when accompanied by southern purple-spotted gudgeons' propensity for basking in sunlight, these conditions potentially exposed these individuals to greater levels of ultraviolet light which may degrade calcein (Simon Westergaard Pers. Comm.).

No Yarra pygmy perch have been recaptured in post-reintroduction monitoring. The initial releases for this species in spring 2011 occurred in large water bodies (i.e. the Finniss River Junction and Blue Lagoon) leading to low detectability of individuals, with limited sampling effort, and thus, the absence of individuals during monitoring does not definitively indicate low survival for released fish. Nonetheless, individuals were released into a more spatially confined site (i.e. Steamer Drain) in March 2012 and thus likelihood of detection, given adequate survival rates, should be greater in future post-reintroduction monitoring.

Habitat conditions in the CLLMM region are continuing to improve and are becoming increasingly favourable for threatened fish species, and further reintroductions and post-reintroduction monitoring will be conducted in 2012/13. It is likely that several reintroduction events will be required to provide the greatest chance of population establishment. A significant number of threatened fish reintroductions have occurred in the south-eastern United States, providing insight and direction for the current project (see Rakes *et al.* 1999; Shute *et al.* 2005; Rakes and Shute 2006; Rakes and Shute 2008; Rakes *et al.* 2010). These programs have involved multiple years of reintroduction events with wild recruitment for some species not detected until 14 years after the commencement of reintroductions. This highlights the potential commitment required to restore self-sustaining populations of threatened species via reintroductions.

The CFH project is in its infancy and work must continue into the future to ensure the success of the current (and future) reintroductions. Ongoing monitoring of the reintroduced populations, as well as broader monitoring of the region, is integral, firstly to provide specific assessment of the success of fish reintroductions and secondly to evaluate temporal changes in condition across the CLLMM region. Targeted post-reintroduction monitoring is required to determine the survival of reintroduced fish and their distribution (i.e. measures of population extent and dispersal) and provide information

on population demographics (i.e. age structure and recruitment), as well as monitoring threats (e.g. changes in habitat water levels, introduced species) at the reintroduction sites and more broadly. Importantly, any future monitoring and management should incorporate knowledge gathered and lessons learned during the drought and through the DAP on efforts required to conserve threatened fish species.

5. Conclusion

The utilisation of a variety of different management actions appears the best approach for conserving threatened species, including threatened fish in the Murray-Darling Basin. Such measures in the CLLMM region, including environmental watering, emergency rescue, captive breeding, establishment of surrogate refuge populations and reintroductions, have to this point in time been successful, and work in the following year will provide greater insight on the success of reintroductions. Nonetheless, the current framework guiding reintroductions appears effective and may be informative for future threatened species management. Ultimately, threatened species management presents both challenges and opportunities, as it must be pre-emptive, ongoing and collaborative. Funding, resources and stakeholder coordination are often difficult to align with the need for emergency actions during unpredictable conditions, but are highly valuable to the long-term survival of threatened species.

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6. Appendices

Appendix 1. Species and abundance of fish sampled from all sites in spring 2011

	Murray hardyhead	Southern pygmy perch	Yarra pygmy perch	Southern purple-spotted gudgeon	Bony herring	Golden perch	Australian smelt	Flat-headed gudgeon	Dwarf flat-headed gudgeon	Carp gudgeon spp.	Common galaxias	Congolli	Lagoon goby	Tamar River goby	Bluespot goby	Small-mouthed hardyhead	Sandy sprat	Redfin perch	Eastern gambusia	Common carp	Godfish	Native species richness	Non-native species richness
Finniss above Winery Road	0	0	0	0	0	0	2	1	0	0	0	0	0	0	0	0	0	29	1	3	2	**2**	**4**
Blue Lagoon	0	0	0	0	0	0	26	14	2	1	1	1	1	0	1	14	0	7	0	11	1	**9**	**3**
Finniss River junction	0	0	0	0	2	3	31	62	6	6	97	3	23	6	2	9	1	3	1	18	2	**13**	**4**
Hunters Creek (us Denver Rd causeway)	0	0	0	0	0	0	0	2	1	0	89	1	0	0	0	0	0	2	5	16	13	**4**	**4**
Hunters Creek (ds Denver Rd causeway)	0	0	0	0	0	0	1	25	0	4	83	7	1	0	1	36	0	2	0	157	20	**8**	**3**
Eastick Creek	0	0	0	0	0	0	0	46	0	2	2	0	0	0	0	20	0	0	3	129	20	**4**	**3**
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	0	0	0	0	0	0	0	4	0	0	6	0	0	0	1	1	0	0	3	1	35	**4**	**3**
Steamer drain	0	0	0	0	0	0	0	8	0	0	12	2	0	0	0	0	0	12	1	50	53	**3**	**4**
Holmes Creek at Eastick Creek mouth	0	0	0	0	0	0	7	26	0	2	31	12	8	4	0	0	0	8	2	36	6	**7**	**4**
Turvey's drain	0	1	0	0	0	0	0	15	5	7	0	1	0	0	0	0	0	0	1	19	15	**5**	**3**
Currency Creek Game Reserve	1	0	0	0	0	1	13	81	3	0	60	4	1	6	1	5	2	6	17	42	5	**12**	**4**
Black Swamp	0	0	0	0	0	2	0	21	2	21	0	0	0	0	0	0	0	4	0	4	0	**4**	**2**
Total	**1**	**1**	**0**	**0**	**2**	**6**	**80**	**305**	**19**	**43**	**381**	**31**	**34**	**16**	**6**	**85**	**3**	**73**	**34**	**486**	**172**	**15**	**4**

Appendix 2. Species and abundance of fish sampled from all sites in autumn 2012

	Murray hardyhead	Southern pygmy perch	Yarra pygmy perch	Southern purple-spotted gudgeon	Unspecked hardyhead	Bony herring	Golden perch	Australian smelt	Flat-headed gudgeon	Dwarf flat-headed gudgeon	Carp gudgeon spp.	Common galaxias	Congolli	Lagoon goby	Tamar River goby	Small-mouthed hardyhead	Sandy sprat	Redfin perch	Eastern gambusia	Common carp	Godfish	Native species richness	Non-native species richness
Finniss Winery Road	0	0	0	3	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	**3**	**0**
Blue Lagoon	0	0	0	0	23	27	7	1	55	4	1	4	8	0	1	0	18	57	0	39	3	**11**	**3**
Finniss River junction	12	0	0	0	6	67	6	4	44	1	1	8	0	0	0	1	0	19	27	19	2	**10**	**4**
Hunters Creek (us Denver Rd causeway)	0	0	0	0	0	1	0	0	13	0	0	31	9	1	0	0	0	7	9	32	6	**5**	**4**
Hunters Creek (ds Denver Rd causeway)	0	0	0	0	0	254	1	4	27	0	0	246	3	0	0	4	0	55	0	66	9	**7**	**3**
Drain behind Wyndgate	0	0	0	0	0	1	0	0	2	0	0	0	1	0	0	0	0	4	0	31	6	**3**	**3**
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	12	11	5	**2**	**3**
Steamer drain	0	0	0	0	0	0	1	0	11	0	0	2	1	0	0	0	0	12	1	9	10	**4**	**4**
Holmes Creek at Eastick Creek mouth	0	0	0	0	0	9	0	0	150	2	1	19	4	0	0	0	0	20	0	19	1	**6**	**3**
Turvey's drain	0	1	0	0	0	0	0	0	17	10	1	2	0	0	0	0	0	0	214	1	4	**5**	**3**
Currency Creek Game Reserve	0	0	0	0	0	56	2	0	22	0	0	4	1	0	0	0	0	14	0	28	1	**5**	**3**
Black Swamp	0	0	0	0	0	2	0	0	16	3	0	0	0	0	0	0	0	16	0	10	0	**3**	**2**

Appendix 2 continued.

	Murray hardyhead	Southern pygmy perch	Yarra pygmy perch	Southern purple-spotted gudgeon	Unspecked hardyhead	Bony herring	Golden perch	Australian smelt	Flat-headed gudgeon	Dwarf flat-headed gudgeon	Carp gudgeon spp.	Common galaxias	Congolli	Lagoon goby	Tamar River goby	Small-mouthed hardyhead	Sandy sprat	Redfin perch	Eastern gambusia	Common carp	Godfish	Native species richness	Non-native species richness
Mundoo Island Channel east*	0	0	0	0	0	0	0	0	14	0	1	0	1	0	0	4	0	1	0	1	3	**4**	**3**
Mundoo Island Channel west*	0	0	0	0	0	0	0	0	1	0	2	2	0	0	0	0	0	2	0	3	7	**3**	**3**
Boundary Creek drain*	0	0	0	0	0	17	2	0	9	0	0	1	1	0	0	0	0	125	2	43	4	**5**	**4**
Boggy Creek*	0	0	0	0	0	0	0	0	13	0	0	10	0	0	0	0	0	0	4	4	0	**2**	**2**
Dunn's Lagoon*	0	0	0	0	6	15	2	80	124	0	0	11	0	0	0	0	0	21	7	3	0	**6**	**3**
Shadows Lagoon*	0	0	0	0	0	12	0	0	19	0	0	2	0	0	0	0	0	10	0	27	18	**3**	**3**
Total	**12**	**4**	**0**	**3**	**35**	**461**	**21**	**89**	**537**	**20**	**7**	**345**	**32**	**1**	**1**	**9**	**18**	**363**	**276**	**346**	**79**	**16**	**4**

*denotes sites sampled by Wedderburn and Barnes (2012).

Appendix 3. Macroinvertebrate families and subjective abundance scores (R – rare, C – common, A – abundant, V – very abundant) from sampling conducted during fish monitoring in spring 2011.

	Damselfly nymph	**Dragonfly nymph**	**Mayfly nymph**	**Caddisfly nymph**	**Paratya**	**Macrobrachium**	**Yabby**	**Snail (*Physa*)**	**Water strider**	**Predacious diving beetle**	**Beetle larvae**	**Corixids (boatmen)**	**Notonectid (backswimmers)**	**Micronecta**	**Amphipod**	**Lepidopteran larvae**	**Non-biting midge larvae**	**Microcrustaceans**	**Needle bug**
Finniss above Winery Road	R		R				R	A		A		A			A				
Blue Lagoon	C				A	C	R									R	A	A	
Finniss River junction					V	R	R	R	C			C			A		V	V	
Hunters Creek (us Denver Rd causeway)	C	C			C		A			R		A	R	A			A	C	
Hunters Creek (ds Denver Rd causeway)	C			R	C		A	R		R		C		A			A	A	
Eastick Creek	C	C		R	R	R			R	R				R			C		
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	A	V					A	R	C	A	R	C	A	A	A		A	C	A
Steamer drain	C				C		A					C	C				C	C	
Holmes Creek at Eastick Creek mouth		R			A	C	R	R						C	A		C	C	
Turvey's drain	A	R		R	R		A			R					A			A	
Currency Creek Game Reserve	A	R			V	C	C								C		C	C	
Black Swamp		C			A		R	R	C					A			R	C	

Appendix 4. Macroinvertebrate families and subjective abundance scores (R – rare, C – common, A – abundant, V – very abundant) from sampling conducted during fish monitoring in autumn 2012.

	Damselfly nymph	**Dragonfly nymph**	**Mayfly nymph**	**Caddisfly nymph**	**Paratya**	**Macrobrachium**	**Yabby**	**Snail (*Physa*)**	**Snail (gilled)**	**Water strider**	**Predacious diving beetle**	**Water scavenger beetle**	**Whirligig bettle**	**Crawling water beetle**	**Beetle larvae**	**Corixids (boatmen)**	**Notonectid (backswimmers)**	**Amphipod**	**Non-biting midge larvae**	**Biting midge larvae**	**Mosquito larvae**	**Copopoda**	**Cladocera**	**Ostracoda**	**Water mite**	**Leech**	**Fishing spider**	**Freshwater limpet**
Finniss Winery Road	R		C							A		R	R	R			C	C	C					C				
Blue Lagoon	C			C	A	A	R	C								C		C	C			C					R	**R**
Finniss River junction	R		R	R	C	V	C	R										C	C					C				
Hunters Creek (us Denver Rd causeway)	C				V		A									V	V	A	C	C				A		R		
Hunters Creek (ds Denver Rd causeway)	A	R		C	A		A				A					A			A	C								
Drain behind Wyndgate	R				A		A	R								V	C		C			C	R		R			
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	A	A			C		A			V	V				R	V	A	A	V			C		C				
Steamer drain	V	R	R	R			V	R	R							C	C		C	C		C		C				
Holmes Creek at Eastick Creek mouth	R		C		C	V	C											C									R	
Turvey's drain		C	A		R		V				R	C				C		R				C		C				
Currency Creek Game Reserve					A	V	C	R										A	R	R				C			R	
Black Swamp	C				A	A													C		C		R	R				

Appendix 4 continued.

	Damselfly nymph	**Dragonfly nymph**	**Mayfly nymph**	**Caddisfly nymph**	**Paratya**	**Macrobrachium**	**Yabby**	**Snail (*Physa*)**	**Snail (gilled)**	**Water strider**	**Predacious diving beetle**	**Water scavenger beetle**	**Whirligig bettle**	**Crawling water beetle**	**Beetle larvae**	**Corixids (boatmen)**	**Notonectid (backswimmers)**	**Amphipod**	**Non-biting midge larvae**	**Biting midge larvae**	**Mosquito larvae**	**Copopoda**	**Cladocera**	**Ostracoda**	**Water mite**	**Leech**	**Fishing spider**	**Freshwater limpet**
Mundoo Island Channel east*	C			C	A											C		C		R		R		R				
Mundoo Island Channel west*	A									R						C		C	C	R		C		C				
Boggy Creek*	R			R												V	A	A		R		C		C	R			
Dunn's Lagoon*	A			C	C			R								A			C									
Boundary Creek drain*	Not sampled																											
Shadows Lagoon*	Not sampled																											

Appendix 5. Habitat cover and physico-chemical parameters measured at all sites during sampling in spring 2011.

	Habitat				**Physico-chemical parameters**							
	Submerged (%)	**Emergent (%)**	**Physical (%)**	**Open water (%)**	**DO surface (ppm)**	**DO depth (ppm)**	**pH**	**Temp (˚C)**	**Conductivity (µS.cm^{-1})**	**Secchi depth (m)**	**Mean depth**	**Max depth**
Finniss Winery Road	0	40 (*Typha, Phragmities, Triglochin, Azolla, Berula,* grasses)	0	60	7.74	7.56	8.51	14.3	1217	0.26	0.66	0.8
Blue Lagoon	20 (*Myriophyllum, Potamogetan crispus*)	20 (*Typha, Phragmites, Schoenoplectus, Cotula,* grasses)	0	60	9.36	8.44	7.29	15.7	1395	0.15	0.6	0.75
Finniss River junction	45 (*Myriophyllum*)	40 (*Typha, Phragmites, Schoenoplectus*)	0	15	10.55	5.75	8.09	15	782	0.18	-	0.8
Hunters Creek (us Denver Rd causeway)	10 (algae, *Myriophyllum*)	25 (*Typha, Juncus, Azolla, Bolboschoenus,* grasses)	0	65	5.33	5.41	5.85	17.6	643	0.25	0.54	1.0
Hunters Creek (ds Denver Rd causeway)	2 (*Myriophyllum, Potamogetan crispus*)	25 (*Typha, Cotula, Lemna,* grasses)	0	73	5.94	4.52	5.4	17.5	669	0.2	0.65	0.8
Eastick Creek	0	35 (*Typha, Triglochin, Juncus, Bolboschoenus, Lemna,* grasses)	0	65	3.83	2.99	7.46	16.1	2560	0.1	0.45	0.5
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	25 (*Myriophyllum, Potamogetan crispus, Ruppia* sp.)	25 (*Typha, Juncus, Azolla, Bolboschoenus,* grasses)	0	50	5.24	4.76	7.47	14.8	863	>depth	0.66	0.75
Steamer drain	25 (*Myriophyllum*)	25 (*Typha, Schoenoplectus, Bolboschoenus*)	0	50	6.13	3.48	7.42	16.3	356	0.1	0.87	1
Holmes Creek at Eastick Creek mouth	0	40 (*Typha, Schoenoplectus, Bolboschoenus, Triglochin, Cotula, Juncus*)	0	60	10.83	8.38	8.55	16.6	350	0.2	0.5	1.4
Turvey's drain	60 (*Myriophyllum, Ceratophyllum*)	25 (*Typha, Phragmites,* grasses)	0	15	2.61	2.13	7.55	14.2	1463	0.8	1.01	1.1
Currency Creek Game Reserve	5 (*Myriophyllum*)	45 (*Typha, Phragmites*)	0	50	10.18	9.14	7.47	16.3	450	0.18	0.89	1.0
Black Swamp	0	50 (*Typha, Phragmites*)	0	50	5.5	3.76	7.10	15.7	921	0.25	1.19	1.3

Appendix 6. Habitat cover and physico-chemical parameters measured at all sites during sampling in autumn 2012.

	Habitat				**Physico-chemical parameters**							
	Submerged (%)	**Emergent (%)**	**Physical (%)**	**Open water (%)**	**DO surface (ppm)**	**DO depth (ppm)**	**pH**	**Temp (˚C)**	**Conductivity (µS.cm^{-1})**	**Secchi depth (m)**	**Mean depth**	**Max depth**
Finniss Winery Road	9 (*Azolla, Lemna*)	40 (*Typha, Phragmities, Triglochin, Berula, Rumex*)	1 (snag, tree root)	50	3.6	3.19	8.24	23.1	2700	>depth	0.48	0.55
Blue Lagoon	15 (*Myriophyllum*)	25 (*Typha, Phragmites, Schoenoplectus, Lignum*)	0	60	8.01	6.51	7.52	20	2004	0.28	0.72	0.83
Finniss River junction	40 (*Myriophyllum*)	20 (*Typha, Phragmites, Schoenoplectus*)	0	40	9.86	2.68	8.1	22	708	0.32	0.64	0.75
Hunters Creek (us Denver Rd causeway)	0.5 (*Myriophyllum*)	19.5 (*Typha, Bolboschoenus*, grasses)	0	80	5.75	4.4	7.66	17.1	788	0.38	0.37	0.6
Hunters Creek (ds Denver Rd causeway)	10 (*Myriophyllum*)	20 (*Typha*, grasses)	0	70	8.4	6.25	7.18	18.7	779	0.53	0.63	0.72
Drain behind Wyndgate	0	30 (*Typha*, grasses)	0	70	3.57	0.22	8.19	17.9	795	0.46	0.93	1.1
Natural channel connected to Hunters Creek (behind DENR-Wyndgate)	70 (*Myriophyllum*)	25 (*Typha, Bolboschoenus*, grasses)	0	5	7.9	1.6	7.77	16.5	1351	>depth	0.65	0.75
Steamer drain	60 (*Myriophyllum*, algae)	25 (*Typha, Bolboschoenus*)	0	15	6.2	0.68	7.79	19	583	0.34	0.81	1
Holmes Creek at Eastick Creek mouth	0	48 (*Typha, Bolboschoenus, Triglochin*,grasses)	2 (rock)	50	10.04	9.63	7.98	19.4	566	0.41	0.54	0.8
Turvey's drain	70 (*Myriophyllum, Ceratophyllum*)	20 (*Typha, Phragmites*, grasses)	0	10	8.62	4.73	7.67	22.5	724	>depth	1.1	1.35
Currency Creek Game Reserve	5 (*Myriophyllum*)	35 (*Typha, Phragmites, Schoenoplectus*)	0	60	6.25	4.77	8.64	21.6	678	0.22	0.76	0.8
Black Swamp	0	40 (*Typha, Phragmites, Bolboschoenus, Baumea*)	0	60	7.11	6.32	7.8	21	1452	0.4	1.32	1.45

Appendix 6 continued.

	Habitat				Physico-chemical parameters							
	Submerged (%)	**Emergent (%)**	**Physical (%)**	**Open water (%)**	**DO surface (ppm)**	**DO depth (ppm)**	**pH**	**Temp (˚C)**	**Conductivity (µS.cm^{-1})**	**Secchi depth (m)**	**Mean depth**	**Max depth**
Mundoo Island Channel east*	10 (*Azolla*)	60 (*Typha*, grasses)	0	30	9.98	9.66	7.95	20.3	1211	0.25	0.68	-
Mundoo Island Channel west*	2 (*Azolla*)	8 (*Typha*,grasses)	0	90	2.98	1.44	7.44	19.7	723	0.38	0.79	-
Boggy Creek*	0	40 (*Typha, Phragmites, Triglochin, Juncus*)	0	60	5.73	4.8	7.92	20.8	592	0.33	0.33	-
Dunn's Lagoon*	78 total vegetated cover		0	22	-	-	7.46	23.2	613	0.42	0.32	-
Boundary Creek drain*	20 total vegetated cover		0	80	-	-	7.85	20.3	713	0.4	0.82	-
Shadows Lagoon*	46 total vegetated cover (*Vallisneria, Potamogetan crispus*)		0	54	-	-	8.04	20.5	956	0.31	0.28	-

*denotes sites sampled by Wedderburn and Barnes (2012).