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Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2012–2013)

Report to the Murray–Darling Basin Authority and the South Australian Department for Environment, Water and Natural Resources

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Summary

Murray hardyhead, Yarra pygmy perch and southern pygmy perch are threatened small-bodied fish species inhabiting the Lower Lakes. Drought in the Murray–Darling Basin (MDB) from 1997–2010 had adverse ecological consequences, including their population declines. High inflows during 2010–11 led to vast increases in the abundance of many obligate freshwater species in the Lower Lakes, mostly carp, goldfish and bony herring. However, only low numbers of Murray hardyhead and southern pygmy perch were captured, but with little or no evidence of recruitment in 2010–11 and 2011–12. Yarra pygmy perch was not recorded from 2008 to 2012. Several thousand Murray hardyhead, southern pygmy perch and Yarra pygmy perch were released into suitable habitats from 2011–13 as part of a re-stocking project.

The Murray–Darling Basin Authority has funded, through The Living Murray (TLM) program, the condition monitoring of the three threatened fish populations at the Lower Lakes since 2005. It is directed by the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Target F2, which aims to improve spawning and recruitment success of the threatened fish populations in the Lower Lakes. The main objectives of this study were to locate populations of the three threatened fish species at the Lower Lakes and establish if they successfully recruited over 2012–13.

In 2012–13, all three threatened fish species were recorded for the first time since 2008. In regards to Yarra pygmy perch and southern pygmy perch, this was largely because of re-stocking. There was strong evidence of recruitment of Murray hardyhead in the Finniss River and Goolwa Channel region. However, the low numbers and limited evidence of recruitment in southern pygmy perch and Yarra pygmy perch suggest unknown factors (e.g. predation, lack of prey) have hindered their population recovery (see summation Table 6 on page 20).

The findings also suggest that freshwater aquatic habitat has somewhat re-established at many sites fringing the Lower Lakes. Generally, salinity was much lower in 2012–13 compared with the last five years. Habitat structure consisted of freshwater aquatic macrophytes, most commonly cumbungi, hornwort, water milfoil and ribbon weed, at sites that are or were inhabited by the threatened fishes. Although recruitment within the Murray hardyhead population is a positive sign of ecosystem recovery at the Lower Lakes, the apparent limited recruitment in the pygmy perch populations indicates otherwise. To some extent, the lack of re-establishment in the Yarra pygmy perch population is unsurprising, given its extirpation during the drought. Its population recovery relies solely on the re-stocking project, but this is scheduled to cease in mid-2013.

The restoration of freshwater habitat for small-bodied fishes in the Lower Lakes should include the creation of habitat diversity, so that a suite of native species can coexist, including Murray hardyhead and the pygmy perches. However, there is a lack of understanding regarding the relationships between fish and flow regimes that determine habitat conditions in the Lower Lakes and Coorong. For management purposes, continued monitoring and investigations of fish and habitat in the Coorong and Lower Lakes region is crucial because of its significance to the Ngarrindjeri people, its high biodiversity value (i.e. Ramsar site, Icon site, many EPBC Act listed species), the commercial and recreational fishing interests, and that the lower River Murray will likely be the most threatened region of the MDB under climate change forecasts.

Introduction

Rivers of the intensively regulated Murray–Darling Basin (MDB) in south-eastern Australia feed two shallow lakes (max. depth of 4.1 m), Lake Alexandrina and Lake Albert (Lower Lakes), which are separated from the Coorong estuary by five tidal barrages. Collectively they are a Ramsar site, because of their high global conservation value as habitat for rare and endangered plants and animals. The Lower Lakes are inhabited by estuarine, diadromous and freshwater fishes. Of particular interest are three threatened small-bodied, short-lived species that are ecological specialists, namely Murray hardyhead *Craterocephalus fluviatilis*, Yarra pygmy perch *Nannoperca obscura* and southern pygmy perch *N. australis*.

The genetically distinct population of Yarra pygmy perch occurs nowhere else in the MDB (Hammer et al. 2010). The species is 'Vulnerable' under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and 'Critically Endangered' in South Australia (Hammer et al. 2009), due to population decline and regional extinctions (Saddlier et al. in press; Wager and Jackson 1993). Yarra pygmy perch was not recorded in the Lower Lakes between February 2008 and November 2011, before fish were re-stocked from a captive maintenance program (Bice et al. 2012). The closely related southern pygmy perch is 'Endangered' in South Australia (Hammer et al. 2009) and 'Protected' under the *Fisheries Management Act 2007*. It also has a patchy distribution in the upper Murray catchment (Hammer 2001). Importantly, southern pygmy perch in the Lower Lakes is genetically unique from other populations in Australia (Unmack et al. 2013).

Murray hardyhead is endemic to the MDB, occurring in fragments upstream from Kerang in Victoria to downstream approximately 2000 km in the Lower Lakes. The small population fragments in the lower River Murray, South Australia, include isolates near Berri and Murray Bridge (Wedderburn et al. 2007). It is 'Critically Endangered' in South Australia (Hammer et al. 2009), and 'Endangered' under the *EPBC Act* due to a recent severe population decline and localised extinctions. Notably, the Lower Lakes population of Murray hardyhead is genetically distinct from populations in northern regions of the MDB (Adams et al. 2011), and substantial effort was made during the recent drought to maintain each genetic management unit in a captive breeding program (Ellis et al. in press).

Drought in the MDB from 1997–2010 had adverse effects on fish communities, which were most pronounced near the Lower Lakes and Coorong (Wedderburn et al. 2012a; Zampatti et al. 2010). Drought conditions resulted in lake water levels falling to approximately -1 m Australian Height Datum (AHD; approx. sea level) (Figure 1), with a corresponding deterioration of water quality (Aldridge et al. 2011). The lake edge contracted over 100 metres in some areas, leaving fringing waterbodies isolated and desiccated (Bice et al. 2010; Wedderburn and Hillyard 2010). Consequently, there was a substantial decline in the proportion of ecological specialists in the fish community, especially diadromous and threatened species, and an emerging dominance of generalist freshwater and estuarine species (Wedderburn et al. 2012a). Additionally, the Murray was disconnected from its estuary for several years, which placed further stress on the local biota. For example, recruitment of congolli *Pseudaphritis urvillii,* a diadromous fish that requires connectivity between the sea and the river, significantly declined because of disruptions to its life cycle (Zampatti et al. 2010).

High flows in the MDB over 2010–11 refilled wetlands and channels, reduced salinity and re-established connectivity between off-channel sites, the Lower Lakes and Coorong. There was a massive increase in the abundance of many obligate freshwater species in the Lower Lakes, which mostly consisted of young-of-the-year carp and goldfish (>50% of total catches: Bice et al. 2011; Wedderburn and Barnes 2011). Importantly, only low numbers of Murray hardyhead and southern pygmy perch were captured during this period, but with little or no evidence of recruitment over 2010–11 and 2011–12, and Yarra pygmy perch remained absent (Wedderburn and Barnes 2011; Wedderburn and Barnes 2012).

In an effort to assist the population recovery of the three threatened species following drought, fish have been released into the Lower Lakes from a captive maintenance program managed by the South Australian Department of Environment, Water and Natural Resources (DEWNR), under its CLLMM program, and implemented by SARDI Aquatic Sciences, Aquasave and Flinders University (Bice et al. 2012). The Critical Fish Habitat (CFH) project (previously the Drought Action Plan) is funded by the federal Department of Sustainability, Environment, Water, Populations and Communities. Several thousand Murray hardyhead, southern pygmy perch and Yarra pygmy perch were released into suitable habitats over 2011–12 and 2012–13.

The MDBA has funded, through The Living Murray (TLM) program, the condition monitoring of the three threatened fish species at the Lower Lakes since 2005 (Bice and Ye 2006; Bice and Ye 2007; Bice et al. 2008; Wedderburn and Barnes 2009; Wedderburn and Hillyard 2010; Wedderburn and Barnes 2011; Wedderburn and Barnes 2012). It is directed by the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Target F2 of "improved spawning and recruitment success in the Lower Lakes for endangered fish species including Murray hardyheads (*Craterocephalus fluviatilis*) and pygmy perch (*Nannoperca* sp.)" (Maunsell 2009). This report presents the results of TLM condition monitoring in November 2012 and March 2013. The main objectives of this study were to locate populations of the three threatened fish species at the Lower Lakes and establish if they successfully recruited over 2012–13. The results are also compared with previous condition monitoring data to describe 5-year population and habitat trends at sites that hold, or previously held, the three threatened fish species. The study also examines general shifts in fish communities and habitat over the last several years.

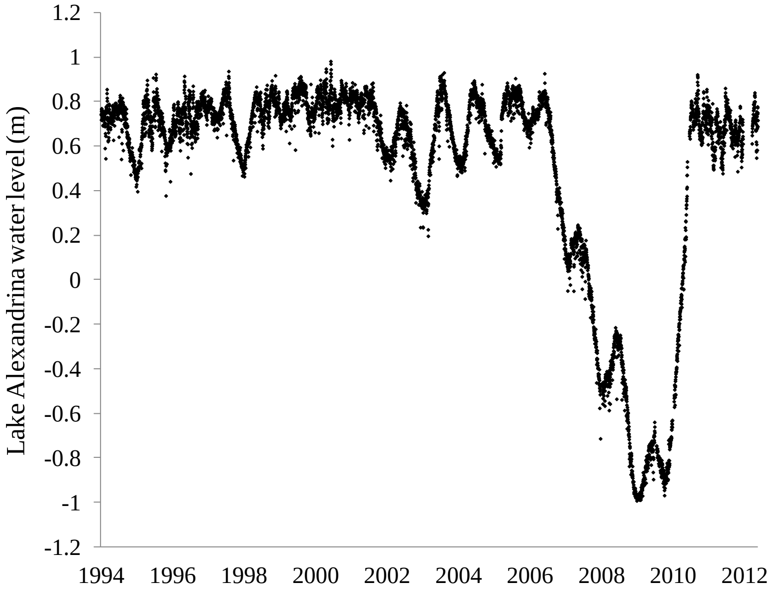


Figure 1. Daily water levels (Australian Height Datum) at Lake Alexandrina from April 1994 to August 2012 (Source: Department of Environment, Water and Natural Resources).

Point Sturt in March 2010 (left) when water level in Lake Alexandrina was approximately -1 m AHD during drought, and in March 2013 (right) at approximately 0.75 m AHD.

Materials and methods

Sampling sites

Twenty-four sites were sampled in November 2012 and re-sampled in March 2013 (Figure 2; Table 1). Data for additional locations (sites 3, 5, 14, 18, 37 and 38) were supplied by SARDI Aquatic Sciences and Aquasave from the Critical Fish Habitat (CFH) project (Bice et al. 2012). This is a continuation of data sharing between TLM condition monitoring and CFH project monitoring, which increases the coverage of information regarding fish assemblages and habitat at the Lower Lakes. The reports by Bice et al. (2012) and Bice et al. (2013) include further information regarding fish releases, monitoring and habitat at the CFH project sites (Table 2).

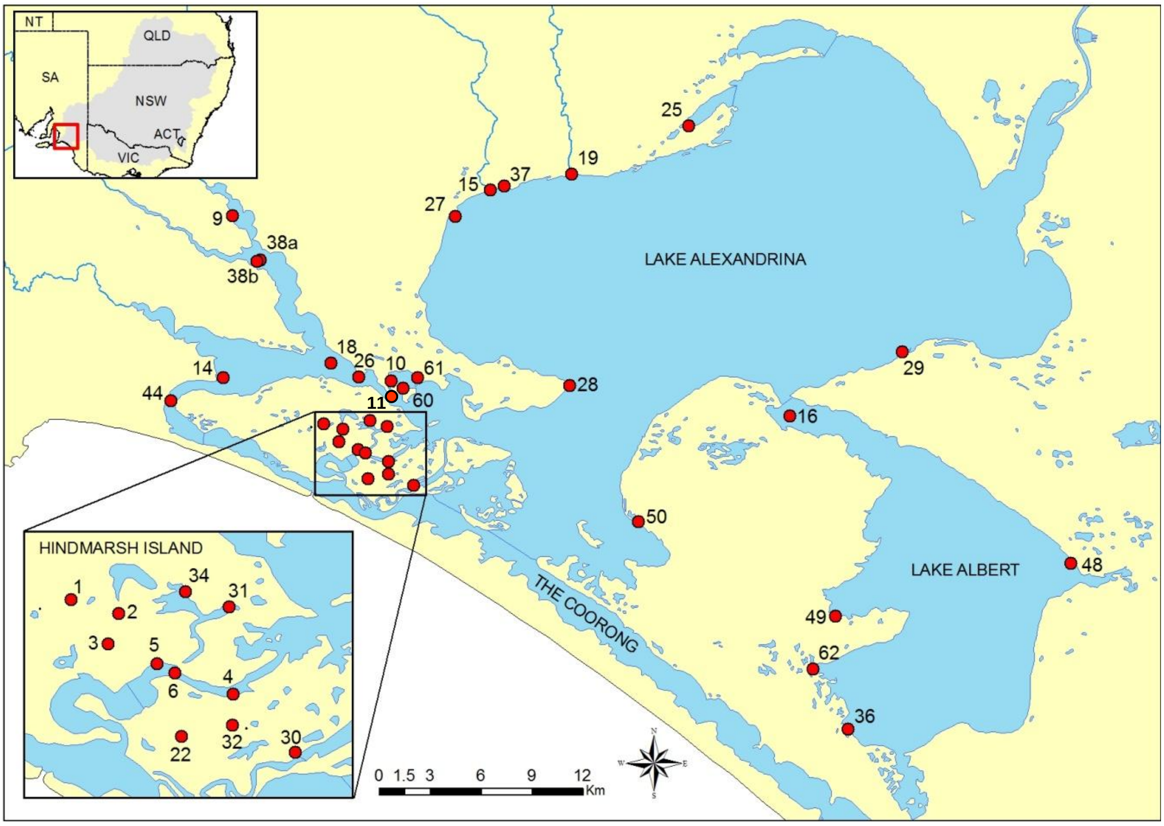


Figure 2. Current and former sampling sites at the Lower Lakes.

Table 1. Sampling sites in November 2012 and March 2013 (UTM zone 54H, WGS84).

Site	Site description	Easting	Northing	Habitat type
2	Wyndgate, Hindmarsh Island	309580	6067037	modified channel
3*	Hunter's Creek, Wyndgate	309336	6066321	natural channel
4	Holmes Ck (Fishtrap Ck mouth)	312287	6065135	natural channel
5*	Steamer Drain, Wyndgate	310487	6065853	modified channel
6	Holmes Ck (Boggy Ck mouth)	310913	6065636	natural channel
9	Finniss River (Wally's Wharf)	303084	6079610	natural channel
10	Dunn Lagoon	312414	6069870	wetland
11	Dunn Lagoon	312421	6069267	wetland
14*	Currency Ck (Goolwa Channel)	302559	6070065	natural channel
15	Angas River (mouth)	318245	6081200	natural channel
16	Narrung Narrows, Lake Albert	335914	6067832	lake edge
18*	Finniss River (Goolwa Channel)	308882	6070934	natural channel
19	Bremer River (mouth)	323062	6082057	natural channel
22	Mundoo Island	311065	6064130	modified channel
25	Dog Lake	329963	6084901	wetland
26	Old Clayton	310519	6070104	lake edge
27	Milang	316188	6079597	lake edge
28	Point Sturt	322934	6069625	lake edge
29	Poltalloch	342532	6071580	lake edge
30	Mundoo Is (near Boundary Ck)	313752	6063750	modified channel
31	Boggy Creek (Tarr's property)	312194	6067197	modified channel
32	Mundoo (nearest Homestead)	312275	6064403	modified channel
34	Shadow's Lagoon	311165	6067555	wetland
36	Campbell House, Lake Albert	339327	6049381	lake edge
37*	Turvey's drain	319095	6081360	modified channel
38*	Black Swamp	304545	6076940	wetland
48	Waltowa, Lake Albert	352454	6059134	lake edge
49	Nindethana, Lake Albert	338591	6056042	lake edge
60	Dunn Lagoon	313141	6069457	wetland
62	Belcanoe	337274	6052900	wetland

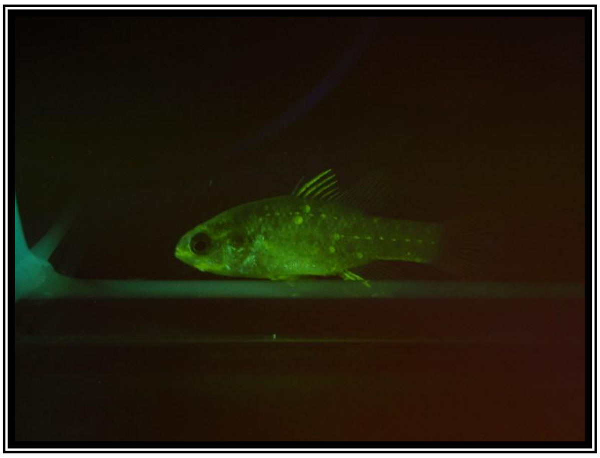
*Site sampled by SARDI Aquatic Sciences & Aquasave for DEWNR's Critical Fish Habitat project.

Table 2. Summary of 2011–13 fish reintroductions through the Critical Fish Habitat project.

Site	Species	Number	Release date
Wyndgate (site 2)	Southern pygmy perch	750	2/11/2011
Blue Lagoon (Finniss River confluence)	Yarra pygmy perch	400	8/11/2011
Finniss River junction (site 18)	Yarra pygmy perch	800	8/11/2011
Finniss River (Winery Road, near site 9)	Purple-spotted gudgeon	200	9/11/2011
Turvey's Drain (site 37)	Southern pygmy perch	400	9/11/2011
Steamer Drain (site 5)	Yarra pygmy perch	2200	27/03/2012
Shadow's Lagoon (site 34)	Yarra pygmy perch	1500	29/03/2012
Mundoo Island (site 32)	Murray hardyhead	3500	28/03/2012
Mundoo Island (site 32)	Southern pygmy perch	280	29/03/2012
Finniss River (Winery Road, near site 9)	Purple-spotted gudgeon	400	29/03/2012
Finniss River (Winery Road, near site 9)	Purple-spotted gudgeon	320	3/12/2012
Mundoo Island (site 32)	Murray hardyhead	3500	4/12/2012
Wyndgate (Hunters Creek, site 3)	Yarra pygmy perch	400	5/12/2012
Wyndgate (Hunters Creek, site 3)	Murray hardyhead	520	5/12/2012
Shadow's Lagoon (site 34)	Yarra pygmy perch	250	5/12/2012
Wyndgate (Hunters Creek, site 3)	Yarra pygmy perch	300	31/02/2013
Finniss River (Winery Road, near site 9)	Purple-spotted gudgeon	200	20/03/2013

See details in Bice et al. (2012) and Bice et al. (2013).

Releasing Yarra pygmy perch into a soft release enclosure at Steamer Drain on Hindmarsh Island in March 2012 (photo: CFH project).



Southern pygmy perch stained with calcein glows green under ultraviolet light (Photo: CFH project).

Fish sampling

Fish sampling equipment and methods varied between sites depending on habitat conditions. Fyke nets were set at all sites, and seine shots, box trapping and dab netting supplemented some sampling. Total lengths (TL) were measured for all threatened fish, and for the first ten fish of all other species from each fyke net.

Fish sampling equipment:

Three single-leader fyke nets (5-mm half mesh) set perpendicular to the bank or angled when in narrow channels or deep water. Grids (50-mm) at the entrances of nets excluded turtles and fish that might harm threatened fish, but are not expected to affect their ability to capture small fish (cf. Fratto et al. 2008). Three nets were set overnight at each site.

Three seine net (7 m long × 1.5 m deep, 5-mm half mesh) shots for up to 10 m, where conditions allowed, within 10 m of the shoreline. The effectiveness of seine shots was variable due to differences in habitat. For example, muddy sediment prevented rapid hauls.

Six box traps unbaited for 1 hour during the day at some sites.

Dab net (1 mm square mesh) was used for 10 minutes near fringing macrophytes where threatened species were captured using other methods, with the aim of detecting larval or early-juvenile fish.

Seine net (left) and retrieving a fyke net (right).

Habitat measures

Water quality

Secchi depth (cm) was measured, and the following parameters were recorded using a TPS WP-81 meter:

- Salinity in grams per litre (g/L)
- Electrical Conductivity units (EC)
- pH
- Temperature (°C)

Physical habitat

- Average water depth: five measures 1 m apart, beginning 1 m from the bank, or five measures equally spaced if in a narrow channel
- Bank gradient: 0–90 degrees
- Riparian vegetation: estimated percentage covering ground
- Aquatic plant cover: estimated percentage covering sediment
- Habitat complexity score: five 10 m transects set 5 m apart. Objects in the water directly below each meter mark on the tape measure were recorded: rock (1 point), terrestrial grass (1 point), algae (1 point), emergent plant (2 points) and submerged plant (3 points). In channels <10 m wide, transects were run the full width and scores were weighted (total points × 50/number of tape measure readings).
- Habitat type: natural channel (usually >10 m wide), modified channel (<10 m wide; includes natural drainage lines that have been excavated), lake, wetland
- Site 'connected' to a lake or a main channel, or 'isolated'.

Data analyses and interpretation

To examine fish assemblages in November 2012 and March 2013, and to investigate their relationship to habitat characteristics, standardised raw data (number of fish captured/fyke net hour in the TLM condition monitoring) were analysed by Non-metric Multi-dimensional Scaling (NMS) ordination using the Relative Sørensen distance metric, in PC-ORD (ver. 6: McCune and Mefford 2011). Only fyke net data was used in the ordination because it is the only consistent method for comparisons.

Total lengths of threatened fish were placed into 20 categories from 0–100 mm (i.e. 0–5, 6–10, 11–15, 16–20 etc.). Length-frequency charts were prepared (using the same length categories) for threatened species to provide a comparison between the November 2012 and March 2013 samples.

Annual comparisons of fish assemblages

Overall shifts in broad fish groups (e.g. estuarine, diadromous, freshwater, alien) in the Lower Lakes are compared by combining the total numbers captured at all sites using only the March (to avoid seasonal variations) sampling data from 2009–2013. Shifts in fish assemblages at each significant site (i.e. sites that were or are inhabited by a threatened species) are compared using the total numbers for fish captured in the November sampling from 2008–2012. The November data was chosen in this case, because some sites were dry only in March 2010.

Results

Water quality

<u>Salinity</u>

In November 2012, salinities were highest at sites fringing Lake Albert, ranging from 1.850 g/L at Waltowa to 2.710 g/L at Narrung (Table 3). At sites fringing Lake Alexandrina, salinities varied from 0.156 g/L at Milang to 1.205 g/L at Wyndgate. In March 2013, salinities in sites at Lake Albert ranged from 1.146 g/L at Narrung to 2.980 g/L in a wetland at Belcanoe. In sites fringing Lake Alexandrina, salinities ranged from 0.246 g/L at Point Sturt to 1.355 g/L in a channel on Mundoo Island. In November 2012 and March 2013, the average salinity of sites in Lake Albert (2.17 and 1.86 g/L, respectively) were always higher than of sites in Lake Alexandrina (0.390. and 0.45 g/L, respectively). This also represents a gradual reduction of salinity in Lake Albert over the last three condition monitoring seasons, where average salinity was 4.26 g/L in November 2010, 3.09 g/L in March 2011, 3.15 g/L in November 2011 and 2.59 g/L in March 2012 (Wedderburn and Barnes 2011; Wedderburn and Barnes 2012).

<u>Other variables</u>

In November 2012, sites ranged between pH 6.32 in Milang to pH 8.22 in Lake Albert at Campbell House. In March 2013, sites ranged between pH 6.91 at Poltalloch to pH 8.92 in Lake Albert at Waltowa. In November 2012, Secchi depth ranged from 15 cm in Steamer Drain, on Hindmarsh Island, to 65 cm at site 32 on Mundoo Island. Water temperature averaged 23.5ºC in November 2012 and 26.9ºC in March 2013.

Physical habitat

As reflected in the values for aquatic plant cover and habitat complexity score (Table 4), physical habitat varied widely between sites in November 2012. Habitat scores ranged from 35 points (24% aquatic plant cover) at Dog Lake to 133 points (100%) in a heavily-vegetated modified channel in Wyndgate (site 2) on Hindmarsh Island that had continuous beds of water milfoil (*Myriophyllum sp.*). and hornwort (*Ceratophyllum demersum*). Habitat complexity scores were lower in March 2013 at 17 of 24 TLM condition monitoring sites. An exception included site 22 on Mundoo Island, which was overgrown with cumbungi (*Typha domingensis*) and water fern (*Azolla filiculoides*). Also, there was a notable increase in aquatic habitat at site 11 near the entrance to Dunn Lagoon, attributed to the increase in abundance of water primrose (*Ludwigia peploides*) and river club rush (*Schoenoplectus validus*). The increase in aquatic habitat at site 31 Boggy Creek is attributed to increases in the abundance of hornwort, cumbungi and water fern.

Water levels at sites were below an average depth of 1 m in November 2012, with the exception of Fish trap Creek mouth (site 4), Angas River mouth (site 15), Black Swamp (site 38) and Dunn Lagoon (site 60). Water levels at sites generally were lower in March 2013. All sites were connected to the main lake habitats during the study period.

Table 3. Water quality in November 2012 (**N**) and March 2013 (**M**).

Site	Salinity (g/L)		Conductivity (µS/cm) EC		pH		Secchi depth (cm)		Water temperature (ºC)	
	N	**M**	**N**	**M**	**N**	**M**	**N**	**M**	**N**	**M**
2	1.205	1.039	2423	2109	7.09	7.80	45	28	20.5	19.1
3*	-	-	783	761	7.71	7.98	22	>80	20.9	21.1
4	0.175	0.314	378	662	7.32	8.19	22	31	22.4	18.8
5*	-	-	320	582	7.1	7.65	15	25	19.8	23.1
6	0.176	0.481	382	1005	7.28	8.19	32	27	23.0	19.4
9	1.202	0.992	2421	2002	7.21	7.51	41	25	25.9	20.1
10	0.170	0.319	364	678	7.52	7.19	19	31	23.1	19.1
11	0.166	0.353	365	744	7.09	7.44	18	20	22.9	17.2
14*	-	-	415	686	7.44	8.71	25	35	17.5	22.1
15	0.782	0.419	1592	877	6.98	7.58	52	26	17.5	18.2
16	2.710	1.146	5310	2304	8.02	7.55	20	27	19.5	18.8
18*	-	-	562	674	7.77	8.30	22	43	22.1	20.1
19	0.169	0.272	365	566	6.91	7.21	20	24	21.0	19.6
22	0.255	0.358	527	753	6.94	7.76	48	29	19.4	17.2
25	0.295	0.329	628	692	8.41	7.34	21	13	22.1	20.0
26	0.175	0.348	376	736	7.27	8.34	20	37	19.4	19.8
27	0.156	0.254	337	545	6.32	7.91	20	28	23.4	19.6
28	0.157	0.246	343	522	7.60	7.91	24	19	19.1	17.5
29	0.130	0.254	282	540	7.05	6.91	17	15	20.7	22.0
30	0.230	1.355	493	2710	7.33	7.80	29	29	21.9	17.7
31	0.303	0.343	641	721	6.63	7.49	50	21	23.0	19.7
32	1.080	0.421	2398	882	7.84	7.76	65	20	24.4	17.1
34	0.327	0.410	686	860	7.41	7.23	43	24	27.9	20.7
36	2.030	2.030	3940	3970	8.22	8.48	21	18	19.8	17.1
37*	-	-	1340	789	7.32	8.58	70	>95	24.1	20.3
38*	-	-	1501	1508	7.29	7.83	30	25	20.8	24.2
48	1.850	1.930	3670	3810	7.91	8.92	31	19	18.1	16.9
49	2.010	2.060	3900	4020	8.11	8.53	21	21	23.3	22.4
60	0.167	0.308	365	656	8.09	8.31	22	21	21.3	18.8
62	2.250	2.980	4860	5160	7.63	8.39	20	16	18.7	19.6

*Site sampled by SARDI Aquatic Sciences & Aquasave for the Critical Fish Habitat project (dash represents where reading was not taken).

Table 4. Physical habitat in November 2012 (**N**) and March 2013 (**M**).

Site	Average depth (cm)		Aquatic plants (%)		Riparian plants (%)		Habitat complexity (score)		Connected	
	N	**M**	**N**	**M**	**N**	**M**	**N**	**M**	**N**	**M**
2	67	52	100	100	100	100	133	157	yes	yes
3*	90	53	40	40	-	-	-	-	yes	yes
4	104	73	47	22	100	100	78	44	yes	yes
5*	84	60	99	80	-	-	-	-	yes	yes
6	50	27	28	50	100	100	29	62	yes	yes
9	68	45	28	48	100	100	29	62	yes	yes
10	41	40	76	68	100	100	105	71	yes	yes
11	44	42	34	70	100	100	34	71	yes	yes
14*	57	64	70	70	-	-	-	-	yes	yes
15	116	51	67	68	100	100	63	48	yes	yes
16	86	67	76	40	100	70	83	43	yes	yes
18*	56	57	70	90	-	-	-	-	yes	yes
19	34	13	40	50	90	100	40	54	yes	yes
22	61	35	80	43	80	90	85	49	yes	yes
25	34	42	24	20	100	80	35	24	yes	yes
26	48	35	52	78	100	100	74	69	yes	yes
27	45	38	82	40	100	100	83	40	yes	yes
28	42	26	38	28	90	75	42	34	yes	yes
29	63	47	62	56	100	100	66	60	yes	yes
30	98	63	36	42	80	80	36	37	yes	yes
31	68	62	68	66	95	100	85	133	yes	yes
32	75	61	75	85	100	100	120	110	yes	yes
34	46	38	68	46	100	100	119	60	yes	yes
36	47	36	74	36	100	100	72	42	yes	yes
37*	92	96	85	95	-	-	-	-	yes	yes
38*	108	117	30	40	-	-	-	-	yes	yes
48	50	43	64	42	100	80	64	42	yes	yes
49	34	27	48	42	98	100	48	42	yes	yes
60	109	89	72	70	100	100	105	99	Yes	yes
62	30	35	30	24	100	100	27	28	yes	yes

*Site sampled by SARDI Aquatic Sciences & Aquasave for the Critical Fish Habitat project.

Fish assemblages

In November 2012, TLM (24 sites) and CFH project (six sites) monitoring recorded 5530 fish represented by 20 species (Table 5). Alien fishes constituted 24% of the total catch, and consisted of carp (12% of total catch), redfin (7%), goldfish (3%) and Gambusia (3%). Common galaxias (32%), flathead gudgeon (10%) and lagoon goby (9%) were the most numerous native fishes. Notably, the diadromous congolli made up almost 6% of the total catch. A summary of the overall catches for each site sampled in TLM condition monitoring are presented in the Appendices.

In March 2013, TLM and CFH monitoring recorded 7514 fish represented by 24 species. The proportions of carp (2%) and goldfish (1%) in the total catch were substantially lower than in the November sampling. The proportion of redfin (6%) in the catch was similar to November, but there was a substantial increase in Gambusia (29%). The proportion of flathead gudgeon (11%) was similar in March, whereas the proportion of common galaxias (17%) had declined. Despite the low numbers recorded in November, Bony herring (19%) was the second most abundant fish species captured in March. A single tench was captured at the mouth of the Angas River in March 2013. A spangled perch was captured at Dog Lake, which represents an uncommon find because it normally occupies the upper regions of the Murray–Darling Basin (I. Ellis, unpublished data).

The overall number of fish captured in March 2013 was higher than in the March 2012 monitoring (Figure 3). The extremely high overall abundance in March 2010 is likely a result of salinisation in the Lower Lakes, which promoted estuarine fishes, especially lagoon goby and smallmouth hardyhead, however, their abundances are now extremely low (Figure 4). In March 2013, the composition of the fish assemblages in off-channel sites at the Lower Lakes were similar to March 2012, whereby they were largely dominated by alien fishes and common native freshwater generalists. The total numbers of Gambusia captured were highest at the peak of drought in March 2009 and March 2010, and although its numbers were substantially lower immediately following the return of flows, it was the most numerous alien fish species in March 2013 (Figure 5). The numbers of carp captured were comparable between March 2010 and March 2011, but numbers were substantially lower in March 2012. Notably, the relative abundance of juvenile carp (i.e. sampling methods only capture fish <300 mm TL) at the Lower Lakes was relatively low in March 2013. Redfin and goldfish were in relatively low numbers throughout the four seasons, except there was a notable increase in their abundances from March 2011. Indeed, the abundance of redfin appears to have remained constant over the last three years.

During the last five March monitoring events, the overall numbers of freshwater fishes peaked in 2010 and was lowest in 2012 (Figure 6). Two ecological generalists, flathead gudgeon and Bony herring, were the most numerous species in catches, including in March 2013. Australian smelt was common during the drought, but its abundance has been relatively low in the last three years. Notably, unspecked hardyhead was recorded in moderate numbers at the Lower Lakes, for the first time in several years. In March 2013, the freshwater ecological specialists (including the threatened fishes) continued to constitute a minor proportion of the fish assemblages in the Lower Lakes. However, dwarf flathead gudgeon showed signs of population recovery in March 2012, and had another increase in relative abundance in March 2013.

Common galaxias and congolli were the only diadromous fishes captured in the last five TLM condition monitoring events. Common galaxias remained relatively abundant from March 2008 to March 2012, but its numbers were substantially higher in March 2013 (Figure 7). Congolli was notably absent during the peak of drought in March 2009 and March 2010, but relatively low numbers were captured in March 2011 (young-of-the-year) and March 2012 (young-of-the-year and 1+ fish). Recruitment in the population over 2010–11 and 2011–12 apparently led to a substantial increase in the relative abundance of congolli in March 2013.

Table 5. Number of sites recorded and total abundance (*n*) of each fish species captured in November 2012 and March 2013 during TLM and CFH monitoring at 30 sites.

Common name	Scientific name	November 2012		March 2013	
		Sites	*n*	Sites	*n*
Freshwater species					
Southern pygmy perch	*Nannoperca australis*	1	2	1	1
Yarra pygmy perch	*Nannoperca obscura*	2	9	1	2
Murray hardyhead	*Craterocephalus fluviatilis*	2	11	4	68
Unspecked hardyhead	*C. stercusmuscarum fulvus*	5	27	12	132
Golden perch	*Macquaria ambigua*	8	19	12	45
Bony herring	*Nematalosa erebi*	3	15	21	1398
Flathead gudgeon	*Philypnodon grandiceps*	27	565	30	861
Dwarf flathead gudgeon	*Philypnodon macrostomus*	9	28	13	35
Carp gudgeon	*Hypseleotris* sp.	17	265	16	78
Australian smelt	*Retropinna semoni*	11	267	8	43
Spangled perch	*Leiopotherapon unicolor*	0	0	1	1
Carp*	*Cyprinus carpio*	27	669	26	153
Goldfish*	*Carassius auratus*	25	170	20	101
Redfin*	*Perca fluviatilis*	29	365	27	460
Gambusia*	*Gambusia holbrooki*	13	147	23	2213
Tench*	*Tinca tinca*	0	0	1	1
Diadromous species					
Congolli	*Pseudaphritis urvillii*	25	312	28	387
Common galaxias	*Galaxias maculatus*	21	1790	24	1252
Estuarine species					
Smallmouth hardyhead	*Atherinasoma microstoma*	6	40	7	64
Blue-spot goby	*Pseudogobius olorum*	8	287	6	29
Tamar River goby	*Afurcagobius tamarensis*	7	19	4	178
Lagoon goby	*Tasmanogobius lasti*	15	523	1	1
Sandy sprat	*Hyperlophus vittatus*	0	0	2	10
River garfish	*Hyporhamphus regularis*	0	0	1	1

*alien species

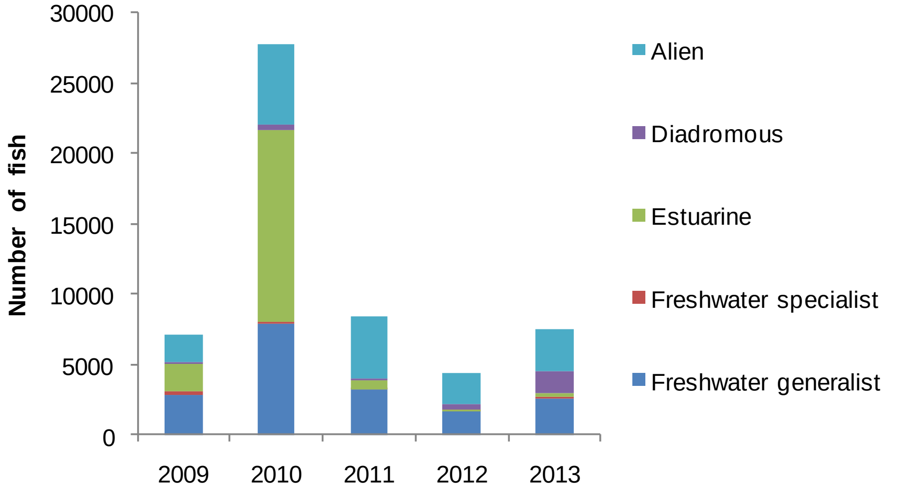


Figure 3. Total numbers of fish captured in each general group during combined TLM and CFH/DAP March monitoring events from 2009–13.

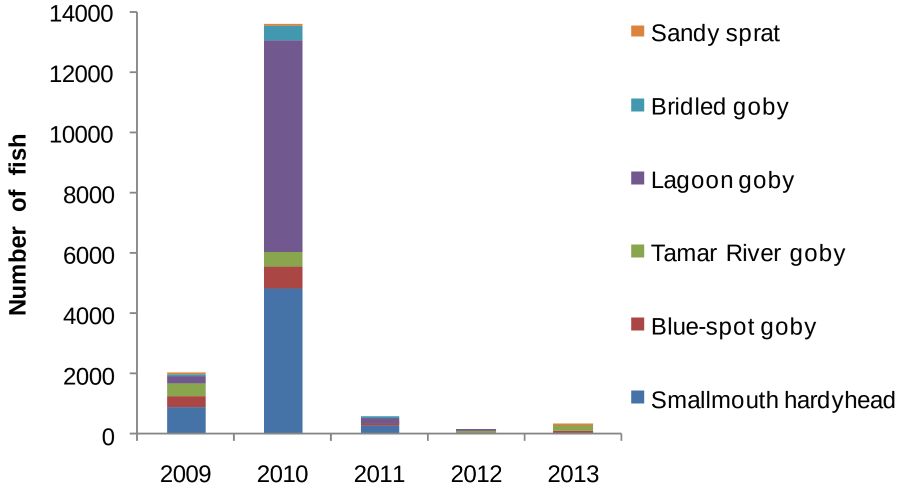


Figure 4. Total numbers of estuarine fishes captured in combined TLM and CFH/DAP March monitoring events from 2009–13.

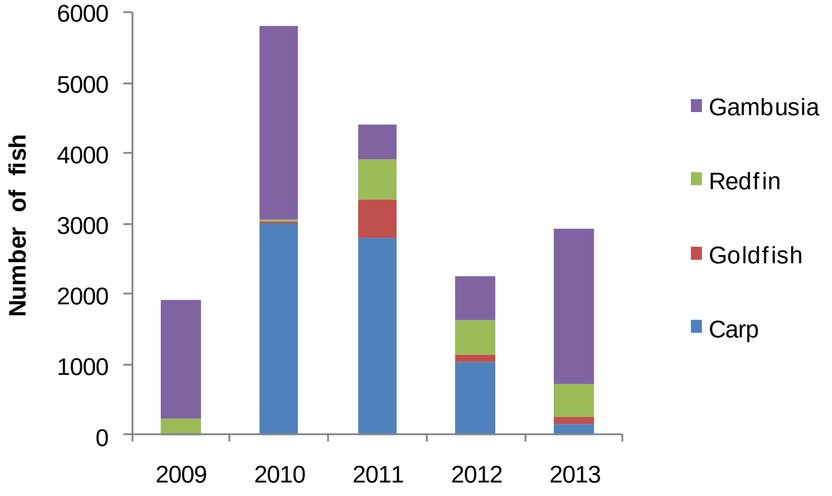


Figure 5. Total numbers of alien fishes captured in combined TLM and CFH/DAP March monitoring events from 2009–13 (tench excluded).

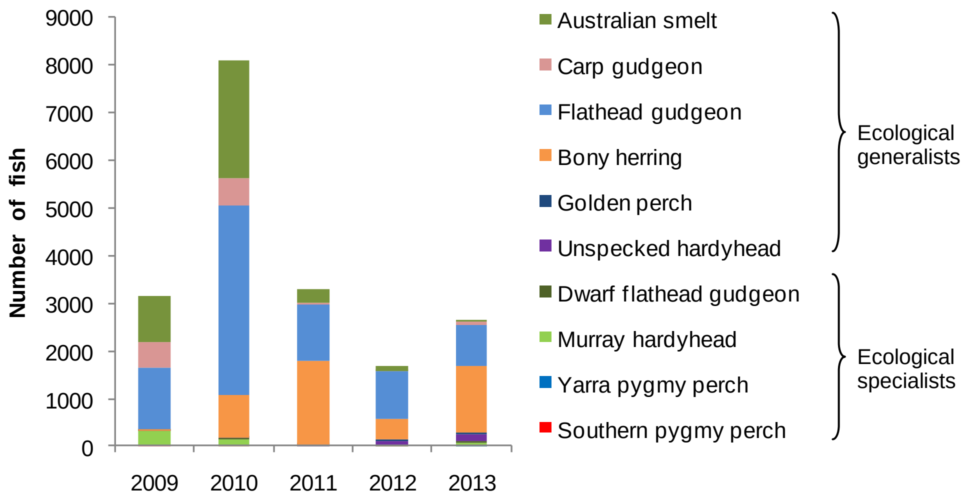


Figure 6. Total numbers of native freshwater fishes captured in combined TLM and CFH/DAP March monitoring events from 2009–13.

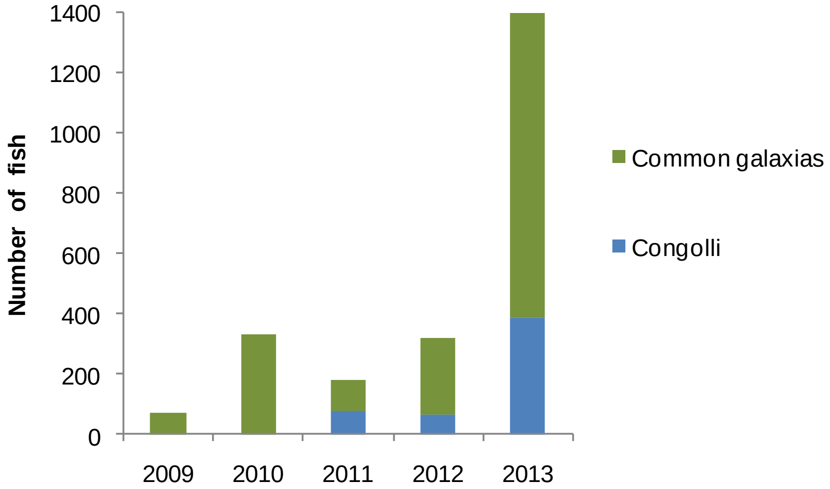


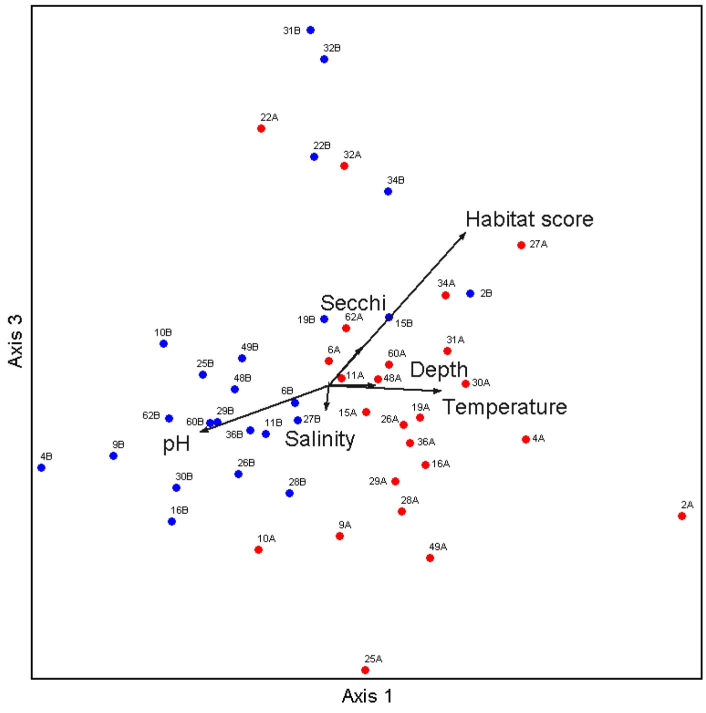
Figure 7. Total numbers of diadromous fishes captured in combined TLM and CFH/DAP March monitoring events from 2009–13.

Processing congolli at Narrung with field assistants from the Ngarrindjeri Regional Authority

The ordination shows a partial clustering of sites based on the time of sampling in the 2012–13 TLM condition monitoring, with most of the November 2012 sites (red dots) on the bottom right-hand corner of the plot (Figure 8). Two exceptions are sites 22 and 32 on Mundoo Island. The majority of sites sampled in March 2013 are on the left of the plot, but some sites on Hindmarsh Island and Mundoo Island (sites 22, 31, 32 and 34) are exceptions. Multi-response Permutation Procedure (MRPP) confirmed that the fish assemblages recorded during the two sampling events are significantly different ($P < 0.001$). MRPP also confirmed that fish assemblages are significantly different ($P < 0.001$) between sites at Lake Albert and Lake Alexandrina, and between the four broad habitat types ($P < 0.001$). Plots representing the last two categories are not presented because no discernable pattern is visible.

The relationships are generally weak, but 'habitat score' is the variable most strongly associated with fish assemblages, on Axis 1 (correlation between habitat score and axis score: $r = 0.38$) and Axis 3 ($r = 0.40$). The correlation for pH shows an opposing trend on Axis 1 ($r = -0.37$) and Axis 3 ($r = -0.22$). Notably, unlike TLM condition monitoring from 2008 to 2012, salinity shows only a weak relationship in the ordination for the 2012–13 season. Similarly, Secchi depth and water depth show weak relationships, while water temperature is positively associated on Axis 1 ($r = 0.34$) with fish assemblages sampled in November 2012.

The relatively strong correlation for Gambusia on Axis 3 ($r = 0.70$) suggests a positive relationship with habitat score and an association with fish assemblages in the sites on Hindmarsh Island and Mundoo Island at the top centre of the plot. Carp gudgeon, flathead gudgeon and Murray hardyhead show a similar but weaker trend on Axis 3 ($r = 0.36$, 0.30 and 0.27, respectively). Bony herring and, to a lesser extent, dwarf flathead gudgeon show a relatively strong relationship on Axis 1 ($r = 0.71$ and 0.30, respectively) towards the March 2013 sampling, and a negative association with water temperature. Congolli, redfin and lagoon goby have a lack of association with any of the two sampling periods (Axis 3: $r = -0.49$, -0.45 and -0.38, respectively), but demonstrate a relationship with lake edge, natural channel and wetland sites. Carp and goldfish are correlated on Axis 1 with the November 2012 sampling event ($r = 0.53$ and 0.28, respectively).



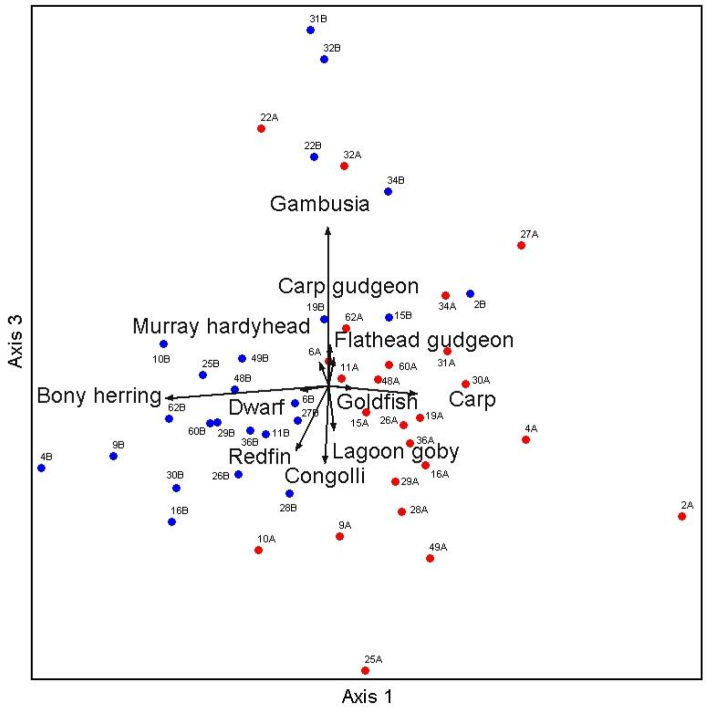


Figure 8. Three-dimensional NMS ordination (Stress = 0.13) of TLM condition monitoring sites based on similarities between fish species composition and abundance. Habitat (top plot) and fish species (bottom plot) are overlaid with the vector length proportional to, and directed towards, their correlation with sites. Red dots represent sites sampled in November 2012, and blue dots represent sites sampled in March 2013.

Threatened fishes

Summation

Southern pygmy perch and Yarra pygmy perch were captured in low numbers in November 2012 and March 2013 (Table 6). Low numbers of Murray hardyhead were captured in November 2012, while relatively high numbers were recorded in March 2013. Fluorometer readings (indicates calcein marking) for Yarra pygmy perch showed they were mostly re-stocked fish, but a few are likely young-of-the-year. Similarly, most of the captured southern pygmy perch gave positive readings for calcein. The test apparently is unreliable for Murray hardyhead (Bice et al. 2013). A genetic study by Flinders University aims to determine the origin (i.e. re-stocked or recruited in the wild) of the captured threatened fish (L. Beheregaray, unpublished data). There is firm evidence that Murray hardyhead is recovering to a self-sustaining population in the Finniss River and Goolwa Channel region of the Lower Lakes (Table 6). The species is yet to re-establish in habitat on Mundoo Island and Hindmarsh Island, and in Lake Albert, where it formerly occurred (see Hammer et al. 2002). There is some evidence of limited recruitment in both pygmy perch species, but the data fails to conclusively show that they represent self-sustaining populations.

Table 6. Numbers of each threatened fish species captured in TLM and CFH project monitoring in November 2012 and March 2013, and a summary of their local (site) population status.

Site	Fish species	Number captured		Population status
		Nov.	Mar.	
5	Yarra pygmy perch	2	0	Two adult fish captured in spring 2012 were re-stocked fish, and absence of young-of-the-year fish suggests a lack of recruitment.
10	Murray hardyhead	0	7	The seven fish captured in March 2013 were late stage young-of-the-year, and were likely recruited in the wild near the Finniss junction of the Goolwa Channel.
18	Murray hardyhead	7	43	Relatively high numbers captured in November 2012 and March 2013, with conclusive signs of strong, local recruitment at the Finniss River junction of the Goolwa Channel, thereby indicating a self-sustaining population.
22	Southern pygmy perch	0	1	A single fish was captured, in March 2013, providing an indication of possible limited recruitment at the site, but evidence of a self-sustaining population is lacking.
26	Murray hardyhead	0	7	The seven fish captured in March 2013 were late stage young-of-the-year, and were likely recruited in the wild near the Finniss River junction of the Goolwa Channel.
32	Murray hardyhead	4	9	Small numbers captured in November and March were re-stocked fish, and absence of young-of-the-year fish suggests a lack of recruitment.
32	Southern pygmy perch	2	0	Two adult fish captured in November were re-stocked fish, and absence of young-of-the-year fish suggests a lack of recruitment.
34	Yarra pygmy perch	7	2	Small numbers of adults captured in November were re-stocked fish, but two fish captured in March are young-of-the-year that likely were recruited in the wild, but small numbers mean evidence of self-sustaining population is lacking.

Murray hardyhead

Relatively low numbers of Murray hardyhead were recorded during TLM condition monitoring in October 2007 and February 2008 (Figure 9). The subsequent increase in relative abundance in 2008–09 is likely a reflection of the concentration of the species in off-channel sites during the drought (i.e. easier to catch), which was followed by a substantial decline as sites dried over 2009–10. In November 2009, relatively low numbers of Murray hardyhead were captured at lake edges, natural channels and modified channels (connected and isolated sites), and a relatively high number in a drainage channel on Mundoo Island (site 32) (Wedderburn and Hillyard 2010). In March 2010, a relatively low number of Murray hardyhead was recorded at a newly selected site adjacent to the Hindmarsh Island Bridge (site 44), which was inundated only because of the Clayton regulator, and moderate numbers were captured from channels at Dog Lake (site 25) and Boggy Creek (site 31) (Wedderburn and Hillyard 2010). The species was undetected in the 2011–12 TLM condition monitoring, but 13 individuals were captured during monitoring in the CFH project (Bice et al. 2012).

During the 2012–13 TLM condition monitoring, Murray hardyhead was mostly associated with the Finniss River and Goolwa Channel area, apart from a few individuals captured at the CFH project release site on Mundoo Island (site 32). Length-frequency distributions for all Murray hardyhead captured in TLM and CFH project monitoring indicate a single cohort of adult fish in November 2012, and two distinct cohorts in March 2013 (Figure 10). Therefore, recruitment is apparent for the Murray hardyhead population at the Lower Lakes in 2012–13.

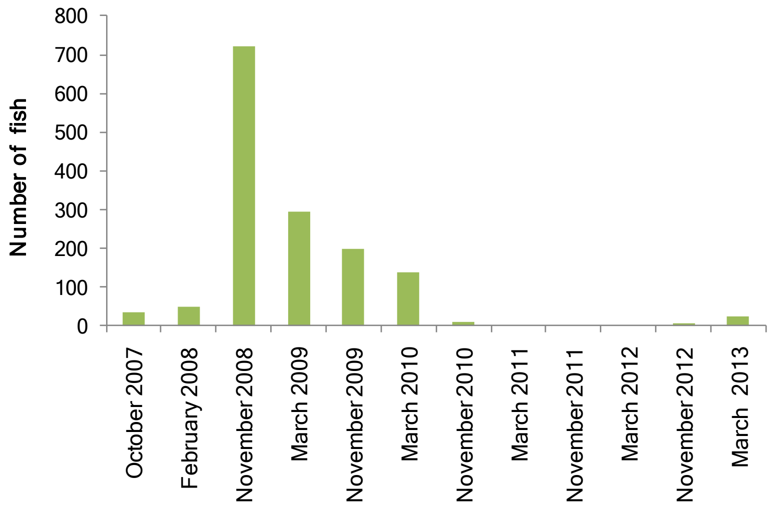
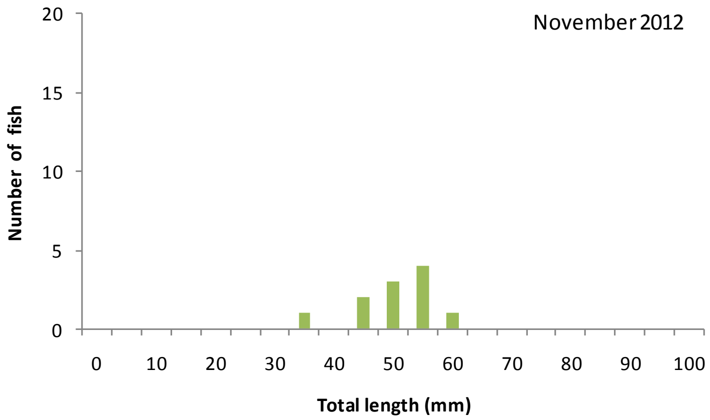


Figure 9. Total numbers of Murray hardyhead captured in TLM condition monitoring at the Lower Lakes in the last six seasons.



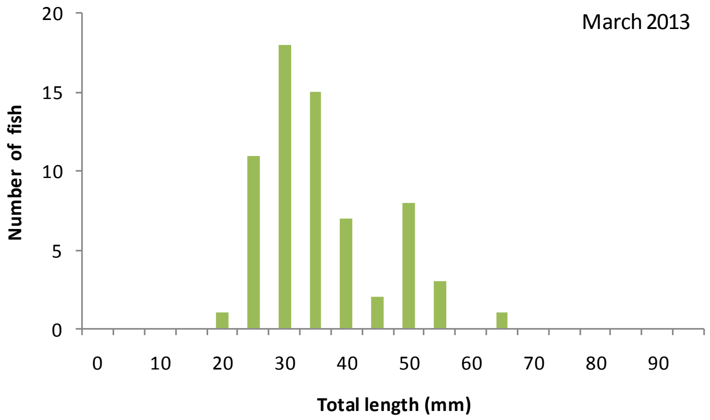


Figure 10. Length frequency distributions of all Murray hardyhead captured at the Lower Lakes during TLM and CFH sampling in November 2012 (*n* = 11) and March 2013 (*n* = 66).

Pygmy perch

Yarra pygmy perch was first recognised at the Lower Lakes in 2002–03, when the species was relatively abundant at sites on Hindmarsh Island (Hammer et al. 2002; Wedderburn and Hammer 2003). Moderate numbers of Yarra pygmy perch were captured in October 2005, before a population collapse in 2007–08 (Figure 11). Similarly, relatively high numbers of southern pygmy perch were captured in October 2005, before a population collapse during the drought. Southern pygmy perch was captured at four sites in November 2008 (Wedderburn and Barnes 2009), including at a modified channel on Mundoo Island (site 22). However, it was not captured at the site in 2009–10 and 2010–11. The 2009–10 TLM condition monitoring also sampled site 35 approximately 300 m from, and formerly connected to, site 22. Four adult southern pygmy perch were captured at site 35 in November 2009, but the species was absent thereafter. Drought Action Plan (DAP) monitoring captured low numbers of southern pygmy perch at Turvey's Drain (site 37) near Milang in 2009–10 (Bice et al. 2010), where the habitat was conserved using an environmental water allocation. Further, seven southern pygmy perch were recorded at Black Swamp (site 38) during spring 2009 (DAP), but the species was not detected in autumn 2010. However, two southern pygmy perch were captured in the nearby channel off Black Swamp in autumn 2010. In 2011–12, two southern pygmy perch were recaptured at Wyndgate following their release a few weeks earlier.

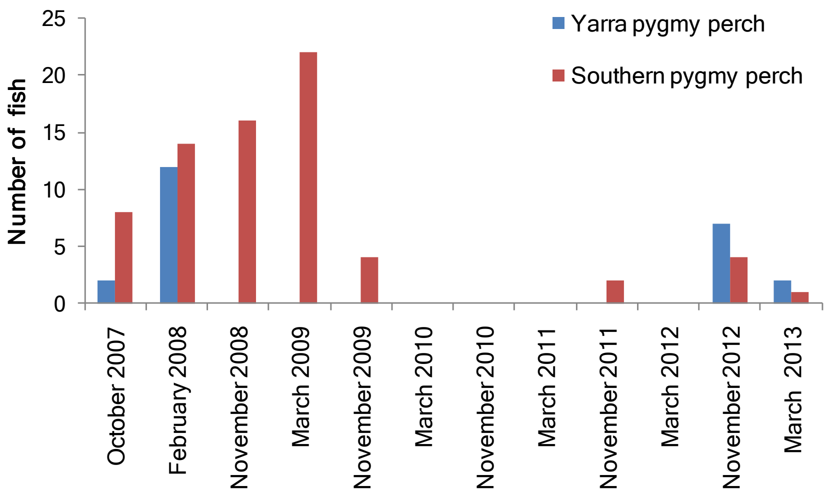


Figure 11. Total number of Yarra pygmy perch and southern pygmy perch captured in TLM condition monitoring at the Lower Lakes in the last six seasons.

In November 2012, several Yarra pygmy perch were recaptured (indicated by calcein staining) at Shadow's Lagoon, Hindmarsh Island. The only two Yarra pygmy perch captured in March 2013 failed to register calcein readings. Similarly, a few of the southern pygmy perch captured on Mundoo Island in 2012–13, including the single fish captured in March 2013, failed to indicate calcein staining. Therefore, determination of its wild or re-stocked origin will need to be confirmed through the Flinders University genetic study (L. Beheregaray, unpublished data). Initial indications are that five southern pygmy perch (four smallest in 2012 and the single fish in 2013), and two Yarra pygmy perch captured in March 2013, were recruited in the wild (Bice et al. 2013).

Length-frequency distributions for all southern pygmy perch captured at the Lower Lakes in TLM and CFH project monitoring are too small to conclusively indicate the level of recruitment success in the Lower Lakes population (Figure 12). Similarly, the length-frequency distributions for all Yarra pygmy perch captured at the Lower Lakes are from an extremely low number of fish, so limited conclusions can be drawn regarding the level of recruitment success (Figure 13).

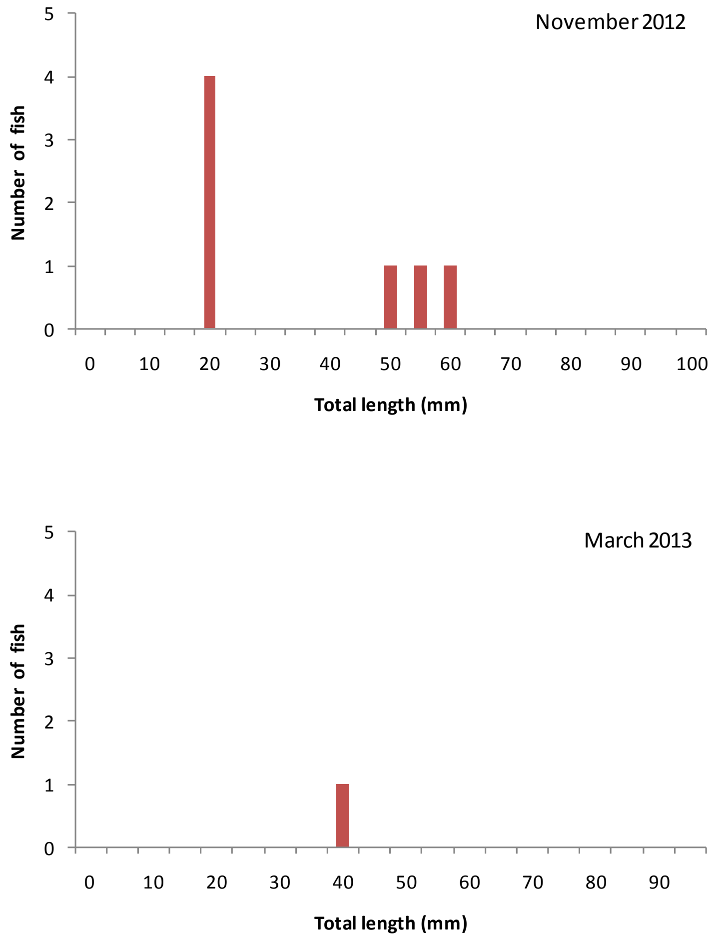
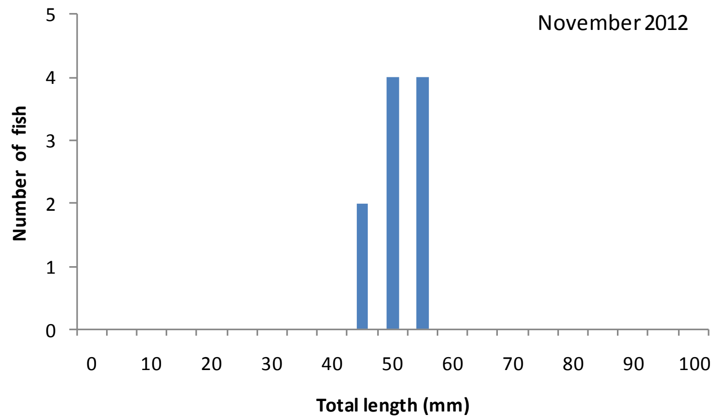


Figure 12. Length frequency distributions of all southern pygmy perch captured at the Lower Lakes during TLM and CFH sampling in November 2012 (*n* = 7) and March 2013 (*n* = 1).



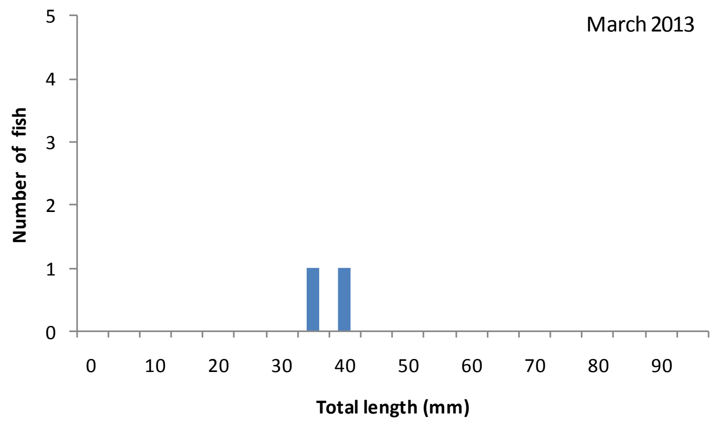


Figure 13. Length frequency distributions of all Yarra pygmy perch captured at the Lower Lakes during TLM and CFH sampling in November 2012 (*n* = 10) and March 2013 (*n* = 2).

Yarra pygmy perch captured at Shadow's Lagoon in November 2012.

Significant sites

Wyndgate Conservation Park (site 2)

Fish were first sampled on Hindmarsh Island as part of the Biological Survey of the Murray Mouth reserves just prior to its proclamation as Wyndgate Conservation Park (Hammer et al. 2002). The survey and a subsequent inventory of the Lower Lakes in the following year (Wedderburn and Hammer 2003) identified that the three threatened fish species thrived in the well-vegetated, freshwater habitats in a diverse fish community. During the middle stage of drought in 2005, Yarra pygmy perch, southern pygmy perch and Murray hardyhead were still abundant at Wyndgate (Bice and Ye 2006). Most of the habitats, which include Hunter's Creek and a series of interconnected modified channels (modified drainage lines), dried during the summer of 2007–08.

In November 2010, after re-inundation of habitat, the catches from Wyndgate Conservation Park were overwhelmingly cyprinids, mostly young-of-the-year carp and goldfish (Figure 14). In November 2011, cyprinids still dominated fish assemblages at the site, but southern pygmy perch (recaptured from the CFH project's restocking), common galaxias, congolli and smallmouth hardyhead were present in low relative abundances. Cyprinids again dominated the fish assemblage in November 2012, when two Yarra pygmy perch (42 and 53 mm TL) were the only threatened fish captured (Steamer drain: Bice et al. 2013). Threatened fish species were not recorded at Wyndgate Conservation Park in March 2013. Although the habitat appeared suitable for the threatened fishes, it seems that the re-stocking has been unsuccessful at the site for unknown reasons. It will be important to track changes in fish assemblages at Wyndgate Conservation Park over coming years to determine if the threatened fishes re-establish. This is pertinent, given that fish provided one of the highest conservation values of any biological group in Wyndgate Conservation Park when it was first proclaimed (see Brandle 2002).

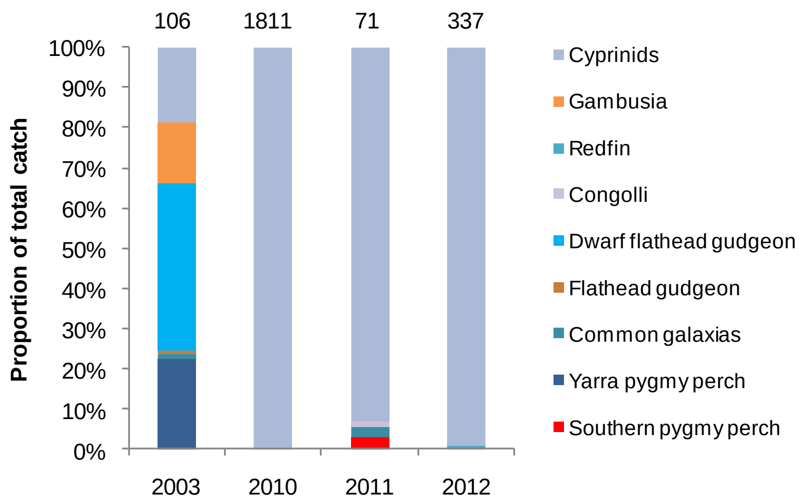


Figure 14. Comparison of species composition and total abundance (value above bar) in fish assemblages at Wyndgate (site 2) in 2003 (site D2 in Wedderburn and Hammer 2003) and for the last three November TLM sampling events.

Dunn Lagoon (sites 10 and 11)

In November 2008, as salinisation continued during drought, the estuarine smallmouth hardyhead was the most abundant species in the fish assemblage at Dunn Lagoon (Figure 15), where it constituted approximately two-thirds of the catch. In November 2009, smallmouth hardyhead was still relatively abundant, but carp dominated the catch. The fish assemblage was more diverse following re-inundation of the lagoon in 2010, but largely consisted of the freshwater ecological generalists Australian smelt, flathead gudgeon and redfin. In November 2011, the catch was the lowest of any November sampling in five years. However, the fish assemblage was relatively diverse, and had shifted to being dominated by common galaxias, carp gudgeon and carp. In November 2012, alien redfin dominated the fish assemblage at Dunn Lagoon, and common galaxias was notable.

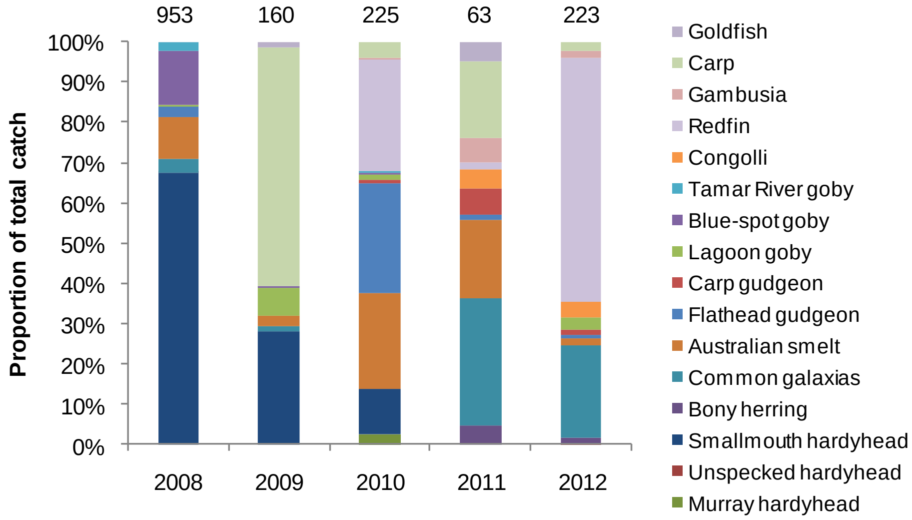


Figure 15. Comparison of species composition and total abundance (value above bar) in fish assemblages at Dunn Lagoon for the last five November TLM sampling events.

Dunn Lagoon site 10 in November 2012 (left) and site 11 in March 2013.

Moderate numbers of Murray hardyhead were recorded in the early stages of monitoring at Dunn Lagoon (Figure 16). Murray hardyhead was undetected during the 2011–12 TLM condition monitoring, despite the additional effort of sampling two new sites (sites 60 and 61: see Wedderburn and Barnes 2012). There was an apparent recovery of aquatic habitat in Dunn Lagoon when water levels returned over 2010–11 (Figure 17). Given the capture of several Murray hardyhead at site 10 in March 2013, there is a suggestion that suitable habitat, in the form of aquatic plants (see Gehrig et al. 2012) and slightly elevated salinity (see Wedderburn et al. 2007), is re-establishing.

The length-frequency distribution for Murray hardyhead captured at Dunn Lagoon in March 2013 suggests that the fish are late stage young-of-the-year (Figure 18). Given that the species was not detected at Dunn Lagoon in November 2012, the fish likely recruited elsewhere before moving into the habitat later in the season. The high proportion of redfin in the lagoon is a key threat to Murray hardyhead, because the alien perch is an efficient and opportunistic predator (see Wedderburn et al. 2012b). Similarly, southern pygmy perch was recorded at the lagoon in a baseline survey (SKM 2005), but its ability to re-establish a population in Dunn Lagoon might be hindered by redfin. Indeed, the vast (approx. 1 ha) and patchy bed of water milfoil in the area adjacent to Goat Island (site 60) seems to be ideal habitat for the two pygmy perch species and Murray hardyhead.

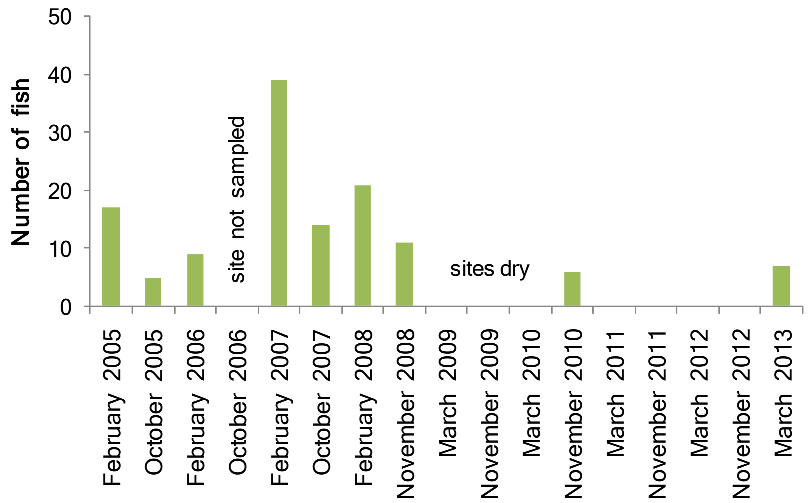


Figure 16. Numbers of Murray hardyhead captured at Dunn Lagoon over the entire TLM condition monitoring program.

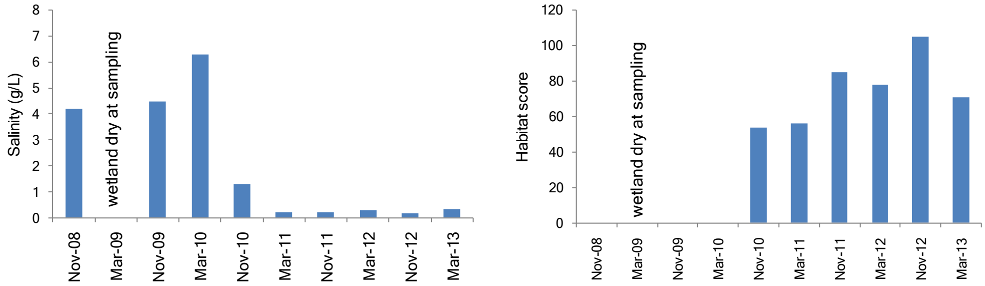


Figure 17. Corresponding changes in salinity and habitat complexity score at Dunn Lagoon from November 2008 to March 2013.

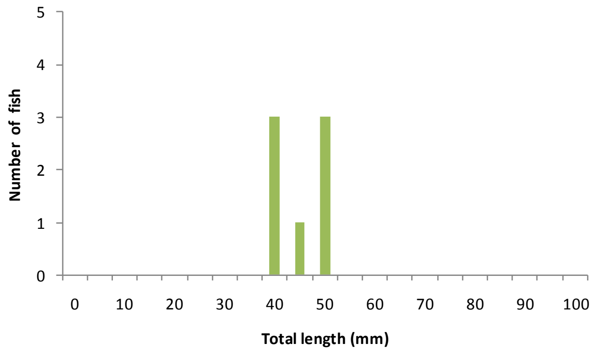


Figure 18. Length frequency distribution of Murray hardyhead captured at Dunn Lagoon in March 2013 (n = 7).

Murray hardyhead (left), and alien redfin (right, top) and native golden perch (right, bottom) captured at Dunn Lagoon in March 2013.

Currency Creek (site 14)

This site at the junction of Currency Creek and Goolwa Channel was sampled under the DAP monitoring program in 2010–11 (Bice et al. 2011). At that time, high numbers of adult Murray hardyhead were captured in November 2010, but the species was not detected in March 2011. Therefore, it was unconfirmed whether Murray hardyhead bred and recruited at the site over that season. In 2011–12 monitoring through the CFH project (Bice et al. 2012), a single adult Murray hardyhead was captured at the site in November 2011. Murray hardyhead was not recorded at the site in 2012–13. Smallmouth hardyhead dominated the fish assemblage at the site in November 2008, 2009 and 2010, but constituted a small proportion thereafter (Figure 19). An extremely high number of smallmouth hardyhead was recorded in 2008. Murray hardyhead made up a small proportion (~5%) of the catch in November 2010. In November 2011, the fish assemblage was more diverse than any other November sampling event, and was predominantly common galaxias, flathead gudgeon and carp. Although the lowest number of fish was recorded at the site in November 2012, common galaxias was the predominant species in the fish assemblage.

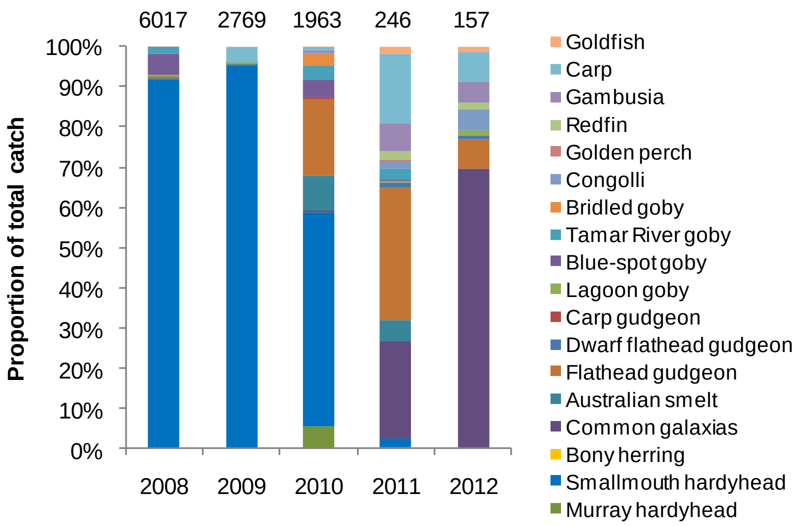


Figure 19. Comparison of composition and total abundance (value above bar) in fish assemblages at Currency Creek for the last five November CFH/DAP sampling events.

Finniss River junction (site 18)

Smallmouth hardyhead dominated the fish assemblage at the Finniss River junction of Goolwa Channel in November 2008, 2009 and 2010, but occurred in low abundance thereafter (Figure 20). In November 2011, the fish assemblage was more diverse than any other previous November sampling event, and was predominantly common galaxias and bridled goby. The number of fish captured was highest in November 2010, largely because of high numbers of smallmouth hardyhead and Australian smelt. As with most sites sampled in 2011–12, the total number of fish captured at the site was substantially lower in November 2011 than in the previous two seasons. In November 2012, the fish assemblage at the site was dominated by common galaxias, flathead gudgeon and Gambusia. Notably, the fish assemblage was dominated by Gambusia, flathead gudgeon and Murray hardyhead in March 2013 (see Appendix 2).

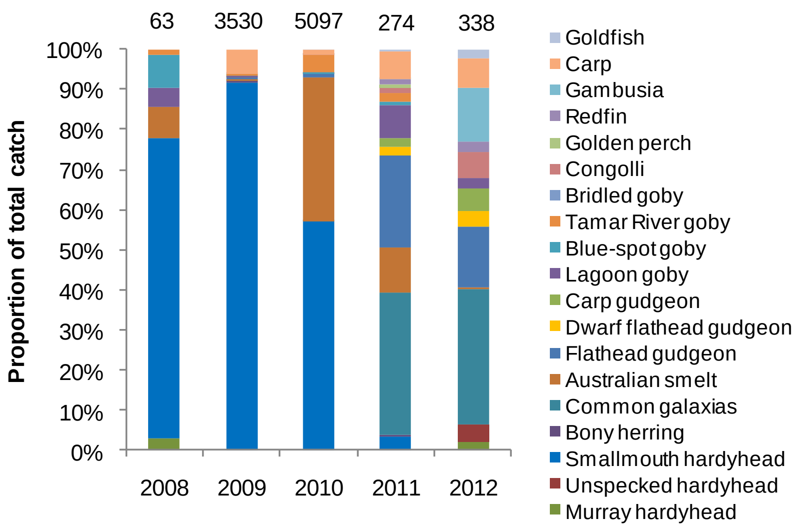


Figure 20. Comparison of composition and total abundance (value above bar) in fish assemblages at the Finniss River junction for the last five November CFH/DAP sampling events.

Seven adult Murray hardyhead were captured at the Finniss River junction of the Goolwa Channel in November 2012 during monitoring under the CFH project (Bice et al. 2013). The length-frequency chart for March 2013 displays a young-of-the-year cohort, which suggests Murray hardyhead successfully recruited over the 2012–13, possibly in the Finniss River or Goolwa Channel region of the Lower Lakes (Figure 21).

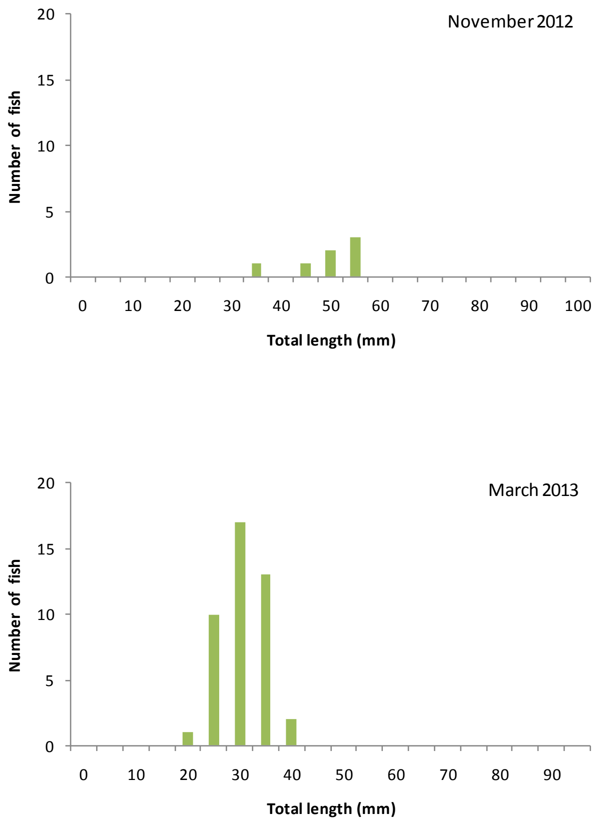


Figure 21. Length frequency distributions of Murray hardyhead captured at the Finniss River junction of Goolwa Channel in November 2012 (*n* = 7) and March 2013 (*n* = 43).

Mundoo Island (site 22)

This site is in a section of channel that is part of a natural drainage system on Mundoo Island (site 22), which has been deepened by excavation. Although southern pygmy perch was recorded at the site in November 2009, it was undetected thereafter until re-stocking under the CFH project (Figure 22). During the drought, there was habitat deterioration that included salinisation (e.g. from 4.6 g/L in November 2009 to 10.3 g/L in March 2010) and a corresponding decrease in habitat complexity (Figure 23). Following re-inundation of the habitat with the return of river flows in 2010, salinity reduced to pre-drought levels and freshwater aquatic plants are re-colonising. Notably, heavy stands of cumbungi now occupy the site.

In 2012–13, cumbungi and water fern dominated the site to the point that very little open water remained. Therefore, the fyke nets were set adjacent to the original site, in the only remaining open water area. A single southern pygmy perch (40 mm TL) was captured in March 2013, and fluorometer readings failed to detect the calcein marking of a re-stocked fish. Its origin should be confirmed through an ongoing genetics investigation by Flinders University (Carvalho et al. 2012), but initial investigations suggest it was recruited in the wild (Bice et al. 2013). Although the fish appeared healthy, it showed some form of 'pinch gut' (indicated by a red arrow in the photo below) that indicates a lack of food in its diet.

The only southern pygmy perch captured in March 2013 in TLM and CFH monitoring, and the only remaining open water at site 22 on Mundoo Island.

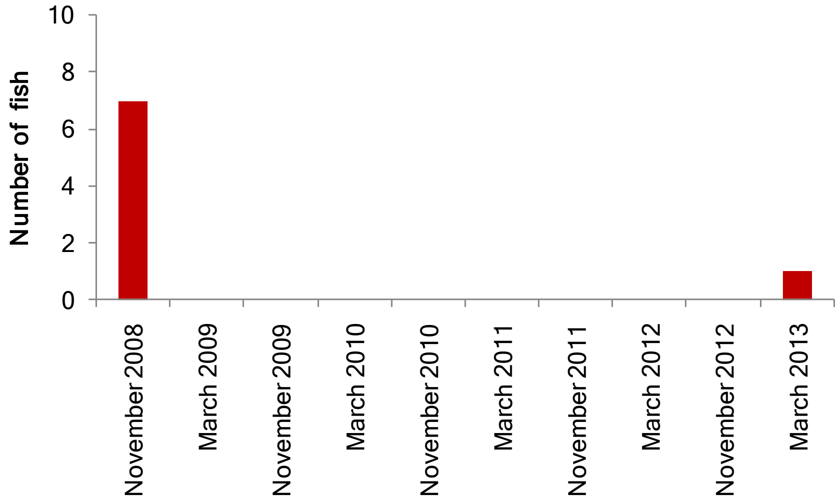


Figure 22. Numbers of southern pygmy perch captured at Mundoo Island (site 22) in the last five TLM monitoring seasons.

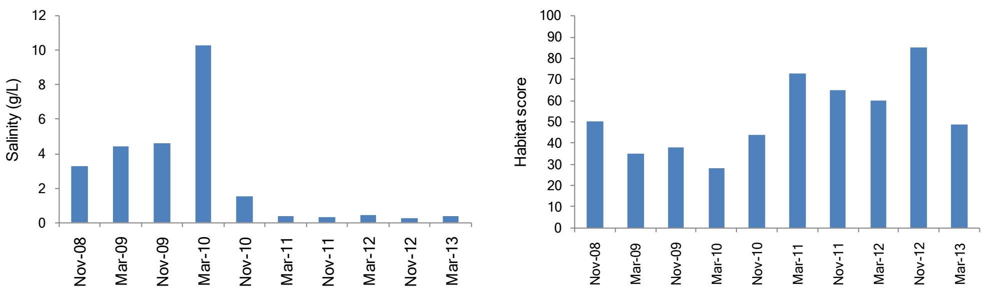


Figure 23. Corresponding changes in salinity and habitat complexity score at Mundoo Island (site 22) from November 2008 to March 2013.

Most native fish species declined at site 22 during the latter stages of the drought, but the native carp gudgeon was predominant (Figure 24). Following the re-inundation of the site, the fish community consisted largely of young-of-the-year carp and goldfish (cyprinids) in November 2010. The fish assemblage was more diverse in November 2011, with moderate numbers of flathead gudgeon and congolli, but alien fish made up more than three-quarters of the catch (redfin, Gambusia, carp and goldfish). The total number of fish captured at the site was substantially lower in November 2011 than at the same time in previous years. Curiously, only 13 fish were captured in November 2012, mostly alien species. During this time, thick beds of water fern smothered the surface of the water, so anoxia might have been influential in shaping the fish assemblage (see McNeil and Closs 2007).

The four fish species captured in November 2012, namely Gambusia, goldfish, redfin and flathead gudgeon, can tolerate low levels of dissolved oxygen (McNeil and Closs 2007). It is possible that without active management of the habitat (e.g. removal of some areas of cumbungi and water fern), the habitat will remain unsuitable for southern pygmy perch. Possibly, if agreed to by the landholder, a trial site could be established to determine the effects on the southern pygmy perch population caused by reducing the density of reeds and water fern, which could be monitored in 2013–14 (i.e. before the re-stocked fish are extirpated). This level of effort would be warranted, given the unique genetic population of southern pygmy perch in the Lower Lakes (Unmack et al. 2013) that requires conservation, and the amount of effort and expense that has been directed towards the captive maintenance and re-stocking program (e.g. Bice et al. 2011; Hammer 2007).

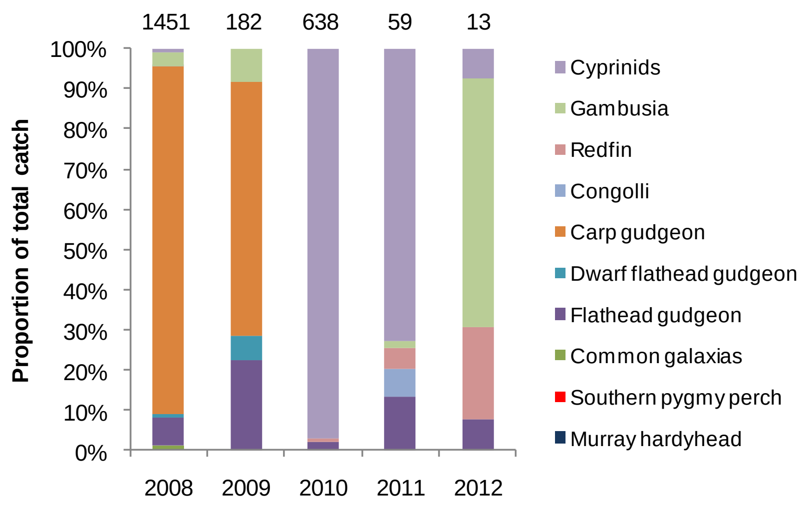


Figure 24. Comparison of species composition and total abundance (value above bar) in fish assemblages at Mundoo Island (site 22) for the last five November TLM sampling events.

Dog Lake (site 25)

The site was originally in an irrigation channel (now too deep to sample at >3 m) fringing Dog Lake, northern Lake Alexandrina. Currently, the site is within 20 m of the original sampling location, on the edge of Dog Lake. Earlier condition monitoring captured Murray hardyhead (Figure 25), and found evidence of local recruitment on one occasion. The species was last recorded at Dog Lake in November 2010, when salinity had returned to normal following inundation (Figure 26). Consequently, habitat complexity score was substantially higher at the site over 2011–12 but showed a decline in 2012–13. Aquatic plants establishing in Dog Lake include water milfoil, ribbon weed (*Vallisneria spiralis* Var. *americana*), cumbungi, water primrose, duckweed (*Lemna sp.*) and small spike rush (*Eleocharis acuta*).

Dog Lake sampling site in November 2011 (left) and November 2012 (right).

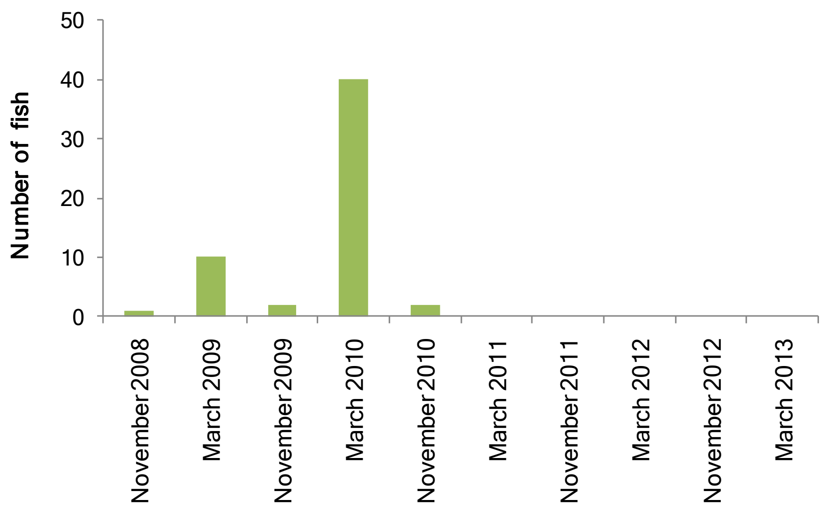


Figure 25. Numbers of Murray hardyhead captured at Dog Lake since its inclusion in the TLM condition monitoring program.

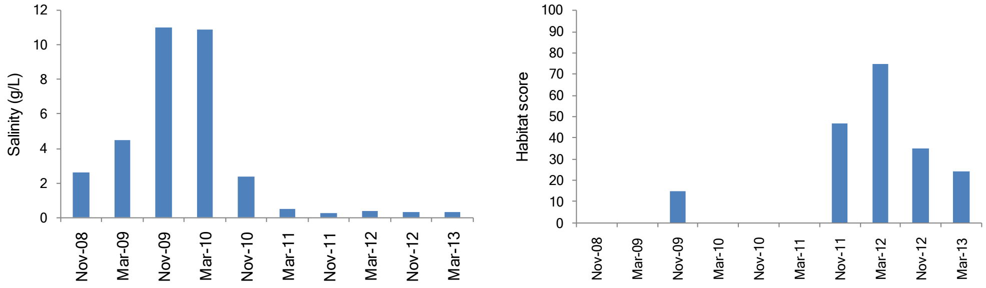


Figure 26. Corresponding changes in salinity and habitat complexity score at Dog Lake from November 2008 to March 2013.

The fish assemblage at the Dog Lake site was dominated by flathead gudgeon, smallmouth hardyhead and Australian smelt in November 2008 (Figure 27). There was an extremely high number of fish captured in November 2010, and more than half were young-of-the-year cyprinids (carp and goldfish). The catch was relatively low in November 2011 but more diverse than the previous year, when more than half of the catch consisted of alien fish. During this time, Australian smelt and the estuarine lagoon goby were the most common native fish species. In November 2012, moderate numbers of fish were captured, and the relatively diverse fish assemblage was dominated by lagoon goby and redfin, and congolli was notable.

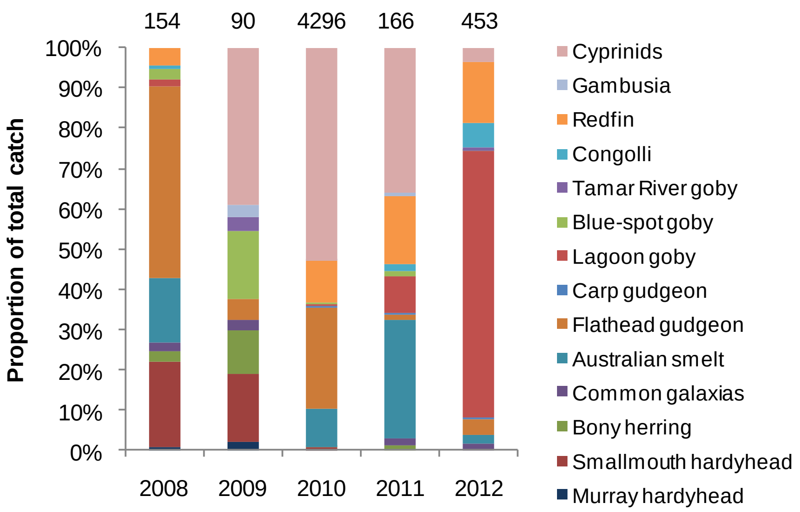


Figure 27. Comparison of species composition and total abundance (value above bar) in fish assemblages at Dog Lake for the last five November TLM sampling events.

Mundoo Island (site 30)

This site is in a natural drainage line that runs off Boundary Creek approximately 20 m above the barrage on Mundoo Island. Moderate numbers of adult Murray hardyhead were captured in November 2008 (Figure 28), and one young-of-the-year fish was captured in March 2009 (Wedderburn and Barnes 2009). Murray hardyhead has not been captured at this site in the last four TLM condition monitoring events. Salinity was elevated to over 18 g/L at the height of drought in November 2009 (Figure 29). Since re-inundation of the site in 2010, salinity has returned to pre-drought levels and freshwater aquatic plants are re-colonising, namely cumbungi and water milfoil.

The channel off Boundary Creek on Mundoo Island (site 30) in March 2012 (left) and March 2013 (right).

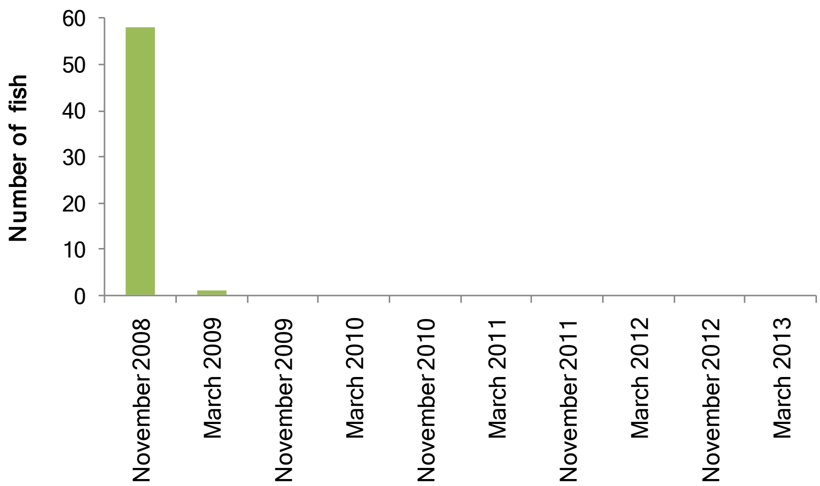


Figure 28. Numbers of Murray hardyhead captured at Mundoo Island (site 30) since the site's inclusion in the TLM condition monitoring program.

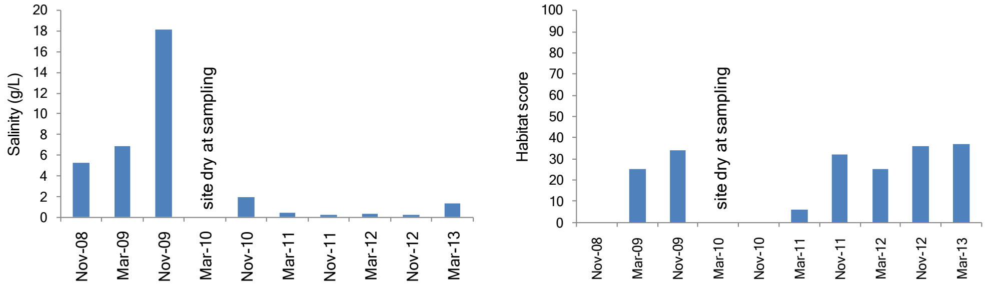


Figure 29. Corresponding changes in salinity and habitat complexity score at site 30 on Mundoo Island from November 2008 to March 2013.

The fish community at site 30 on Mundoo Island was most diverse in November 2008, when Murray hardyhead was a relatively high proportion of the catch (Figure 30). Alien Gambusia made up almost all of the catch in November 2009. The highest number of fish was recorded in November 2010, when redfin comprised more than 90% of the catch. Less than 200 fish were captured in November 2011, which mostly consisted of carp, but flathead gudgeon and the diadromous congolli were notable. Ecological generalists dominated the fish assemblage in November 2012, mostly flathead gudgeon and carp. The highest proportions of congolli and golden perch in the 5-year period were captured in November 2012.

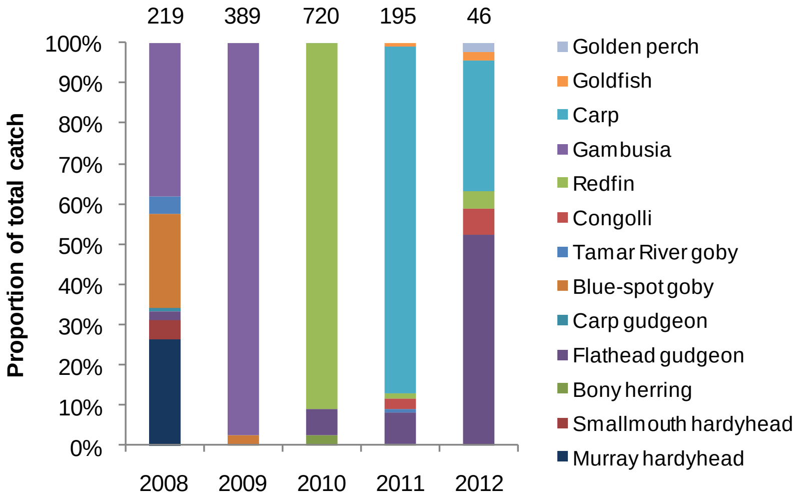


Figure 30. Comparison of species composition and total abundance (value above bar) in fish assemblages at Mundoo Island (site 30) for the last five November TLM sampling events.

Boggy Creek (site 31)

Using environmental water sourced through The Living Murray program and from Healthy Rivers Australia, the drought refuge at Boggy Creek (site 31) received environmental water allocations between October 2009 and March 2010 as part of a State Government management strategy to conserve Murray hardyhead (Wedderburn et al. 2010; Wedderburn et al. 2013). In November 2009, Murray hardyhead was captured in relatively low numbers (Figure 31). In March 2010, the species was moderately abundant. Mostly young-of-the-year Murray hardyhead were captured in November 2009, and only an abundant adult cohort was sampled in March 2010 (Wedderburn and Hillyard 2010). The species was not captured at Boggy Creek in the 2010–11, 2011–12 and 2012–13 TLM condition monitoring events (i.e. after the site reconnected with Lake Alexandrina).

The drying Boggy Creek in November 2008 (left), when Murray hardyhead was very abundant in the drought refuge, and in March 2013 (right).

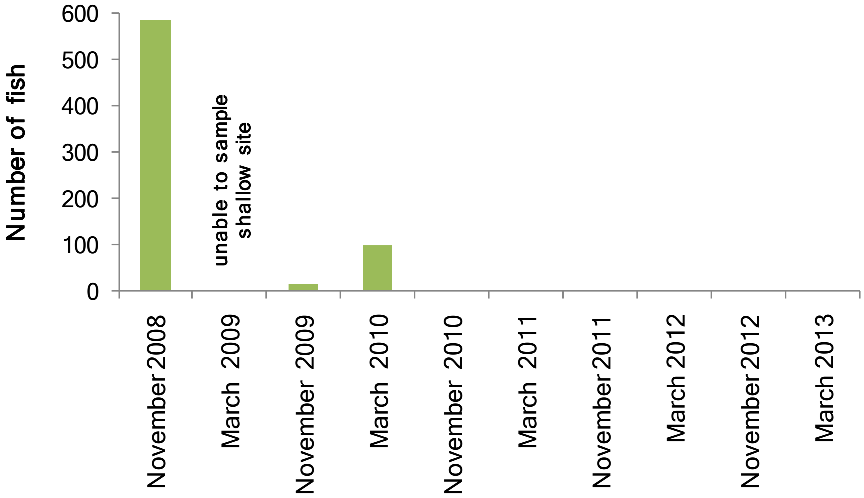


Figure 31. Numbers of Murray hardyhead captured at Boggy Creek since the site's inclusion in the TLM monitoring program.

Salinity at Boggy Creek was high (8.6–17.4 g/L) during the drought from November 2008 to March 2010 (Figure 32), but was prevented from becoming extreme with the environmental water allocations. Following re-connection with Lake Alexandrina in 2010, salinity reduced to normal levels. Despite heavy fluctuations in salinity over the last five seasons, habitat complexity scores have remained at moderate to high levels. In 2012–13, aquatic plants included an abundance of hornwort, cumbungi and water fern, which resulted in the highest habitat complexity score since monitoring commenced at the site.

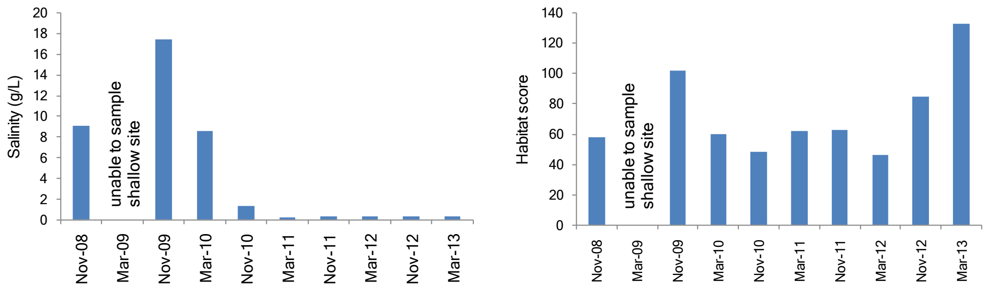


Figure 32. Corresponding changes in salinity and habitat complexity score at Boggy Creek from November 2008 to March 2013.

The fish assemblage at Boggy Creek was dominated by high numbers of Murray hardyhead, carp gudgeon and blue-spot goby in November 2008, and lower numbers of the same species in November 2009 (Figure 33). Thereafter, carp has been a dominant species in the fish assemblage. In November 2012, the site was mostly inhabited by freshwater ecological generalists, including flathead gudgeon and carp gudgeon, but the diadromous common galaxias was notable. The habitat at Boggy Creek in 2012–13 appeared suitable for Murray hardyhead, but obviously other factors are responsible for its absence at the site. For example, the suitability of the habitat for Murray hardyhead is largely determined by salinity (positive association with salinity: Wedderburn et al. 2007), and predatory redfin might be a factor warranting consideration (Wedderburn et al. 2012a).

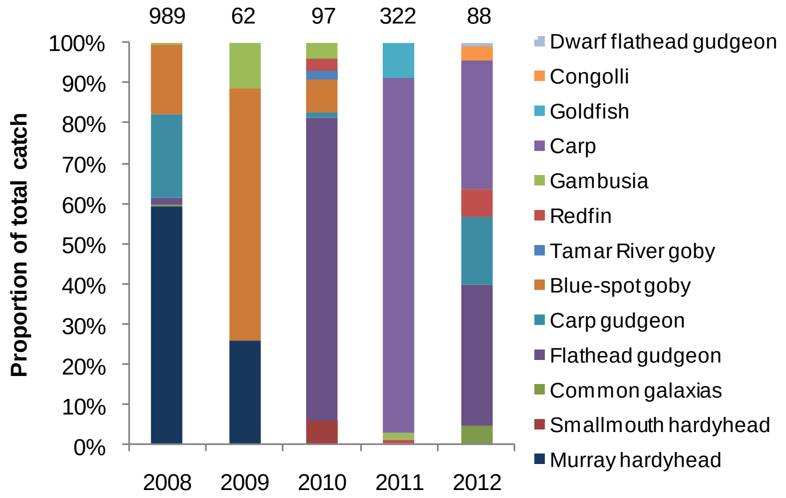


Figure 33. Comparison of species composition and total abundance (value above bar) in fish assemblages at Boggy Creek for the last five November TLM sampling events.

Murray hardyhead captured at Boggy Creek in November 2008.

Mundoo Island (site 32)

This site is in a section of water that is part of a natural drainage system on Mundoo Island, which has been deepened by excavation, and is situated approximately 1 km east of site 22. Murray hardyhead was first recorded at the site in November 2008 (Figure 34). The high numbers captured in March 2009 relate to a highly successful recruitment event (Wedderburn and Barnes 2009). There was an abundant adult cohort of Murray hardyhead captured at the site in November 2009. However, there was no evidence of recruitment over 2009–10, and all fish species were extirpated at the site by January 2010 (Wedderburn and Hillyard 2010). The reasons might be related to the extremely high salinity (Figure 35: 63.3 g/L) or other disruptions to the food web (Wedderburn et al. 2010; Wedderburn et al. 2013). Habitat complexity score has remained consistently high at the site over the last five years, but with exceptional lows in March 2009 (drought) and November 2010 (recently inundated habitat). The habitat consisted of relatively abundant hornwort, water milfoil and cumbungi in 2012–13.

In March 2012, approximately 3500 Murray hardyhead and 280 southern pygmy perch were released into site 32 through the Critical Fish Habitat project (Bice et al. 2012). Sampling in November 2012 captured only four adult Murray hardyhead at the site, and genetic investigations by Flinders University will determine if they are re-stocked fish (L. Beheregaray, unpublished data). Another 3500 Murray hardyhead were released into the site in December 2012 (Bice and etal. 2013). Sampling in March 2013 captured nine Murray hardyhead, which will also be genetically tested. Two adult southern pygmy perch (52 and 56 mm TL) were recaptured (calcien detected) at site 32 in November 2012, but the species was not recorded at the site in March 2013. Therefore, there is no evidence that southern pygmy perch recruited at the site over 2012–13.

The length-frequency distributions for Murray hardyhead captured at site 32 show the same adult cohort in November 2012 and March 2013 (Figure 36). This cohort matches the size of Murray hardyhead released in the site under the CFH project (Bice et al. 2012; Bice et al. 2013), so the fish are likely recaptures. Also, given the small numbers of fish recorded, there is no evidence that Murray hardyhead recruited on Mundoo Island in 2012–13.

It is apparent that Murray hardyhead and southern pygmy perch have been unable to establish sustained populations at the site. The physical habitat (abundant aquatic plants) appears ideal for the threatened fishes, so the reasons for their lack of breeding and recruitment since re-stocking are unclear. Possibly they relate to food web factors. For example, draw down of water levels and re-flooding (using environmental water allocations) triggered a zooplankton response that apparently benefitted Murray hardyhead in the Boggy Creek drought refuge in 2009–10 (Wedderburn et al. 2013). Therefore, the constant water levels at site 32 since its innundation in 2010–11 might not suit ecological specialists such as Murray hardyhead and southern pygmy perch. Another reason might relate to predation on the naïve re-stocked fish, which would be highly vulnerable to predation. In this instance, redfin present a significant threat to the re-stocked adult Murray hardyhead and southern pygmy perch, and any young-of-the-year recruits, because it is a highly efficient, opportunistic predator in the Lower Lakes from approximately 80 mm TL upwards (Wedderburn et al. 2012b).

Site 32 on Mundoo Island, and re-stocked Murray hardyhead and southern pygmy perch captured in November 2012.

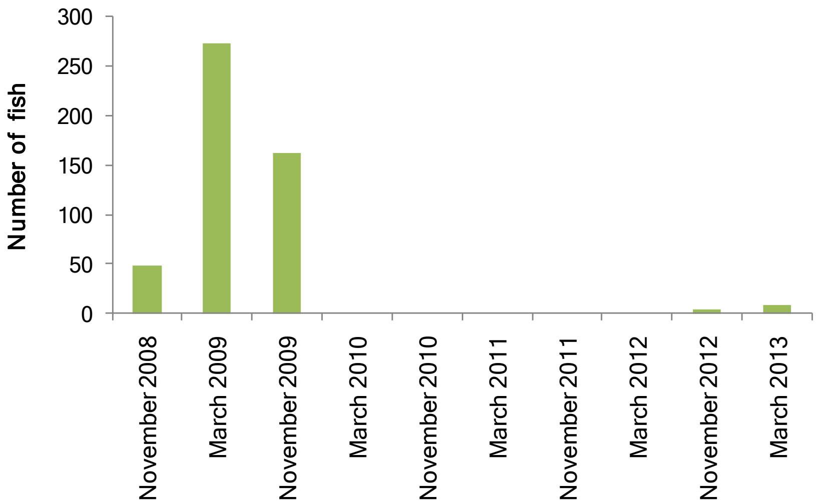


Figure 34. Numbers of Murray hardyhead captured at Mundoo Island (site 32) in the last five TLM condition monitoring seasons.

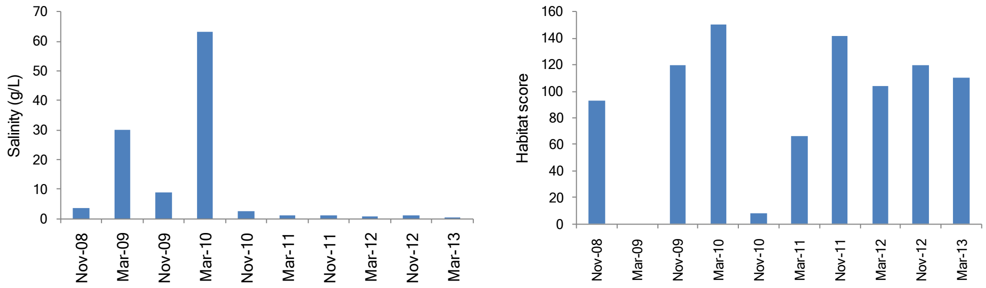


Figure 35. Corresponding changes in salinity and habitat complexity score at Mundoo Island (site 32) from November 2008 to March 2013.

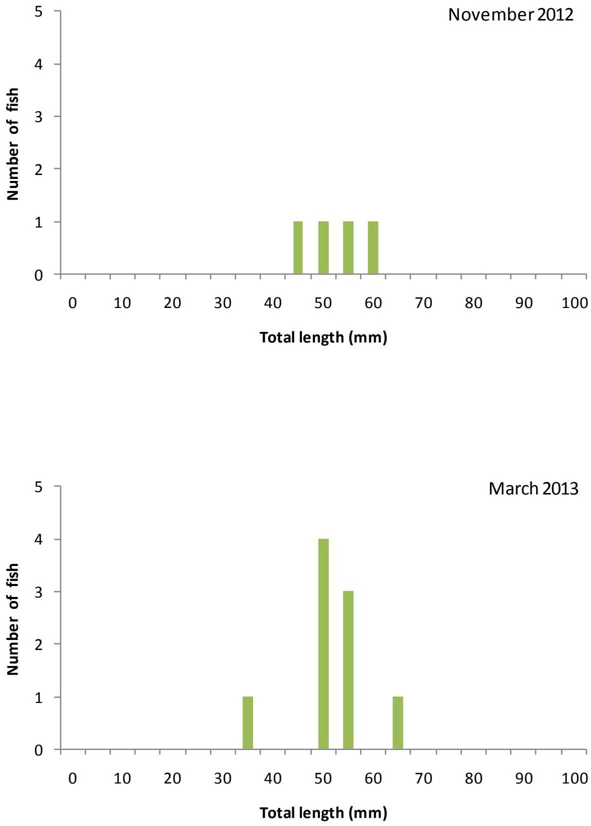


Figure 36. Length frequency distributions of Murray hardyhead captured at site 32 Mundoo Island in November 2012 (n = 4) and March 2013 (n = 9)

The fish assemblage at site 32 on Mundoo Island changed substantially during each of the last five November condition monitoring events (Figure 37). In November 2008, it was largely dominated by Murray hardyhead and Gambusia. The highest total number of fish was recorded in November 2009, and largely consisted of smallmouth hardyhead. The re-connection with Lake Alexandrina following the return of flows in 2010 led to the re-colonisation of aquatic plants and fish at the site. A moderate overall number of fish was recorded in November 2010, of which more than half were young-of-the-year cyprinids (carp and goldfish). Similarly, the fish assemblage was dominated by alien species in November 2011, but congolli was a notable inclusion in the catch. The site was dominated by two native ecological generalists in November 2012, namely carp gudgeon and flathead gudgeon. This further suggests that the habitat is yet to develop into a state that is suitable for the threatened fish species, which are habitat specialists.

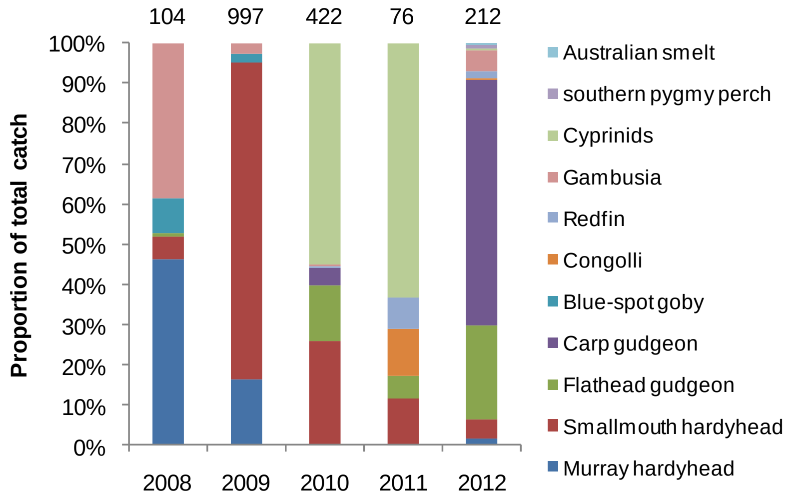


Figure 37. Comparison of species composition and total abundance (value above bar) in fish assemblages at Mundoo Island (site 32) for the last five November TLM condition monitoring seasons.

Shadow's Lagoon (site 34)

This site is located in the north-east of Shadow's Lagoon, Hindmarsh Island. The site was initially sampled in 2008–09 TLM condition monitoring, when southern pygmy perch was recorded (Wedderburn and Barnes 2009). However, the species remained undetected at the site from 2009 to 2012. Approximately 1500 and 250 Yarra pygmy perch were released to the site in March 2012 and December 2012, respectively, through the CFH project (Bice et al. 2012). The site was selected because of the vast beds of ribbon weed growing in shallow water, which forms suitable habitat. Notably, this submerged aquatic macrophyte species persisted in the seed bank during the drought (see Nicol and Ward 2010), and subsequently proliferated following inundation. Salinity has remained relatively low at site 34 (Figure 38), even during the drought when possibly groundwater influenced the remaining waterhole. Habitat complexity score has always been relatively high, due to a constant abundance of aquatic plants. During the drought, habitat consisted of stoneworts (*Chara sp.*), but in 2012–13 ribbon weed and water fern were the major components of aquatic habitat.

Seven adult Yarra pygmy perch were captured at site 34 in November 2012 (Figure 39), of which some were obviously recaptures (calcien marking detected). Several of those, and the two small Yarra pygmy perch captured in March 2013, failed to give substantial calcein readings (Bice et al. 2013). Therefore, it is possbile that the fish are young-of-the-year recruited in the wild. This requires confirmation through the ongoing genetics study by Flinders University (e.g. Carvalho et al. 2011), but initial findings suggest they are fish recruited in the wild (Bice et al. 2013).

Shadow's Lagoon in November 2012, where Yarra pygmy perch was captured.

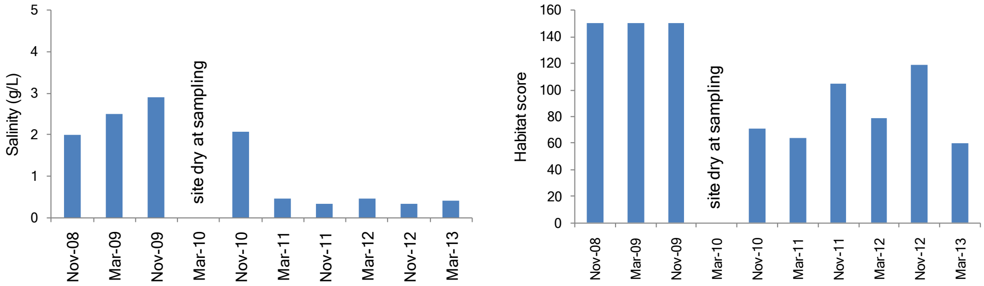
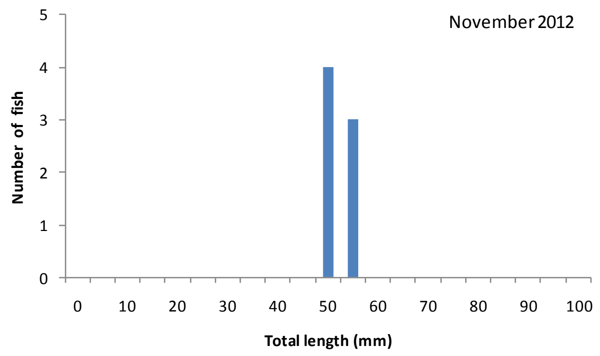


Figure 38. Corresponding changes in salinity and habitat complexity score at Shadow's Lagoon from November 2008 to March 2013.

The fish assemblage was relatively diverse in November 2008, but sampling failed to detect southern pygmy perch near the height of drought in November 2009, when Gambusia was the only fish species captured (Figure 40). Immediately following the return of river flows that inundated the site, the fish assemblage consisted only of extreme numbers of young-of-the-year cyprinids (carp and goldfish). The overall numbers of fish were very low in November 2011, and the fish assemblage included the native flathead gudgeon, but carp dominated the catch. There was an increase in species diversity in the November 2012 sampling, as a result of the inclusion of low numbers of congolli and re-stocked Yarra pygmy perch. The habitat superficially appears suitable for the threatened fish species, however, it was dominated by ecological generalists over 2012–13, including flathead gudgeon, carp gudgeon and the four alien fish species, namely redfin, Gambusia, carp and goldfish.



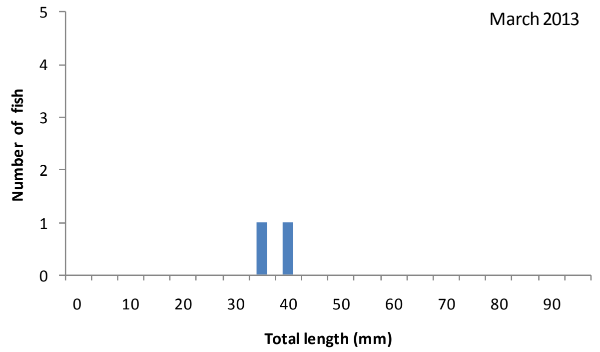


Figure 39. Length frequency distributions of Yarra pygmy perch captured at Shadow's Lagoon in November 2012 (*n* = 7) and March 2013 (*n* = 2).

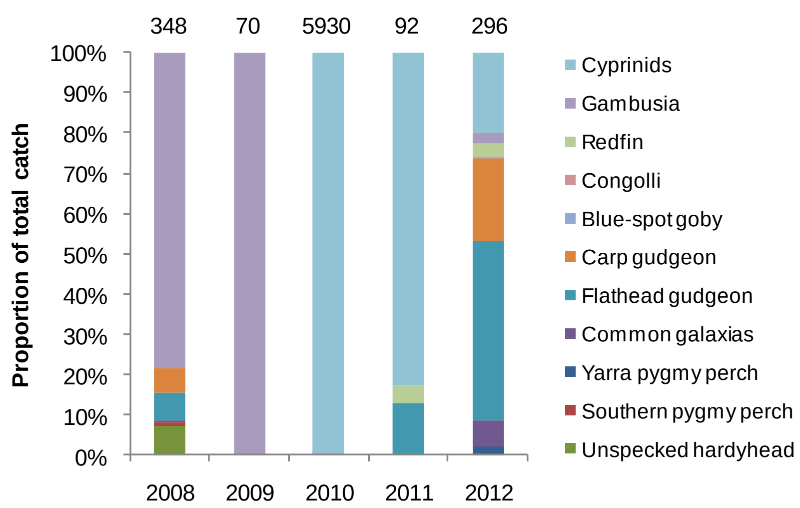


Figure 40. Comparison of species composition and total abundance (value above bar) in fish assemblages at Shadow's Lagoon for the last five November TLM condition monitoring seasons.

Campbell House (site 36)

This lake-fringing site is adjacent to a modified channel near Campbell House, Lake Albert. There was evidence of recruitment in the Murray hardyhead population in 2008–09, during the drought (Wedderburn and Barnes 2009). However, Murray hardyhead was not captured at this site in the 2009–10, 2010–11 and 2011–12 TLM condition monitoring events. Indeed, no fish were captured at this site in March 2010, when salinity was extremely high (49.1 g/L). Since the high freshwater inflows to Lake Albert in 2010, salinity at this site has been lower, which corresponds to an increase in aquatic plant cover (Figure 40). However, for unknown reasons, there was a substantial reduction in habitat cover recorded in March 2013.

The fish community at the site was dominated by the estuarine blue-spot goby in November 2009 and November 2010, and included low numbers of Murray hardyhead (Figure 41). The fish community was more diverse in November 2010 following the freshwater inflows, and included estuarine (e.g. lagoon goby) and freshwater (e.g. Australian smelt) species. In November 2011, common galaxias and carp each constituted a third of the fish community, and blue-spot goby was notable. The overall number of fish captured in November 2011 was substantially lower than during the same time in the previous two years. In November 2012, fewer fish again were captured, when common galaxias, blue-spot goby and goldfish made up the highest proportions in the fish assemblage. Notably, the congolli population appears to be recovering in Lake Albert, where young-of-the-year and 1+ fish are now relatively common. There were no threatened fish captured at this site in 2012–13.

Site 36 fringing Lake Albert at Campbell House in November 2011 and congolli captured in March 2013.

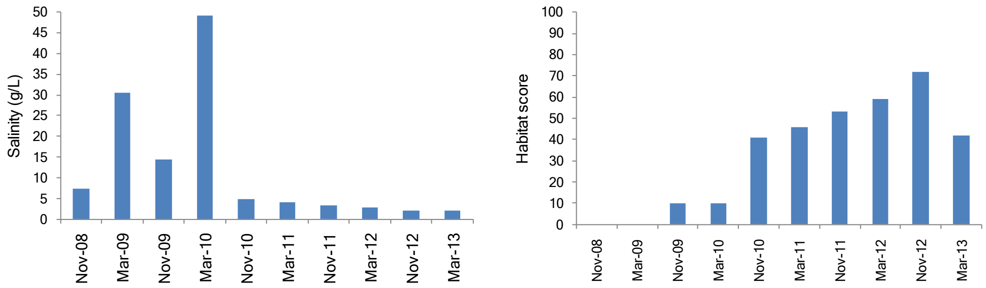


Figure 40. Corresponding changes in salinity and habitat complexity score in Lake Albert at Campbell House from November 2008 to March 2013.

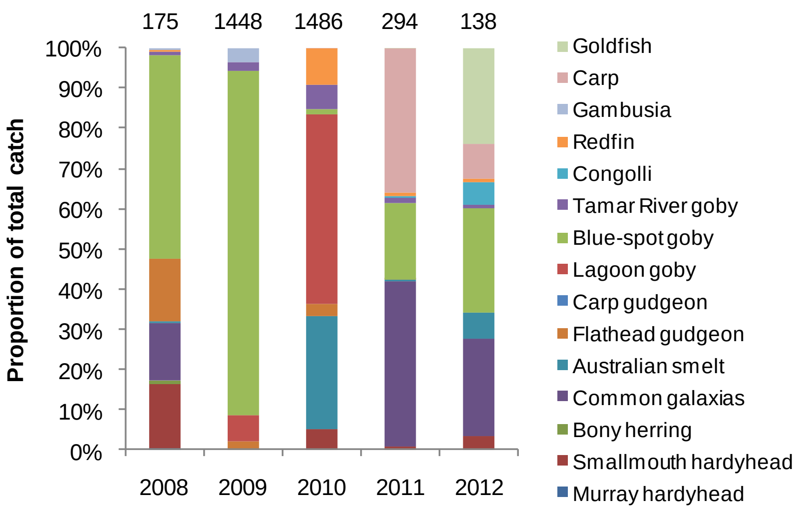


Figure 41. Comparison of species composition and total abundance (value above bar) in fish assemblages at Campbell House for the last five November TLM sampling events.

Turvey's Drain (site 37)

This site is in an irrigation channel that feeds directly off the northern shore of Lake Alexandrina. A relatively high number of southern pygmy perch was first recorded in November 2008 (Figure 42). There were indications that the species had undergone limited recruitment over the 2008–09 season (Bice et al. 2009), but only a single adult fish was capture in March 2010 (Bice et al. 2010). Two adult southern pygmy perch were captured in November 2010, but the species was undetected in March 2011 (Bice et al. 2011).

Under the CFH project, 400 southern pygmy perch were released into Turvey's Drain in November 2011 (Bice et al. 2012). One southern pygmy perch was recaptured a few weeks later (48 mm TL) and another in March 2012 (41 mm TL) (Bice et al. 2012). Southern pygmy perch was not recorded at the site in 2012–13, which indicates the re-stocking attempt failed or, at the least, recruitment was unsuccessful in Turvey's Drain over the 2012–13 breeding-recruitment period. Possibly, the re-stocked fish migrated to an unknown location; however, southern pygmy perch was not captured at the nearby Angas River mouth (site 15) and Bremer River mouth (site 19) during the 2012–13 TLM condition monitoring.

Southern pygmy perch, flathead gudgeon and Gambusia dominated the fish assemblage at Turvey's Drain in November 2008 (Figure 43). The rise in overall numbers of fish captured in November 2009 is largely attributed to Gambusia. Native species dominated the catch in November 2010, but carp and goldfish constituted more than half of the catch in November 2011. Carp gudgeon, carp, dwarf flathead gudgeon and redfin constituted the fish assemblage in November 2013, when only 16 fish were captured.

Turvey's Drain in November 2009 (left) and November 2010 (right).

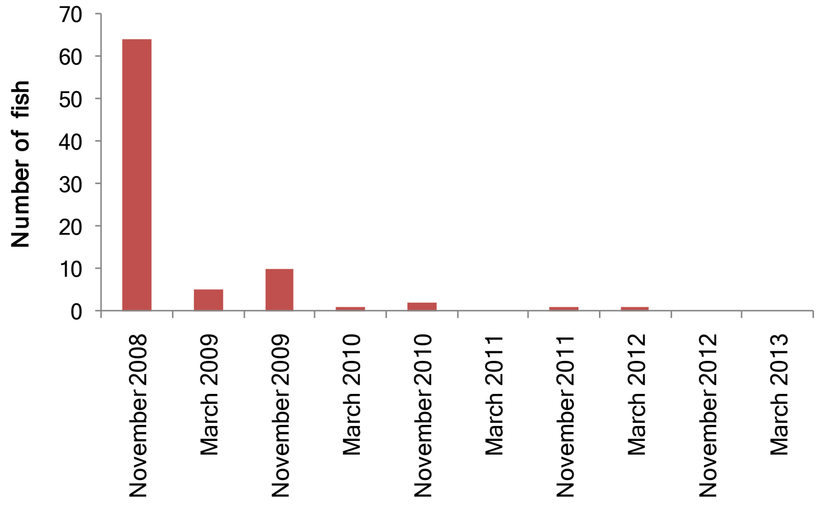


Figure 42. Numbers of southern pygmy perch captured at Turvey's Drain in DAP/CFH project monitoring in the last five seasons.

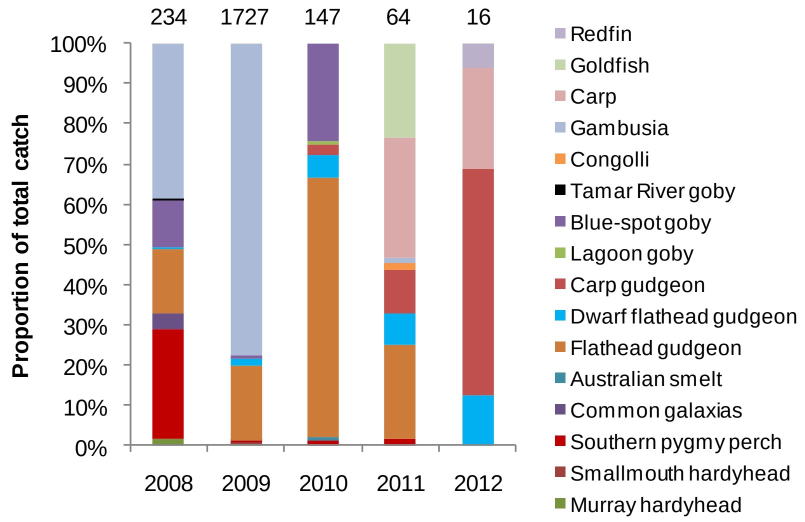


Figure 43. Comparison of species composition and total abundance (value above bar) in fish assemblages at Turvey's drain for the last five November DAP/CFH project sampling events.

Black Swamp (site 38)

This site is near the Tookayerta Creek junction on the Finniss River. Southern pygmy perch and Yarra pygmy perch were first recorded at the site in 2003 (Wedderburn and Hammer 2003). Only southern pygmy perch has been captured since. Black Swamp was dry by March 2009, but was inundated in September 2009 after installation of the Clayton regulator. Adult southern pygmy perch were then captured in low numbers from November 2009 to November 2010 (Figure 44), and had likely migrated from the upper catchment (possibly carried downstream during high flows). The species was not captured at Black Swamp in March 2011. Similarly, southern pygmy perch was not captured in the CFH project monitoring over 2011–12 (Bice et al. 2012) and 2012–13 (Bice et al. 2013), so it is unlikely that breeding and recruitment has occurred at Black Swamp since the drought.

As the site was drying in November 2008, a single carp gudgeon was the only fish captured (Figure 45). Southern pygmy perch dominated the fish assemblage in November 2009, with smaller proportions of flathead gudgeon and carp. A substantially higher number and greater diversity of fish were captured in November 2010, which largely consisted of flathead gudgeon and smaller proportions of southern pygmy perch, Australian smelt, dwarf flathead gudgeon, carp gudgeon and carp. Flathead gudgeon and carp gudgeon dominated the fish assemblage in November 2011. The structure of the fish assemblages was very similar in November 2012, with the addition of congolli.

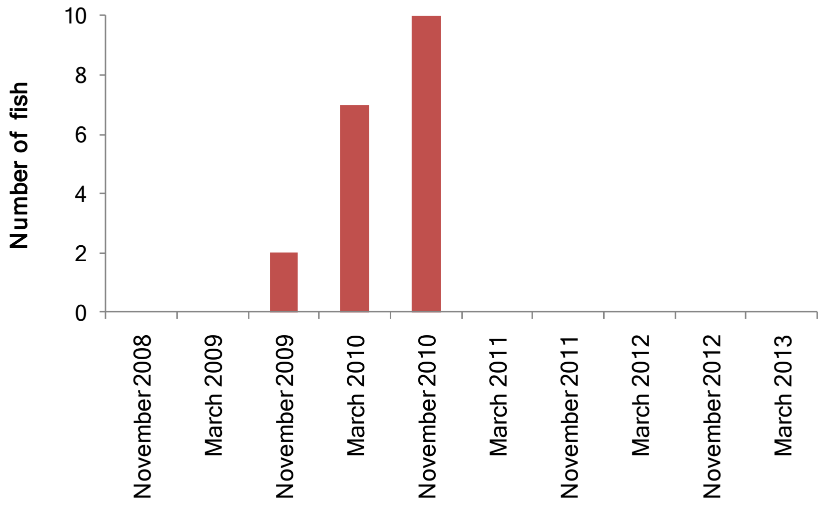


Figure 44. Numbers of southern pygmy perch captured at Black Swamp in DAP/CFH monitoring in the last five seasons.

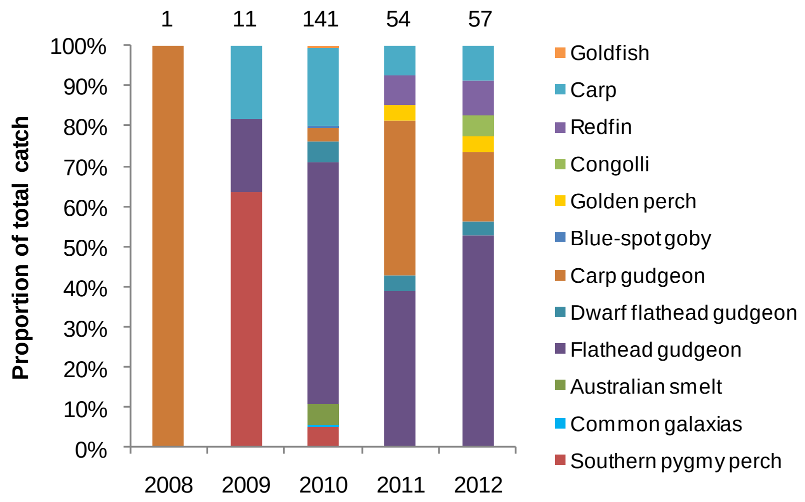


Figure 45. Comparison of species composition and total abundance (value above bar) in fish assemblages at Black Swamp for the last five November sampling events.

Discussion

The main objective of this study was to determine if recruitment was successful over the 2012–13 breeding-recruitment season for the three threatened fish species stated in The Living Murray's (TLM) Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Target F2 (Maunsell 2009). For the first time since 2008, all three threatened fish species were recorded. In regards to Yarra pygmy perch and southern pygmy perch, this was solely because of re-stocking through the Critical Fish Habitat (CFH) program (Bice and et al. 2012; Bice et al. 2013), which aims to re-establish self-sustaining populations. In contrast, the Murray hardyhead population appears to be re-establishing, but whether this is completely through natural means will remain unknown because of the influences of re-stocking. Genetic research at Flinders University might shed some light in this regard.

Murray hardyhead was the only threatened fish species to show obvious signs of recruitment in the Lower Lakes in 2012–13, which meets the aims of the TLM Condition Monitoring Target. There was limited evidence of recruitment for Yarra pygmy perch and southern pygmy perch, so their population recovery appears to be hindered by unknown factors. Fish are ideal biological indicators of river health (Lasne et al. 2007a), so continued monitoring of fishes in the Lower Lakes will provide insight into the course of ecosystem recovery, which is crucial for making management decisions. Further, each of the Lower Lakes populations of the three threatened fishes represent distinct genetic management units within the MDB and Australia (Hammer et al. 2010; Adams et al. 2011; Unmack et al. 2013), so their conservation is critical from an evolutionary perspective.

Southern pygmy perch was abundant in the Hindmarsh Island region of the Lower Lakes in early 2003 (Wedderburn and Hammer 2003). However, a population collapse during the recent drought was first indicated by a lack of recruitment over 2008–09 (Wedderburn and Barnes 2009), which continued over the next two years (Bice et al. 2010; Wedderburn and Hillyard 2010). An environmental water allocation was used to sustaining the southern pygmy perch population in the drought refuge at Turvey's Drain (site 37), however, the species was not captured at the Lower Lakes in March 2011 during monitoring. Through the CFH project, and based on habitat suitability, several hundred southern pygmy perch were released at Turvey's Drain, and sites on Hindmarsh Island and Mundoo Island from November 2011 to December 2012 (Bice et al. 2012; Bice et al. 2013). The small number of captures in 2012–13 monitoring suggests that habitats which once supported southern pygmy perch at the Lower Lakes have not recovered, or other factors (e.g. predation by redfin on naïve re-stocked fish: Wedderburn et al. 2012b) have hindered recruitment and survival.

Yarra pygmy perch formerly inhabited the channel system on Hindmarsh Island, and also occurred in the Finniss River confluence (Wedderburn and Hammer 2003). It is likely that the species was extirpated from the Lower Lakes, and therefore the MDB, soon after it was last recorded in early 2008 (Bice et al. 2008; Wedderburn et al. 2012b). The re-establishment of a self-sustaining Yarra pygmy perch population in the MDB now relies solely on the success of the CFH project (Bice et al. 2013). Monitoring over 2012–13 captured nine Yarra pygmy perch after several hundred were re-stocked, but only limited evidence of recruitment was observed. The apparent low abundance of young-of-the-year fish suggests that survivorship of newly hatch fish was hindered by unknown factors. Alternatively, the Yarra pygmy perch re-stocked into a large aquatic system meant that the fish were difficult to detect (e.g. fish dispersed). Monitoring in coming years would test these propositions if suitable conditions prevail (e.g. adequate river flows).

Murray hardyhead persisted in isolated refuges during drought (Wedderburn and Hillyard 2010; Wedderburn and Barnes 2011). However, there was no evidence of recruitment over 2010–11 (Bice et al. 2011; Wedderburn and Barnes 2011). Similarly, in 2011–12, low numbers of Murray hardyhead were captured at only two sites. However, the length frequency of fish captured at the Finniss River confluence in March 2012 suggested that low levels of recruitment occurred in the Lower Lakes in 2011–12 (Bice et al. 2012; Wedderburn and Barnes 2012). In an obvious overall improvement of the Lower Lakes Murray hardyhead population, length-frequency comparisons demonstrated a relatively abundant young-of-the-year cohort was present in March 2013. Notably, all Murray hardyhead were captured at sites on Hindmarsh Island, Mundoo Island, and in the Goolwa Channel and Finniss River area. However, site by site length-frequency comparisons suggest that recruitment occurred in the Finniss River or Goolwa channel, or both. There was no evidence of recruitment by the re-stocked Murray hardyhead in sites on Mundoo Island and Hindmarsh Island.

During the 2010–11 high flow period following drought, fish assemblages in the Lower Lakes sites were dominated by young-of-the-year carp, goldfish and redfin (Wedderburn and Barnes 2011). Overall abundances of most fish species decreased at the majority of sites between November 2010 and March 2011, but the species compositions were similar. In 2011–12, overall numbers of fish captured at most study sites declined since peaking in 2010–11. This is largely because lower numbers of cyprinids (carp and goldfish) were captured over 2011–12, but carp was still the most numerous species in the fish assemblages at many sites. Notably, the overall relative abundances of carp and goldfish were substantially lower in 2012–13. Interestingly, the relative abundance of young-of-the-year and juvenile redfin (adults not targeted in sampling methods) has remained constant since 2009, thereby demonstrating its ecological flexibility under an array of environmental conditions at the Lower Lakes. Conversely, Gambusia numbers have increased substantially since declining during the high flow conditions of 2010–11.

Several fish species show signs of population recovery since the drought. The most notable is congolli, a diadromous fish species that is 'Vulnerable' in South Australia (Hammer et al. 2009). The re-connection of the Lower Lakes with the estuary obviously has benefitted the congolli population (see Zampatti et al. 2011). Interestingly, three morphological variances of congolli in the same age class were captured at the Lower Lakes in March 2013 (see photo on page 59). The recovery of congolli also is pertinent because, prior to the barrages, it was a significant food source for the Ngarrindjeri people (T. Trevorrow, pers. comm.). The relative abundance of common galaxias, another diadromous species, was substantially higher in 2012–13. This likely relates to its requirement of the interface between fresh and salt water for spawning (Hicks et al. 2010), which was inhibited in the Lower Lakes during the drought (disconnected from the estuary), and during the high flows in 2010–11 (homogonous low salinity). Dwarf flathead gudgeon, a freshwater ecological specialist, also increasingly is being captured at sites, and often in relatively high abundance. Similarly, unspecked hardyhead showed signs of returning to the Lower Lakes in moderate numbers during 2011–12, for the first time since approximately 2006.

Conclusions

Fish are ideal indicators of river health (Lasne et al. 2007a). In this regard, the early stage of population recovery of Murray hardyhead in 2012–13 indicates an initial ecological recovery in the Lower Lakes. The recruitment of Murray hardyhead successfully addresses the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Target F2 (Maunsell 2009). This also is highly pertinent because the species was recently elevated from 'Vulnerable' to 'Endangered' under the EPBC Act, because of a recent severe population decline. Correspondingly, the Murray hardyhead national recovery plan has been updated to address recent and current concerns (Stoessel et al. 2013). Managers and scientists involved in the conservation of Murray hardyhead during the drought suggest that existing natural populations be secured through active on-ground actions (e.g. enhance recruitment through water level manipulation: Wedderburn et al. 2013), and captive fish be re-stocked in appropriate sites to spread risk and reinstate natural dispersal (Ellis et al. in press).

The limited recruitment in the Yarra pygmy perch and southern pygmy perch populations suggest a hindered population recovery (i.e. not self-sustaining). It also indicates that the aquatic ecosystems at the Lower Lakes are yet to fully recover to the best of regulated conditions. This is somewhat expected for Yarra pygmy perch, given its extirpation during the drought, whereby its recovery relies solely on the CFH project's re-stocking program, which will cease in 2013. Indeed, since preparation of the Yarra pygmy perch national recovery plan (Saddlier and Hammer 2010), its risk of extinction has increased throughout its range, and few recovery actions have been completed (Saddlier et al. in press). Therefore, the Condition Monitoring Target F2 is not being met with regards to ensuring the recruitment of Yarra pygmy perch.

The restoration of freshwater habitat should include the creation of habitat diversity, so that a suite of ecological generalists and specialists can cohabit the Lower Lakes (cf. Lasne et al. 2007b), as was the case a decade ago (Wedderburn and Hammer 2003). However, there is a lack of understanding regarding the relationships between fish and flow regimes that determine habitat conditions in the MDB (see Humphries et al. 1999), particularly for the Lower Lakes and Coorong (see Brookes et al. 2009a; Brookes et al. 2009b). For management purposes, continued monitoring and investigations of fish and habitat at the Coorong and Lower Lakes region is crucial because of its significance to the Ngarrindjeri people (Birckhead et al. 2010), its high biodiversity value (i.e. Ramsar site, Icon site, many EPBC Act listed species), the commercial and recreational fishing interests (see Ferguson et al. 2013), and that the lower River Murray will likely be the most threatened region of the MDB under climate change forecasts (Balcombe et al. 2011; Gillanders et al. 2011).

An increased understanding of the factors that drive recruitment in the threatened fishes is required to address the downfalls of meeting the Condition Monitoring Target F2, so that appropriate management can be applied. Some recommendations are (1) test the effects (e.g. anoxia) of extremely high densities of aquatic plants on pygmy perch populations, (2) investigate the reasons for limited recruitment in both pygmy perch populations, which likely relate to predation pressure by redfin (e.g. examine its diet at 'significant sites') and/or starvation of early life stages (e.g. through water level manipulation trials to promote invertebrate prey), and (3) determine if recruitment of the Murray hardyhead population was natural (i.e. Flinders University genetic study) so that managers are informed about the level of intervention required during the next drought.

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Three distinct colour patterns on juvenile congolli captured in Lake Alexandrina at Milang in March 2013.

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Appendix 1. TLM condition monitoring fish catch summary November 2012

Site	Murray hardyhead *Craterocephalus fluviatilis*	Unspecked hardyhead *C. s. fulvus*	Smallmouth hardyhead *Atherinosoma microstoma*	Southern pygmy perch *Nannoperca australis*	Yarra pygmy perch *Nannoperca obscura*	Bony herring *Nematalosa erebi*	Common galaxias *Galaxias maculatus*	Australian smelt *Retropinna semoni*	Lagoon goby *Tasmanogobius lasti*	Congolli *Pseudaphritis urvillii*	Flathead gudgeon *Philypnodon grandiceps*	Dwarf flathead gudgeon *P. macrostomus*	Carp gudgeon *Hypseleotris spp.*	Tamar River goby *Afurcagobius tamarensis*	Western blue spot goby *Pseudogobius olorum*	Golden perch *Macquaria ambigua*	Redfin *Perca fluviatilis*	Gambusia *Gambusia holbrooki*	Carp *Cyprinus carpio*	Goldfish *Carassius auratus*
2							1										2		333	1
4										1	9					4	2		35	1
6							29		1	5	5						6	5	5	1
9						1			3	42	18	7	1		1		38	1	4	4
10		1				3	51	4	6	9	2		3				135	4	5	
11							12			2	9	1					5		1	1
15										5	16	1	1			1	10		2	3
16			2				1		3	16	12		1		4		7		15	3
19							4		3	13	21		4	2			10		17	17
22											1						3	8		1
25							7	11	298	29	17		3	3	1		68		3	13
26							9		4	8	3		2	1		1			2	4
27		6					5	87	36		3				1		3	25	9	4
28							21	15	2	37	3			3			6		12	4
29		4	1			11	4	5		23	13		1				4		19	16
30										3	24					1	2		15	1
31							4			3	31	1	15				16		28	
32	4		10	2				1		1	41		129				4	11		1
34					4		19			1	132		60				10	8	50	9
36			5				33	9		8				1	36		1		12	33
48							99	7	1	11	4			1	61		2	12	28	13
49			11				53	125	149	43	8			8	53		5		6	11
60		1						1	1		37	1	2			2	8		4	
62			11				130		5	1	36				130		1	14	9	12

Appendix 2. TLM condition monitoring fish catch summary March 2013

Site	Murray hardyhead *Craterocephalus fluviatilis*	Unspecked hardyhead *C. s. fulvus*	Small-mouth hardyhead *Atherinosoma microstoma*	Southern pygmy perch *Nannoperca australis*	Yarra pygmy perch *Nannoperca obscura*	Bony herring *Nematalosa erebi*	Common galaxias *Galaxias maculatus*	Australian smelt *Retropinna semoni*	Lagoon goby *Tasmanogobius lasti*	Congolli *Pseudaphritis urvillii*	Flathead gudgeon *Philypnodon grandiceps*	Dwarf flathead gudgeon *P. macrostomus*	Carp gudgeon *Hypseleotris spp.*	Tamar River goby *Afurcagobius tamarensis*	Western blue spot goby *Pseudogobius olorum*	Sandy sprat *Hyperlophus vittatus*	River garfish *Hyporhamphus regularis*	Golden perch *Macquaria ambigua*	Spangled perch *Leiopotherapon unicolor*	Redfin *Perca fluviatilis*	Gambusia *Gambusia holbrooki*	Carp *Cyprinus carpio*	Goldfish *Carassius auratus*	Tench *Tinca tinca*
2							3			1	34				1						5	12	3	
4						132				1	3									2		4		
6						6	11			5	12									8	1	1		
9		1				241	3			7	14	14						2		37	6	2		
10	7	38	1			154	16	2		8	24	5	14					1		25	35	2		
11						37	1			2	41	2						4		83		10	1	
15							1			4	57	1	6							5	1	2	1	1
16			2			60	2			12	2				2					27		2	2	
19		7				5	5			1	9		3					4		4	4	5	2	
22				1		1	29				1		5							1	59		21	
25		3				78	33			9	21		1			1		1		28	25		1	
26	7	6				73	6	12		41	21		2			9		2		35	4	8	1	
27		10				28	32	4		29	38	2								13	4	6	2	
28		4				29	78	10	1	81	12		1					20		34	1	9	1	
29		2				159	60			52	60							3		21	8	2		
30						112				14	12							1		47		9	1	
31							3			1	14		21								197	3	1	
32	9		1							1	32		7								144	1		
34					2		2			6	84	1	1							5	83	9	2	
36			1			8	281			17	2			18	4					5			1	
48		1	8			42	89	1		7	9			6	3					12	9	8	2	
49			47			26	303	10		19	18			150	5		1			9	21	1		
60		7				14				2	8	2						1		6				
62		6	4			184	101	3		3	21			4	14					18	8	5		