An assessment of threatened fish populations in Lake Alexandrina and Lake Albert, South Australia

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Cover Image: Dunn Lagoon, southern pygmy perch, Murray hardyhead, Yarra pygmy perch.

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Contents

Summary

Three threatened small-bodied fishes inhabit the Lower Lakes, namely Murray hardyhead, Yarra pygmy perch and southern pygmy perch. Each underwent population collapse during the recent drought because lake-fringing habitats were desiccated. Interventions to manage threatened fish populations included water allocations to drought refugia, and captive maintenance programs. Lake water levels were reinstated when substantial River Murray flows returned in 2010, and lake-fringing habitats were inundated. Subsequently, the three threatened fish species and the threatened southern purple-spotted gudgeon were re-stocked in the Lower Lakes from the captive maintenance programs. Current monitoring programs for the threatened fish species were established during the recent drought, so might omit recently established populations.

The objective of the current study is to gain a more accurate assessment of the threatened fish populations in the Lower Lakes. The specific project aims are to (1) determine the current distribution and population status of each threatened fish species in the Lower Lakes; (2) consider the contribution of interventions towards the post-drought recovery of the threatened fishes in the Lower Lakes; (3) identify replacements of, or expansion on, current threatened fish monitoring sites in the Lower Lakes; and (4) support several recommendations from a Murray hardyhead review workshop (February 2014), specifically to assess the current distribution and habitat of Murray hardyhead in the Lower Lakes.

Seventy four sites were sampled in autumn 2014, which were representative of potential threatened fish habitat across the Lower Lakes. There was some concentration of sampling in areas that warranted extra effort (e.g. threatened fishes were abundant in the south-western region of Lake Alexandrina prior to the drought). A total of 13,562 fish were captured, represented by 20 native and four alien species. Murray hardyhead, southern pygmy perch and Yarra pygmy perch constituted 1.85%, 0.10% and 0.01% of the overall catch, respectively. Southern purple-spotted gudgeon was not captured in autumn 2014. Murray hardyhead was captured at 13 sites, which were shallow, moderately saline and well vegetated habitats. Yarra pygmy perch and southern pygmy perch were each captured at single but separate sites.

The early stage of population recovery is apparent for Murray hardyhead in Lake Alexandrina. Its absence in samples from Lake Albert demonstrates that full recovery is lacking. Only a single Yarra pygmy perch was captured in this assessment, thereby suggesting the species is again close to extinction in the MDB. Its re-establishment in the Lower Lakes relies on further reintroductions. The precarious nature of one remaining southern pygmy perch population warrants immediate attention, specifically habitat protection and threat abatement. The absence of southern purple-spotted gudgeon in samples suggests the species is close to regional extinction. The specific contribution of interventions to protect and maintain the threatened fish species are difficult to determine, because the underlying processes were mostly unstudied. Water allocations to drought refugia sustained some populations, which may have assisted the recovery of Murray hardyhead. The aim to establish self-sustaining populations of the other three threatened species through reintroductions appears unsuccessful. There are 29 sites of high priority, 18 sites of moderate priority and 28 sites at the lowest priority, which are suggested for refinement of the Condition Monitoring program methods.

Introduction

Several short-lived (1–5 years) threatened small-bodied fishes inhabit Lake Alexandrina and Lake Albert (the 'Lower Lakes'), namely Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscura*), southern pygmy perch (*N. australis*) and southern purple-spotted gudgeon (*Mogurnda adspersa*). They are listed as threatened with extinction under various state and federal legislations, including the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). During the recent drought, their lake-fringing habitat was desiccated because of severe water level recession (Wedderburn et al. 2012; Wedderburn et al. 2014). Consequently, various interventions were implemented to save threatened fish populations, including the delivery of environmental water to drought refugia, fish rescues and captive breeding programs (Hammer et al. 2013; Wedderburn et al. 2013; Bice et al. 2014).

Lake water levels were reinstated when substantial river flows returned in 2010, and wetlands fringing the Lower Lakes were inundated. Subsequently, Murray hardyhead dispersed from drought refugia when habitat connectivity with the lakes returned (Wedderburn and Barnes 2011). The pygmy perch species, however, were previously extirpated (Wedderburn et al. 2012). In attempts to re-establish populations following drought, fish reared in captivity were reintroduced to apparently suitable habitat (see Bice et al. 2014). The program was implemented through the Murray–Darling Basin Authority's (MDBA) The Living Murray (TLM) initiative by South Australia's Department of Environment, Water and Natural Resources (DEWNR).

The Living Murray Condition Monitoring of threatened small-bodied fish species undertakes sampling twice a year, at sites that were inhabited by the fishes during the early stages of drought (Wedderburn and Hammer 2003). Post-drought monitoring detected very few threatened fish populations (Wedderburn and Barnes 2012; Wedderburn and Barnes 2013). The TLM Condition Monitoring program was established during the drought when habitat for threatened fish was sparse. It now only covers a proportion of their suitable habitat across the Lower Lakes. Therefore, it is possible that current monitoring omits recently established threatened fish populations. In order to test this proposition, and gain a more accurate assessment of the threatened small-bodied fish populations in the Lower Lakes, additional sites were sampled in March and April 2014. Monitoring at additional sites occurred immediately after the March 2014 round of TLM Condition Monitoring (Wedderburn and Barnes 2014).

The specific project aims are to:

(1) determine the current distribution and population status of Murray hardyhead, Yarra pygmy perch, southern pygmy perch and southern purple spotted gudgeon;
(2) consider the contribution of interventions during and after the recent drought (i.e. water allocations, reintroductions) towards the post-drought recovery of the threatened fishes in the Lower Lakes;
(3) identify replacements of, or expansion on, current threatened small-bodied fish monitoring sites in the Lower Lakes in line with recommendations from the Condition Monitoring Plan refinement project (see Robinson 2013); and
(4) support some of the recommendations of the Murray hardyhead review workshop, specifically to assess the current distribution and habitat requirements of Murray hardyhead in the Lower Lakes (see Ellis and Kavanagh 2014).

Methods

Study sites

Seventy-four sites were sampled in autumn 2014 (Figure 1; Table 1). They comprise 24 sites sampled during the March round of TLM Condition Monitoring (Wedderburn and Barnes 2014) and 13 sites sampled under the DEWNR's Critical Fish Habitat project (Bice et al. 2014). The remaining 37 sites were new locations sampled for the current Intervention Monitoring project.

The spread of sites was representative of potential threatened fish habitat across the Lower Lakes (as informed by previous monitoring). There was some concentration of sampling in areas that warranted extra effort. Specifically, the south-western region of the Lower Lakes was a hotspot of fish diversity in 2003, where three of the threatened fish species were abundant (Wedderburn and Hammer 2003). In this region, Shadows Lagoon was more widely targeted because it was a reintroduction site for 1750 Yarra pygmy perch in 2012, and it was the only location the species was detected in 2013–14 regular monitoring programs (Bice et al. 2014; Wedderburn and Barnes 2014).

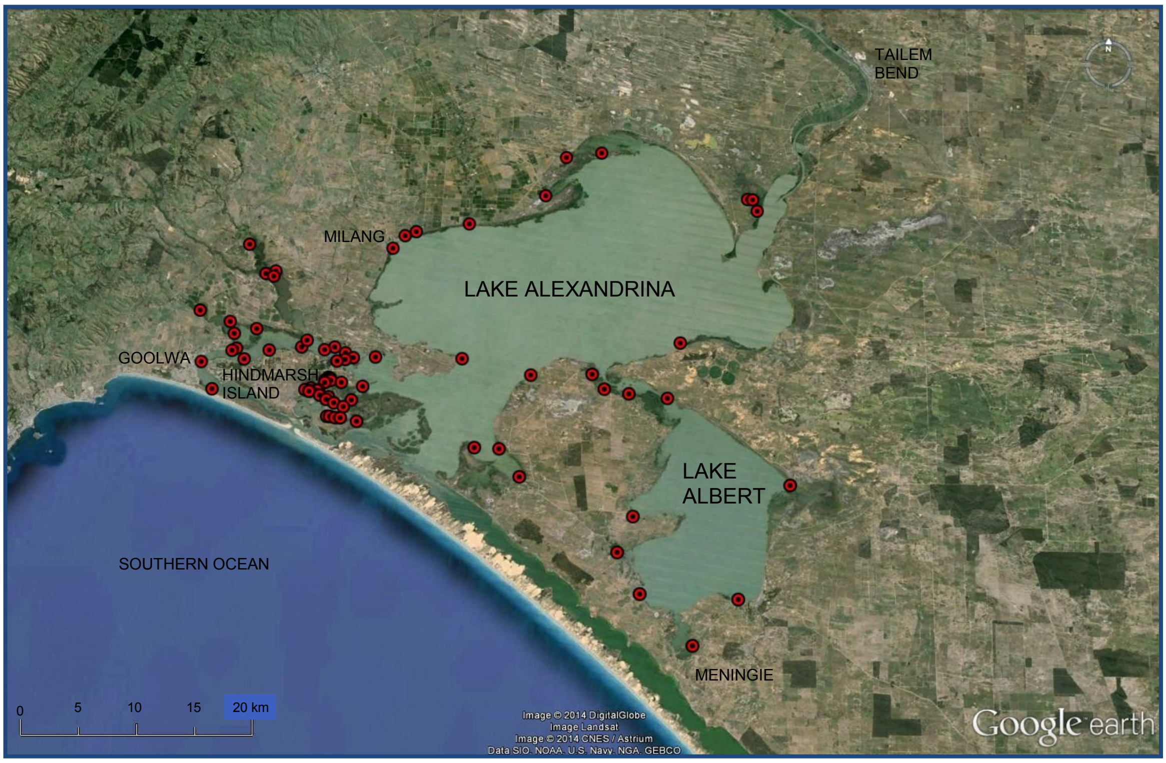

Figure 1. Sampling sites at the Lower Lakes in autumn 2014.

Table 1. Sampling sites in autumn 2014 (UTM zone 54H, WGS84).

Site	Site description	Easting	Northing	Habitat type
2	Wyndgate, Hindmarsh Island	309580	6067037	modified channel
3[1]	Hunter's Creek upstream	309336	6066321	natural channel
4	Holmes Creek–Fish trap Creek	312489	6065025	modified channel
5[1]	Steamer Drain	310487	6065853	modified channel
6	Holmes Creek–Boggy Creek	310913	6065636	natural channel
9	Finniss River–Wally's Wharf	303084	6079610	natural channel
10	Dunn Lagoon 1	312414	6069870	wetland
11	Dunn Lagoon 2	312421	6069267	wetland
14[1]	Goolwa Channel–Currency Ck (S)	302559	6070065	natural channel
15	Angas River mouth	318245	6081200	natural channel
16	Lake Albert–Narrung	334667	6068532	wetland
18[1]	Goolwa Channel–Finniss River (S)	308882	6070934	natural channel
19	Bremer River mouth	323062	6082057	natural channel
20	Nalpa Station	349401	6083975	modified channel
22	Mundoo Island 1	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 Island–Boundary Creek	313752	6063750	modified channel
31	Boggy Creek (N)	312194	6067197	modified channel
32	Mundoo Island 2	312275	6064403	modified channel
34	Shadows Lagoon	311165	6067555	wetland
35	Mundoo Island (channel junction)	311321	6064129	modified channel
36	Lake Albert–Campbell House	339327	6049381	lake edge
37[1]	Turvey's drain	319095	6081360	modified channel
38[1]	Black Swamp	304545	6076940	wetland
44[2]	Hindmarsh Island bridge	299474	6068733	natural channel
48	Lake Albert–Waltowa	352876	6058248	lake edge
49	Lake Albert–Nindethana	338591	6056042	lake edge
60	Dunn Lagoon 3	313141	6069457	wetland
62	Lake Albert–Belcanoe	337274	6052900	wetland
65	Pelican Lagoon 1	348983	6085034	wetland
66	Pelican Lagoon 2	348501	6085056	wetland
67	Shadows Lagoon (N/W)	310716	6067347	wetland
68	Shadows Lagoon (S/W)	310705	6067150	wetland
69	Shadows Lagoon (N)	311006	6067625	wetland
70	Shadows Lagoon (E)	311027	6067370	wetland
71	Shadows Lagoon channel (S)	311250	6067348	modified channel
72	Shadows Lagoon channel (N)	311168	6067502	modified channel
73	Steamer Drain–Hunters Creek	310191	6066467	modified channel
74	Boggy Creek (S)	311110	6065864	natural channel
75	Currency Creek (S/W)	302267	6071370	natural channel

Site	Site description	Easting	Northing	Habitat type
76	Currency Creek (N/W)	299032	6073402	natural channel
77	Currency Creek (N/E)	301825	6072443	natural channel
78	Goolwa Channel–Currency Ck (N)	304258	6071852	natural channel
79	Goolwa Channel–Hindmarsh Is	305522	6069939	natural channel
80	Goolwa Channel–Finniss River (N)	308433	6069566	natural channel
81	East of Dunn Lagoon	315536	6070305	lake edge
82	Hindmarsh Island east shoreline	311690	6069115	lake edge
83	Holmes Creek	313177	6065647	natural channel
84	Boggy Lake–Mosquito Creek	331764	6088578	modified channel
85	Clayton Bay	311418	6070364	wetland
86	Goolwa Channel–Goolwa Barrage	300622	6066308	natural channel
87	Lake Albert–Narrows confluence	341455	6066555	wetland
88	Lake Albert–Narrung Narrows 1	338000	6066870	wetland
89	Lake Albert–Narrung Narrows 2	335790	6067228	wetland
90	Lake Albert–Meningie	347935	6049152	lake edge
91	Lake Albert–south shore	344003	6045115	wetland
92	Loveday Bay (N)	326566	6061656	lake edge
93	Loveday Bay–Wamwarrum	324358	6061703	wetland
94	Loveday Bay (S)	328454	6059236	wetland
95[2]	Goolwa Channel–north boat ramp	302173	6069825	natural channel
96[2]	Hindmarsh Island–north boat ramp	303320	6069074	natural channel
97[2]	Holmes Creek–Lake Alexandrina	314123	6066890	wetland
98[2]	Boggy Lake	335009	6089087	wetland
101[1]	Blue Lagoon 1	305643	6077193	wetland
102[1]	Blue Lagoon 2	305489	6076720	wetland
103[1]	Channel off Hunters Creek	309494	6066624	natural channel
104[1]	Hunters Creek downstream	308968	6066459	natural channel
105[1]	Drain behind Wyndgate	310031	6066426	modified channel
106[1]	Holmes Creek–Eastick Creek	311624	6065344	natural channel
107[1]	Mundoo Island 3	311794	6064030	modified channel

[1] Data supplied by Bice et al. (2014)

[2] Supplementary sites – three seine shots only

Fish sampling

Sampling was undertaken in autumn because it is at the end of the annual recruitment cycles of most local fishes. Fyke nets, seine shots and dab netting were applied at all sites. Box trapping supplemented some sampling. All fish were identified to species (Lintermans 2007) and counted. An exception was the carp gudgeon complex (*Hypseleotris* spp.), which includes undescribed species and hybrids (Bertozzi et al. 2000). Total length (TL) was measured for all threatened fish.

Fish sampling equipment:

> <u>Three 6 m single-leader fyke nets (5-mm half mesh)</u> 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 fish <250 mm long (cf. Fratto et al. 2008). Three nets were set overnight at each site.
>
> <u>Three seine net (7 m long × 1.5 m deep, 5-mm half mesh) shots</u> for up to 10 m 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.
>
> <u>Dab net (1 mm square mesh)</u> was used for 10 minutes near fringing macrophytes.
>
> <u>Six unbaited box traps</u> for 1 hour during the day at some sites.

Data for 24 sites sampled using the same methods in the March round of TLM Condition Monitoring are presented herein (Wedderburn et al. 2014). Data for an additional 13 sites was supplied by Bice et al. (2014). Their sampling method was five fyke nets set overnight at each site. For the purpose of this assessment of threatened small-bodied fish populations, the extra two fyke nets were deemed comparable to the three seine net shots employed in the current study.

Habitat measures

The following parameters were recorded using a TPS WP-81 meter:

- Salinity in grams per litre (g/L) (except Bice et al. 2014 data)
- Electrical Conductivity (EC) units (µS/cm)
- pH
- Temperature (°C)

Other measured habitat variables were:

- Secchi depth (cm).
- Average water depth: five measures approximately 1 m apart, beginning 1 m from the bank, or five measures equally spaced if in a narrow channel.
- Bank gradient: 0–90 degrees.
- Aquatic plant cover: estimated percentage covering sediment.
- Site ‘connected’ to a lake or a main channel, or ‘isolated’.

Data interpretation

South Australian Museum specimens and a few unpublished reports provide earlier indications of only the regional presence of some threatened fish species in the Lower Lakes (see Hammer et al. 2009). Wedderburn and Hammer (2003) conducted the first known inventory of fish in the Lower Lakes. Therefore, the current distributions and relative abundances of the threatened fish species were compared against data collected between 2001 and 2005 (Wedderburn and Hammer 2003; Wedderburn 2008). Data was compared from sampling at eight sites in 2001–02 and 43 sites in summer–autumn 2003 by Wedderburn and Hammer (2003), and five sites sampled in summer 2004–05 by Wedderburn (2008). Site locations in 2014 were often the same or close to the 2003 sampling locations. For example, on both occasions sampling occurred in the Currency Creek and Finniss River confluences, and in Lake Albert. Further, the use of Wedderburn and Hammer (2003) is relevant because it is recommended as the baseline data for indices of population assessments in future TLM Condition Monitoring (Robinson 2013). An assessment of the level of post-drought population recovery for each species was made by comparing distribution maps.

General results

A total of 13,562 fish, represented by 20 native and four alien species, were captured at 74 sites in autumn 2014 (Table 2). As a general comparison, 7493 fish, represented by 18 native species and the same four alien species, were captured at 51 sites by Wedderburn and Hammer (2003). The two additional species in the current study are Murray–Darling rainbowfish and river garfish.

In autumn 2014, Murray hardyhead, southern pygmy perch and Yarra pygmy perch constituted 1.85%, 0.10% and 0.01% of the overall catch, respectively. Southern purple-spotted gudgeon was not captured in autumn 2014. The most numerous native fishes were flathead gudgeon (19.60%), common galaxias (12.90%), bony herring (11.01%) and unspecked hardyhead (9.95%). The alien eastern Gambusia constituted the highest proportion of the overall catch (30.76%). The other alien fishes, namely redfin perch, goldfish and common carp, constituted low proportions of the overall catch in autumn 2014 (1.70%, 0.82% and 0.75%, respectively).

In autumn 2014, sites sampled in Lake Alexandrina had a mean EC of 1265 µS/cm (range 470–4610 µS/cm; *n* = 64). Sites sampled in Lake Albert had a mean EC of 2670 µS/cm (range 1139–3740 µS/cm; *n* = 10) (Table 3). Murray hardyhead was captured at sites 6, 14, 18, 25, 26, 32, 75, 76, 77, 78, 79, 86 and 96, which had an average salinity of 1134 µS/cm (range 921–1677 µS/cm; *n* = 13). At the same sites, mean depth ranged from 23–77 cm, and the proportion of aquatic plant cover ranged from 20–60% (predominantly *Myriophyllum* and *Typha*). Yarra pygmy perch was captured only at site 34, where EC was 1767 µS/cm, mean depth was 22 cm and the proportion of aquatic plant cover was 58% (predominantly *Vallisneria*). Southern pygmy perch was captured only at site 22, where EC was 1145 µS/cm, mean depth was 55 cm and the proportion of aquatic plant cover was 77% (predominantly *Typha and Myriophyllum*).

Table 2. Fish species and total numbers recorded at the Lower Lakes in autumn 2014.

Common name	Taxonomic name	Conservation status	Total captured
Native species			
Southern pygmy perch	*Nannoperca australis*	E[2]; V[3]	14
Yarra pygmy perch	*Nannoperca obscura*	V[1;] CE[2]; V[3]	1
Murray hardyhead	*Craterocephalus fluviatilis*	E[1]; CE[2]; CE[3]	251
Unspecked hardyhead	*C. stercusmuscarum fulvus*		1350
Australian smelt	*Retropinna semoni*		364
Bony herring	*Nematalosa erebi*		1493
Murray–Darling rainbowfish	*Melanotaenia fluviatilis*	V[3]	82
Southern purple-spotted gudgeon	*Mogurnda adspersa*	CE[2]; RE[3]	0
Carp gudgeon	*Hypseleotris* spp.		218
Flathead gudgeon	*Philypnodon grandiceps*		2658
Dwarf flathead gudgeon	*Philypnodon macrostomus*		65
Golden perch	*Macquaria ambigua ambigua*		13
Congolli	*Pseudaphritis urvillii*	V[2]	354
Common galaxias	*Galaxias maculatus*		1749
Smallmouth hardyhead	*Atherinosoma microstoma*		110
Lagoon Goby	*Tasmanogobius lasti*		48
Tamar River goby	*Afurcagobius tamarensis*		49
Western blue spot goby	*Pseudogobius olorum*		128
River garfish	*Hyporhamphus regularis*		1
Sandy sprat	*Hyperlophus vittatus*		1
Alien species			
Common carp	*Cyprinus carpio*		101
Goldfish	*Carassius auratus*		111
Eastern Gambusia	*Gambusia holbrooki*		4171
Redfin perch	*Perca fluviatilis*		230

[1] *Environment Protection and Biodiversity Conservation Act 1999*: E = Endangered; V = Vulnerable
[2] South Australia (Hammer et al. 2009): CE = Critically Endangered; E = Endangered; V = Vulnerable
[3] Victorian *Flora and Fauna Guarantee Act 1988*: RE = Regionally Extinct; CE = Critically Endangered; V = Vulnerable

Dunn Lagoon was prime habitat for Murray hardyhead in 2003.

Table 3. Habitat characteristics at the 74 sites sampled in autumn 2014.

Site	Salinity (g/L)	Cond. (µS/cm) EC	pH	Secchi depth (cm)	Water temp. (ºC)	Mean depth (cm)	Aquatic plants (%)	Habitat type
2	0.96	1989	7.05	49	19.0	43	100	modified channel
3	-	1180	7.12	>90	20.4	51	50	natural channel
4	0.43	927	7.21	41	17.3	57	95	modified channel
5	-	879	7.39	>90	17.4	70	90	modified channel
6	0.46	989	7.52	36	18.7	39	36	natural channel
9	1.34	2757	7.08	28	23.0	31	78	natural channel
10	0.43	936	7.31	51	16.7	37	92	wetland
11	0.42	900	7.02	32	17.6	39	76	wetland
14	-	989	7.95	36	21.4	77	60	natural channel
15	0.81	1705	6.74	42	19.6	33	26	natural channel
16	1.34	2760	7.29	23	18.9	52	52	wetland
18	-	921	8.24	33	21.7	61	60	natural channel
19	0.36	790	6.73	38	19.9	100	44	natural channel
20	0.21	470	7.64	22	19.5	28	80	modified channel
22	0.54	1145	6.83	38	17.2	55	77	modified channel
25	0.44	954	7.15	21	17.4	23	42	wetland
26	0.44	954	7.53	24	19.0	30	40	lake edge
27	0.35	765	7.69	27	19.6	36	80	lake edge
28	0.36	796	7.63	26	19.2	22	82	lake edge
29	0.39	847	6.97	24	19.7	48	54	lake edge
30	0.50	1068	7.42	33	16.9	87	53	modified channel
31	0.62	1314	7.04	115	17.9	75	100	modified channel
32	0.80	1677	6.97	49	15.6	39	100	modified channel
34	0.84	1767	7.09	61	19.5	22	58	wetland
35	0.49	1049	6.84	29	17.0	75	72	modified channel
36	1.44	2970	7.56	23	19.9	21	16	lake edge
37	-	1060	7.13	>140	22.0	117	80	modified channel
38	-	1650	7.54	33	21.2	116	50	wetland
44	0.54	1134	7.92	27	18.6	65	15	natural channel
48	1.53	3120	7.26	26	17.7	25	22	lake edge
49	1.53	3140	7.42	16	16.9	32	24	lake edge
60	0.41	880	7.92	27	16.8	92	50	wetland
62	1.82	3660	7.32	17	21.6	25	60	wetland
65	1.35	2820	6.67	>24	22.7	19	53	wetland
66	0.51	1081	7.23	11	22.6	36	60	wetland
67	1.09	1861	7.31	19	18.8	23	67	wetland
68	0.82	1730	7.08	20	19.3	22	60	wetland
69	0.79	1669	7.20	20	19.6	33	55	wetland
70	0.80	1691	7.51	21	16.3	28	50	wetland
71	0.55	1173	7.02	40	17.6	64	72	modified channel
72	0.78	1643	7.09	34	17.6	56	46	modified channel
73	0.48	1025	7.20	>19	16.6	92	90	modified channel

Site	Salinity (g/L)	Cond. (µS/cm) EC	pH	Secchi depth (cm)	Water temp. (ºC)	Mean depth (cm)	Aquatic plants (%)	Habitat type
74	0.47	1007	7.01	35	16.9	63	80	natural channel
75	0.56	1192	7.77	27	17.8	41	35	natural channel
76	0.71	1512	7.39	24	18.8	53	20	natural channel
77	0.56	1200	7.37	34	18.3	64	60	natural channel
78	0.52	1115	7.46	37	18.5	32	25	natural channel
79	0.47	1006	7.62	41	18.2	60	45	natural channel
80	0.53	1143	7.55	38	18.3	65	40	natural channel
81	0.40	856	8.13	36	19.2	37	37	lake edge
82	0.40	870	7.18	38	19.9	33	40	lake edge
83	0.41	877	7.49	34	18.8	45	41	natural channel
84	2.27	4610	7.39	21	16.5	19	22	modified channel
85	0.42	910	7.34	48	17.9	42	55	wetland
86	0.56	1201	7.58	33	18.1	23	47	natural channel
87	0.94	1958	7.72	>24	16.1	16	35	wetland
88	0.68	1446	7.31	25	17.6	39	37	wetland
89	0.53	1139	7.38	24	18.1	66	30	wetland
90	1.33	2766	7.84	21	15.6	33	24	lake edge
91	1.84	3740	7.84	23	16.6	45	15	wetland
92	0.37	821	6.98	49	16.3	29	55	lake edge
93	0.35	768	7.48	44	16.7	30	25	wetland
94	0.40	865	7.59	35	17.3	50	20	wetland
95	0.53	1125	8.07	27	18.3	33	35	natural channel
96	0.48	1030	7.83	28	18.7	51	20	natural channel
97	0.41	881	7.63	33	18.9	55	37	wetland
98	0.39	838	7.63	25	20	16	40	wetland
101	-	2200	7.98	25	21.4	64	40	wetland
102	-	2200	7.66	22	21.2	60	50	wetland
103	-	2020	7.98	>60	20.6	32	85	natural channel
104	-	1200	7.49	30	20.7	57	40	natural channel
105	-	1060	7.34	>110	17.8	83	95	modified channel
106	-	802	8.68	43	21.3	54	40	natural channel
107	-	1080	7.14	>85	15.7	73	90	modified channel

Findings and discussion

The Lower Lakes fish assemblage

Prior to the consequences of drought, the Lower Lakes harboured a diverse fish assemblage that comprised healthy threatened fish populations (Wedderburn and Hammer 2003). The most common and widespread native fishes were common galaxias, flathead gudgeon and western blue-spot goby. The least sampled species were sandy sprat, golden perch and Tamar River goby. Four alien fish species were widely distributed throughout the Lower Lakes, namely eastern Gambusia (26.65% of total catch), redfin perch (2.24%), common carp (1.99%) and goldfish (0.41%). Murray hardyhead (2.16% of total catch) was captured in several sites mostly concentrated near Hindmarsh Island. Yarra pygmy perch (5.18%) was captured in wetlands associated with Hindmarsh Island and the Finniss River confluence. Southern pygmy perch (2.90%) had a similar distribution to Yarra pygmy perch, but was also captured at an irrigation channel near Milang. Notably, southern pygmy perch has previously been captured in Pelican Lagoon (site 66) (Hammer et al. 2009), where it was not recorded by Wedderburn and Hammer (2003).

A similar suite of fish species was recorded in autumn 2014. The only exceptions were the inclusion of river garfish and Murray–Darling rainbowfish. The distribution of rainbowfish has recently extended to the Lower Lakes after decades of absence (Wedderburn and Barnes 2012). In autumn 2014, the most numerous native fishes again included flathead gudgeon and common galaxias. Notably, flathead gudgeon remained abundant throughout and after the drought, thereby highlighting its ecological generalist nature. Conversely, the diadromous common galaxias declined during drought because of disconnection between the Coorong and the Lower Lakes (Zampatti et al. 2010; Wedderburn et al. 2012). Therefore, its population recovery, and that of congolli, indicates a level of ecological recovery in the Lower Lakes (e.g. reconnection of habitats). In autumn 2014, the proportion of Murray hardyhead (1.85% of total catch) in the fish assemblage of the Lower Lakes was comparable to sampling by Wedderburn and Hammer (2003). Conversely, southern pygmy perch and Yarra pygmy perch constituted minor proportions of the overall catch (0.10% and 0.01%, respectively). The alien eastern Gambusia again constituted a high proportion of the overall catch (30.76%), which is consistent with findings across the MDB (e.g. Beesley et al. 2012). The proportions of the other alien fishes, namely redfin perch, goldfish and common carp (1.70%, 0.82% and 0.75%, respectively), were comparable to sampling by Wedderburn and Hammer (2003).

Population status and recovery

The following presents the findings for each threatened fish species. Maps for southern purple-spotted gudgeon are excluded because it was absent before and during the current study. To address the project aims, the current distribution and abundance of each species is compared against its former distribution as a means to assess its present population status and level of population recovery following drought and reintroductions.

Murray hardyhead

Craterocephalus fluviatilis

There was a shift in the distribution of Murray hardyhead between pre-2005 and autumn 2014 in the southern region of Lake Alexandrina (Figure 2). Formerly, the species was recorded in the area between Hindmarsh Island and Loveday Bay. In autumn 2014, its distribution centred at the Goolwa Channel and the associated confluences of Currency Creek and Finniss River. Regardless of the apparent distribution shift, an early stage of population recovery is obvious in the south-west region of the Lower Lakes.

In broad terms, Murray hardyhead is yet to recover to its full range in the Lower Lakes. The range of Murray hardyhead was greater in pre-2005, where it was also captured in Lake Albert (site 48 Waltowa and site 62 Belcanoe). Additionally, it was recorded at Campbell House (site 36) during 2008–09 TLM Condition Monitoring (Wedderburn and Barnes 2009). In autumn 2014, habitat fringing Lake Albert had the features required for Murray hardyhead, including elevated salinity (i.e. >900 EC) and low to moderate abundances of submerged aquatic plants. In particular, sites 16, 48, 49, 62, 87 and 91 would provide a widespread and representative sample of habitat for Murray hardyhead in Lake Albert, and should be considered for future TLM Condition Monitoring (see Appendix).

The early stage of population recovery for Murray hardyhead might relate to a combination of factors. First, Murray hardyhead may have persisted in unknown locations during drought. Second, water allocations into drought refugia maintained healthy populations of Murray hardyhead that may have dispersed when connectivity was regained in 2010 (e.g. site 31 Boggy Creek: Wedderburn et al. 2010). Third, reintroductions of Murray hardyhead may have supplemented the natural population (Bice et al. 2014). Notably, adult Murray hardyhead were recorded in Dunn Lagoon for the first time in several years immediately following the water level rise, prior to the reintroductions (Wedderburn and Barnes 2011). The details of population recovery will remain unknown because these topics were not examined at the time.

The natural recovery of a Murray hardyhead population in Dog Lake, Lake Alexandrina, demonstrates the species' resilience to prolonged drought. The failure of an irrigation pump in November 2009, which flooded habitat and triggered a positive recruitment response (see Wedderburn and Hillyard 2010), may have inadvertently supported this success (Wedderburn et al. 2010). Given its isolation, continued monitoring of Dog Lake will provide a good basis for examining the natural ability of Murray hardyhead to recover after the impacts of prolonged drought without other potential influences (e.g. reintroductions). Further, its population recovery at the site would be better understood with more detailed data collection (e.g. increased sampling effort, measure prey availability) (also see Robinson 2013).

Based on the current assessment, Murray hardyhead has the potential to expand its range to re-colonise former locations. It is a highly mobile, schooling species (Hammer and Wedderburn 2008), so it is conceivable that the Dog Lake population can recolonise the nearby Boggy Lake. The species' ability to naturally recolonise Lake Albert is somewhat questionable, given the closest population is approximately 30 km away via lake edge. Importantly, continued monitoring will determine its ability to naturally recolonise Lake Albert.

The objectives of the National Recovery Plan for Murray hardyhead centre on two key themes (Stoessel et al. in prep.). First, they highlight the need to manage extant populations through the protection, planning and raising of community awareness. Second, the objectives raise the issue of increased understanding of threats, particularly interactions with alien fishes (i.e. eastern Gambusia and redfin perch), and of life history requirements. The latter theme aims to understand the processes and requirements that increase early-life survivorship to promote recruitment, ultimately leading to self-sustaining populations.

The current study addressed some of the recommendations from a Murray hardyhead review workshop held in Adelaide in February 2014 (see details in Ellis and Kavanagh 2014). Specifically, the workshop discussed streamlining recovery processes, as detailed in the National Recovery Plan, by translating research and recommendations into action and policy. The objectives and recommendations of the workshop were to gather biological knowledge of Murray hardyhead, review the current distribution and local status of populations after the drought (i.e. the current study for the Icon Site), assess the effectiveness of management strategies, and identify knowledge gaps that might limit future recovery efforts. The development of a list of locations for future monitoring was another recommendation, which is addressed for the Icon Site by the current study (see Appendix). The final recommendation from the workshop was to develop a list of potential translocation locations, particularly in TLM Icon Sites. Notably, the suggestion to translocate Murray hardyhead to Lake Albert by Ellis and Kavanagh (2014) may be politically sensitive, given proposals currently being assessed through the South Australian Government's Lake Albert Scoping Study.

Site 75 Currency Creek where Murray hardyhead was captured in April 2014.

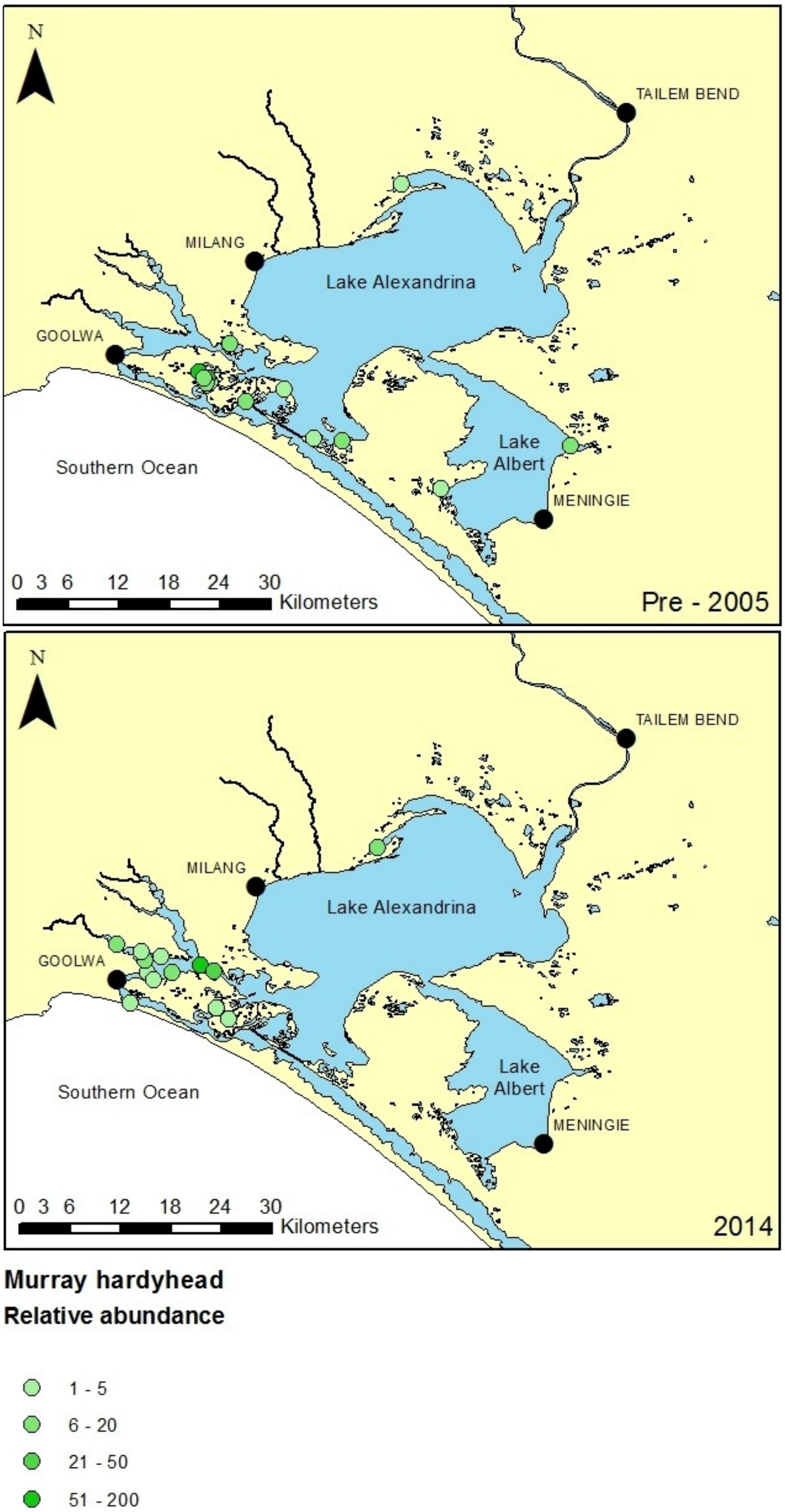

Figure 2. Distribution and relative abundance of Murray hardyhead in pre-2005 (2001–05) and in autumn 2014.

Southern pygmy perch

Nannoperca australis

There was a substantial shift in the distribution and abundance of southern pygmy perch in the Lower Lakes between pre-2005 and autumn 2014 (Figure 3). Formerly, the species was relatively abundant in the area between Hindmarsh Island and the Finniss River Confluence. There was also a population recorded in an irrigation channel near Milang (Wedderburn and Hammer 2003). Notably, a population previously recorded in Pelican Lagoon (Hammer et al. 2009) is not represented in this study. A single localised population was recorded in autumn 2014, inhabiting a drainage channel on Mundoo Island approximately 500 m from a southern pygmy perch reintroduction site (site 107). Overall, population recovery is lacking for southern pygmy perch in the Lower Lakes. The species again appears to be on the brink of local extinction.

The population decline and extinction of southern pygmy perch in the Lower Lakes resulted from the deterioration of habitat caused by water level recession during the recent drought (Wedderburn et al. 2012; Wedderburn et al. 2014). Water allocations to drought refugia aimed to conserve southern pygmy perch, but were unsuccessful. For example, the last natural southern pygmy perch population was recorded in Turvey's Drain (site 37) in spring 2010 (Bice et al. 2011). Despite the reintroduction of 1430 southern pygmy perch at three sites in 2012 (sites 2, 37 and 107), the population on Mundoo Island (site 22, near site 107) represents the only success.

During the drought, efforts to maintain southern pygmy perch in the wild at the Lower Lakes consisted of environmental water allocations to only one site (Turvey's Drain) (Hammer et al. 2013; Bice et al. 2014). The ecological and biological responses of water allocations were not monitored, so the reasons for the species' extirpation from Turvey's Drain are unknown. A southern pygmy perch population was reintroduced to the site following drought. It was monitored to examine demographic population changes, until it was undetected in spring 2013 (Bice et al. 2014). The underlying ecological factors were not monitored, so the reasons for the failed reintroduction efforts remain unknown.

The remaining southern pygmy perch population on Mundoo Island is precarious, but sampling confirmed recruitment in 2013–14 (Wedderburn and Barnes 2014). Sampling in other nearby sections of the same drainage system failed to capture the species. The reasons for this distribution pattern are unknown, but might relate to several factors. First, cumbungi (*Typha*) has congested the drainage channel system on Mundoo Island, so related factors might influence southern pygmy perch spawning and recruitment. Second, redfin perch was recorded at all sites on Mundoo Island, except where the southern pygmy perch remain, so its predation might influence distribution, abundance and recruitment. Third, food resources might limit the survivorship of newly hatched southern pygmy perch, and there might be a factor about the remaining site that meets its requirements.

There is some biological information available for southern pygmy perch (e.g. Humphries 1995; Llewellyn 1974), but its ecological requirements are only partially known (e.g.

Woodward and Malone 2002). For example, flooding of habitat promotes recruitment in southern pygmy perch (Hammer 2001; Tonkin et al. 2008), but the underlying reasons are unstudied. The habitat requirements of southern pygmy perch in the Lower Lakes can be generalised as shallow (<1 m) wetlands with low salinity (approx. <1000 EC) and abundant submerged macrophytes (e.g. *Myriophyllum*, *Vallisneria*). Aquatic plant assemblages appeared suitable during the current study, having recovered after the impacts of drought (Nicol et al. 2013; Wedderburn et al. 2014). The most probable reasons for failed recruitment at most southern pygmy perch reintroduction sites in 2012–13 and 2013–14 relate to starvation and/or predation of early life stages. Inadequate flow regime (e.g. to promote zooplankton prey) might also be a factor.

There is no recovery plan for southern pygmy perch, because it is not listed under the *EPBC Act 1999*. The species is listed as 'Protected' under South Australia's *Fisheries Management Act 2007*, but this affords it little attention for management. Instead, the species is listed as 'Endangered' in the Action Plan for South Australian Freshwater Fishes (Hammer et al. 2009). The Action Plan lists the key recovery objectives in South Australia as prioritising management on populations in Lake Alexandrina and its adjoining tributaries to improve the species' population status by securing habitat and minimising threats.

The site holding the remaining southern pygmy perch population presents an opportunity to study the reasons for success and failure of population recovery in the Lower Lakes. Comparisons between site 22 and sites where reintroduction efforts have failed would provide important insights (e.g. site 3 Wyndgate, site 37 Turvey's Drain). Specifically, temporal examinations of food availability for southern pygmy perch would determine if starvation of larval and juvenile fish is limiting recruitment. Also, an examination of the potential impacts of predation by redfin perch on southern pygmy perch would determine if local (site) alien fish control is necessary. The anecdotal pattern observed in this study warrants investigation, given the implied threats of redfin perch to the threatened fishes in recovery and action plans, and other literature (e.g. Woodward and Malone 2002; Lintermans 2007; Hammer et al. 2009; Saddlier and Hammer 2010; Stoessel et al. in prep.).

Southern pygmy perch from site 22 (left) and redfin perch from the nearby site 34 (right) on Mundoo Island.

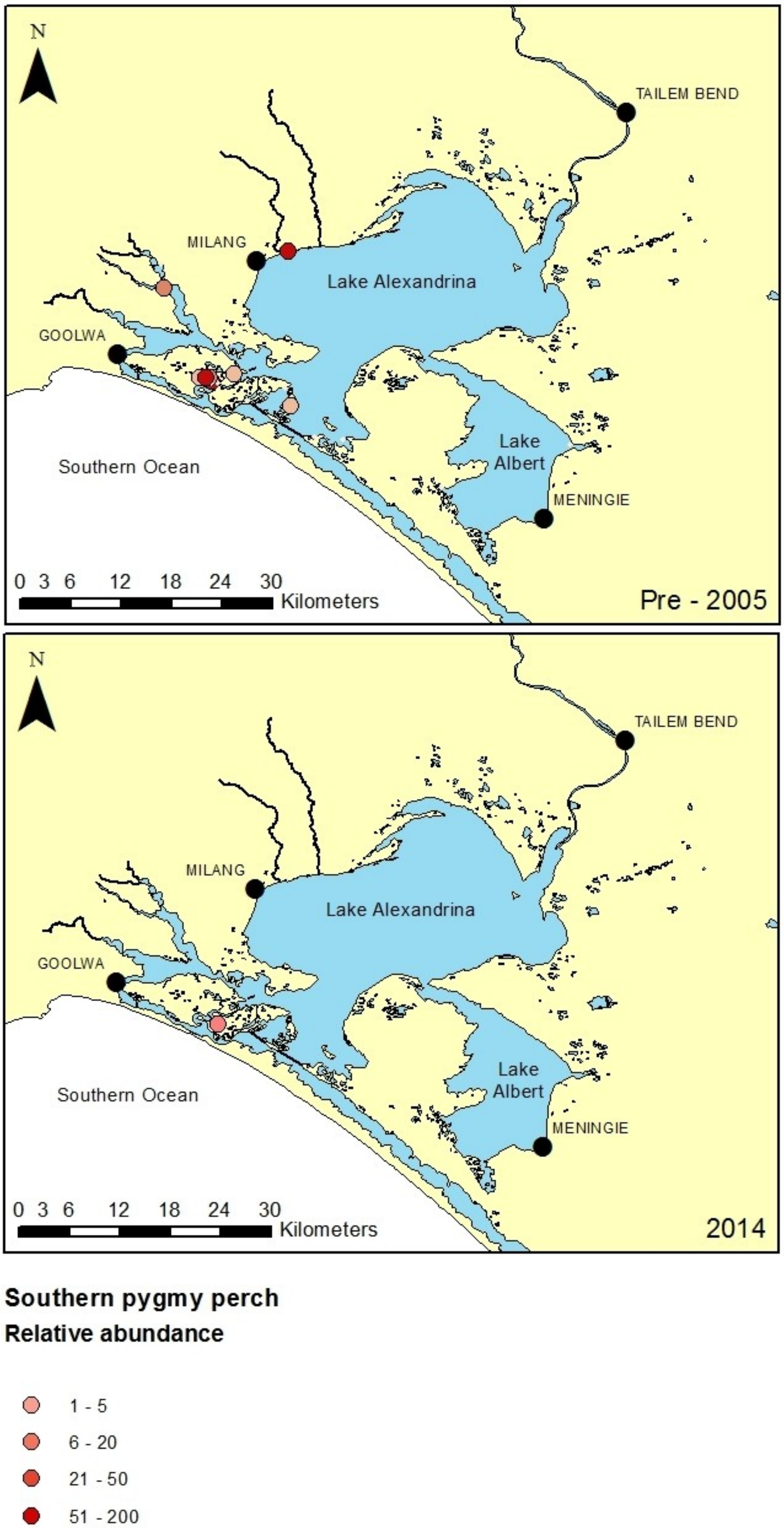

Figure 3. Distribution and relative abundance of southern pygmy perch in pre-2005 (2001–05) and in autumn 2014.

Yarra pygmy perch

Nannoperca obscura

There was a shift in the distribution and abundance of Yarra pygmy perch in the Lower Lakes between pre-2005 and autumn 2014 (Figure 4). Previously, the species was recorded only in the area between Hindmarsh Island and the upper Finniss River Confluence (Wedderburn and Hammer 2003). In autumn 2014, only a single Yarra pygmy perch was captured. The fish was recorded at one of the five reintroduction sites (site 34) (Bice et al. 2014). There are no signs of population recovery for Yarra pygmy perch in Lower Lakes. It appears to be on the brink of extinction in the MDB.

Almost 6000 Yarra pygmy perch were reintroduced to sites 3, 5, 18, 34 and 101 between 2011 and 2013 (Bice et al. 2014). The species was only detected at Shadows Lagoon (site 34) during all regular 2013–14 sampling (Bice et al. 2014; Wedderburn and Barnes 2014). Hence, particular effort went into sampling Shadows Lagoon during the current study. The size of the single fish captured in March 2014 confirms that it was not a re-stocked fish (see Bice et al. 2014). Therefore, some limited spawning and recruitment occurred in Shadows Lagoon since the species' reintroduction.

The habitat requirements of Yarra pygmy perch in the Lower Lakes can be generalised as wetlands with low salinity (approx. <1000 EC) and abundant submerged macrophytes (e.g. *Myriophyllum*; *Vallisneria*). Generally, habitat appeared adequate during the current study. The survival rate of larval and juvenile stages of fish is intrinsically linked to recruitment levels, and is largely determined by food availability and predation (Houde 1987). Hence, the most probable reasons for poor recruitment in 2012–13 and 2013–14 relate to starvation and/or predation of early life stages.

Based on the current study, there appears to be limited opportunity for recovery of Yarra pygmy perch in the Lower Lakes without further reintroductions. Shadows Lagoon proved to be the most successful release site, therefore it should be considered for any future reintroductions and monitoring. The fate of reintroduced Yarra pygmy perch, and their offspring, was not studied. Therefore, the reasons for the apparent failure will remain unknown, and future reintroductions will again be uninformed. If future reintroductions occur, the underlying causes of recolonising success or failure should be examined. In this regard, Shadows Lagoon provides an ideal intervention monitoring site.

The Yarra pygmy perch Recovery Plan lists 10 objectives (Saddlier and Hammer 2010). Some objectives have been addressed, including "*Determine the genetic and taxonomic status of Yarra Pygmy Perch populations*" and "*Establish a captive breeding population of Yarra Pygmy Perch*" (Hammer et al. 2010; Brauer et al. 2013; Hammer et al. 2013; Saddlier et al. 2013). Several important objectives are yet to be adequately addressed, including "*Determine Yarra Pygmy Perch habitat characteristics and requirements*" and "*Identify and manage potentially threatening processes impacting on Yarra pygmy perch conservation*" (Saddlier et al. 2013). Threatening processes include interactions with alien species (e.g. eastern Gambusia, redfin perch), habitat loss and disconnection, and altered flow regimes (Saddlier and Hammer 2010).

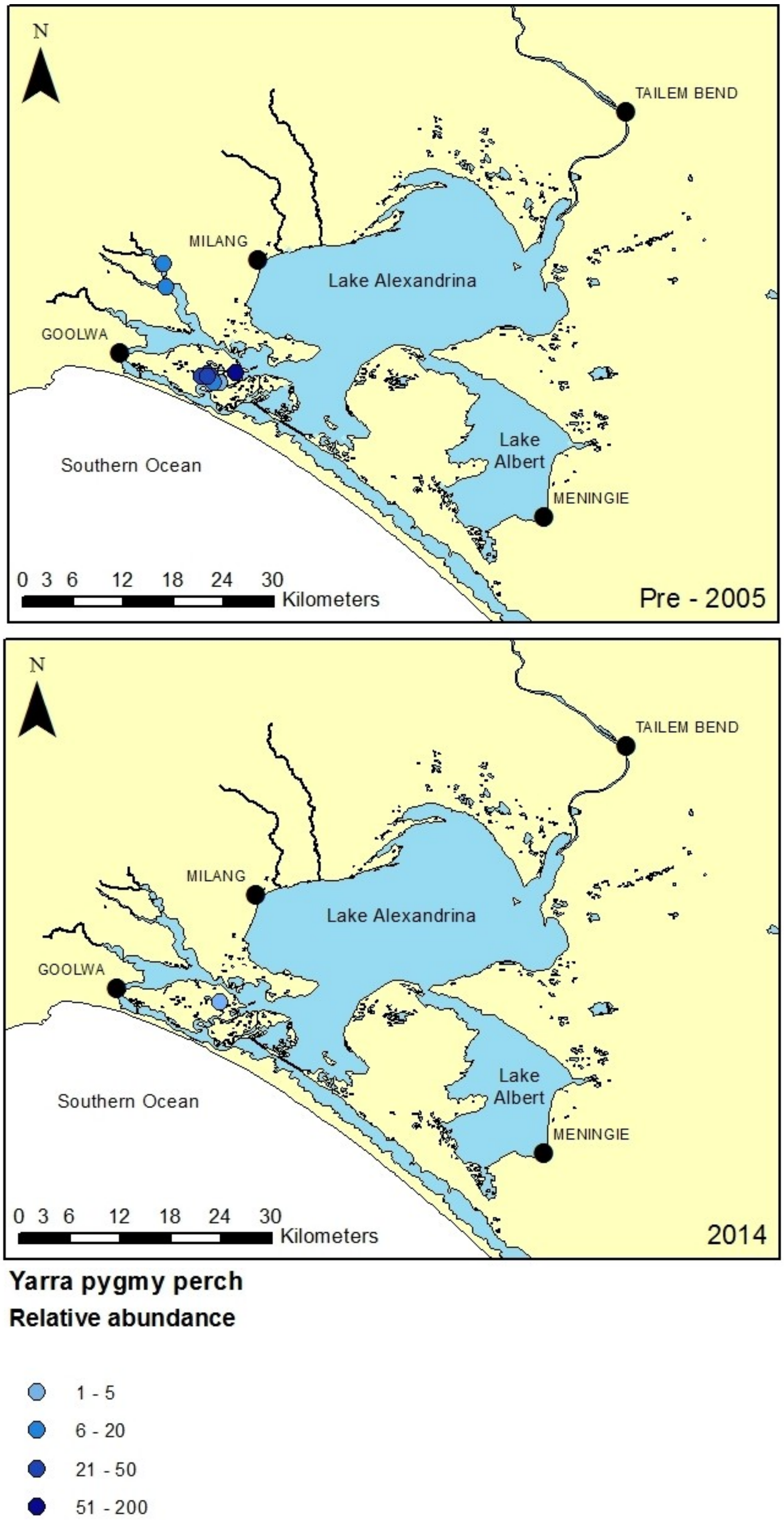

Figure 4. Distribution and relative abundance of Yarra pygmy perch in pre-2005 (2001–05) and in autumn 2014.

Southern purple-spotted gudgeon

Mogurnda adspersa

There is no comparison between the 2003 and 2014 distribution and abundance of southern purple-spotted gudgeon. The last known population in the lower River Murray was recently discovered near Murray Bridge (Hammer et al. 2009). A captive population was established from the wild fish prior to extirpation during drought (Hammer 2007). From this stock, the species was reintroduced to the Finniss River confluence of the Lower Lakes when water levels were reinstated (Bice et al. 2014). Small numbers of southern purple-spotted gudgeon were recorded near the reintroduction site in November 2013 (Bice et al. 2014). Its absence in autumn 2014 sampling suggests the reintroduced population is declining. The findings are in line with its current population status of 'Critically Endangered' in South Australia (Hammer et al. 2009). Ongoing monitoring is required to determine if the species establishes a self-sustaining population in the Lower Lakes. Further reintroductions may be necessary (Bice et al. 2014).

Given its rarity, there is limited information regarding the habitat requirements of southern purple-spotted gudgeon in the lower River Murray and Lower Lakes. Prior to extirpation of the last known population near Murray Bridge, its habitat comprised rock banks (core habitat) and submerged and emergent vegetation (Hammer 2007). At the time, water level fluctuations were apparently important to sustain the population (Hammer 2007).

The Reintroduction Plan gives details of the activities required for establishing self-sustaining populations of southern purple-spotted gudgeon in the southern MDB (Hammer et al. 2012). This includes assessments of habitat and biota, site preparations, reintroductions and adaptive management. The latter topic includes monitoring and investigations. The report highlights that "*reduced freshwater flow leading to rapid and catastrophic habitat loss should be considered the primary threat at any reintroduction sites (i.e. natural flows and security of environmental water)*". Notably, this does not appear to be the cause of low population numbers at the release site in the Finniss River confluence of the Lower Lakes (Bice et al. 2014). Other suspected threats to reintroduced populations of southern purple-spotted gudgeon include unsuitable flow variability, poor water quality, interactions with alien fishes (e.g. redfin perch, eastern Gambusia), and disease (Hammer et al. 2012).

Condition Monitoring

The Department of Environment, Water and Natural Resources manages The Living Murray program in South Australia, including the Condition Monitoring program for threatened fishes in the Lower Lakes. The Coorong, Lower Lakes and Murray Mouth Icon Site Condition Monitoring Plan (Maunsell 2009) was recently evaluated to determine if the monitoring targets provide an accurate assessment of change in the ecological condition of the Icon Site (Robinson 2013). As a result, recommendations from the evaluation will be implemented, possibly including changes in sampling strategy and re-defining of the monitoring targets for threatened fish. The current study addresses this point, by expanding the number of sampling locations in autumn 2014 from 24 to 74 sites with the aim of identifying new threatened fish populations or apparently suitable habitat.

Robinson (2013) recommends a refinement of the Condition Monitoring Plan objectives, which include the use of indices as a means to examine changes in the condition of threatened fish populations. Indices require a ‘point of reference’ (baseline data) which can be related to new data. In this case, Robinson (2013) suggests the use of data collected in 2003 as the baseline, when healthy threatened fish populations inhabited sites fringing the Lower Lakes (Wedderburn and Hammer 2003). Therefore, future Condition Monitoring sites should correspond with, but need not be confined to, those of Wedderburn and Hammer (2003). In this regard, former Condition Monitoring sites where the threatened species occurred are also relevant. A list of sites for potential future TLM Condition Monitoring is provided in the Appendix.

Intervention Monitoring

A growing paradigm in Australia is to take a holistic approach to fish conservation (Cooke et al. 2012; Koehn and Lintermans 2012; Lintermans 2013). In this regard, the Lower Lakes provide the opportunity to collectively monitor and manage four threatened small-bodied fish species, and other threatened flora and fauna, because they cohabit in lake-fringing sites. First, gaps in ecological knowledge must be addressed. At the forefront is the influence of flow regimes on physical habitat, water quality and connectivity (Beesley et al. 2014). A common theme throughout the relevant recovery and action plans is the need to determine the ecological requirements of the threatened fishes as part of a long-term approach to management. This includes determining the water requirements of threatened fishes so that the appropriate volumes and timing of flows and water level fluctuations can be established. Another collective theme of the respective plans is to understand the impacts of threatening processes on fish populations. They largely relate to habitat deterioration (often linked to flow regime), and interactions with alien redfin perch and eastern Gambusia. These two key themes (flow regimes and threats) are mostly unstudied in the Lower Lakes.

Intervention monitoring projects in the Lower Lakes should, for now, focus on the underlying factors determining population recovery of the threatened small-bodied fish species (Box 1). The early stage of population recovery of Murray hardyhead provides the opportunity to measure the roles of water quality (e.g. salinity variations), connectivity (for expanding its range) and recruitment (survival of early life-stages) in this success (e.g. aim 4 herein; Ellis and Kavanagh 2014). Populations of Yarra pygmy perch and southern pygmy perch were not conserved during the drought. The species have thus far failed to recover through reintroductions. Therefore, further re-stocking appears necessary. If implemented, additional investigations would increase understanding of the underlying causes of population dynamics observed through Condition Monitoring.

In line with relevant recovery and action plans for the threatened fishes, the two key themes for potential intervention monitoring are (1) investigations of water requirements of the threatened fishes at local (wetland) and broad (MDB) scales to understand the links between flow regime (water management), habitat restoration and life history requirements of fishes, including habitat connectivity, and (2) determine if alien fish control (i.e. eastern Gambusia, redfin perch) would enhance population recovery and reintroduction efforts, which could possibly be linked to laboratory or pond experiments. Notably, there may be the opportunity to utilise captive fish for experimentation, if appropriate approvals are obtained.

Box 1. Example of an Intervention Monitoring project to examine the population response of a threatened fish population to water management in the CLLMM Icon Site.

Murray hardyhead was not recorded in Dog Lake from November 2010 to March 2013, and was presumed extirpated. It was recorded in 2013–14 and successful recruitment was evident (Wedderburn and Barnes 2014). The status of the population is still tenuous, due to its low abundance, but there are promising signs of recovery. This is an important population which should be further monitored. Also, its isolation makes it an ideal population for a drought resilience and recovery study. For example, examining population responses to future biological (e.g. prey availability) and habitat (e.g. water level fluctuations, salinity, submerged macrophytes) shifts would generate valuable information to manage the species in the MDB. A study could be developed from the methods and findings of the Boggy Creek case study (conducted in 2009–10: Wedderburn et al. 2010; MDBA 2014). An Intervention Monitoring project of this type would address the Environmental Water Management Plan's Intervention Monitoring objective to account for and report on how TLM environmental water is used and managed at the Lower Lakes, Coorong and Murray Mouth Icon Site (MDBA 2014, page 64). Specifically, it could determine the influence of Lake Alexandrina water level management on the Murray hardyhead population in Dog Lake. The outcomes could then be used to help meet the TLM Target F2 (Maunsell 2009).

Conclusions

The current distributions and population status of Murray hardyhead, Yarra pygmy perch, southern pygmy perch and southern purple spotted gudgeon were assessed in autumn 2014. Following population collapse during the recent drought, recovery is apparent for Murray hardyhead in Lake Alexandrina. Murray hardyhead is yet to fully re-establish to its former range, which included Boggy Lake and Lake Albert. Conversely, that only a single Yarra pygmy perch was captured suggests the species is again close to extinction in the MDB. Its existence and recovery in the Lower Lakes probably relies on further reintroductions. The precarious nature of one remaining southern pygmy perch population warrants immediate attention, possibly through habitat protection (e.g. adequate volumes of water, water quality) and threat abatement (e.g. control of redfin perch and eastern Gambusia). The absence of southern purple-spotted gudgeon in sampling suggests the species is close to regional extinction.

The specific contribution of interventions to protect and maintain the threatened fish species are difficult to determine, because the underlying processes were mostly unstudied. An exception was a study that found a positive recruitment response of Murray hardyhead to environmental water allocations in the Boggy Creek drought refuge. Fish from this site, and possibly from reintroductions, may have contributed to the recovery of Murray hardyhead in the Lower Lakes. Given the extirpation of Yarra pygmy perch and southern pygmy perch from the Lower Lakes during the recent drought, fish captured in this study undoubtedly result from the reintroductions. The thorough assessment in and around reintroduction sites suggest the objective to re-establish self-sustaining populations of the pygmy perches are failing, with the exception of the single isolate of southern pygmy perch on Mundoo Island.

Sites sampled in this study were selected based on habitat attributes that are requirements of one or more of the threatened small-bodied fish species. Ideally, future monitoring would occur at most of the sites because fish populations are highly variable (seasonal and daily shifts). The appendix prioritises the sites based on the former or current presence of one or more threatened fish species. Several sites where threatened species have not been recorded are deemed high priority because they have habitat attributes that suggest monitoring is warranted. For example, sampling at several sites is recommended to determine if Murray hardyhead recolonises Lake Albert. In all, there are 29 sites of highest priority, 18 sites of moderate priority and 28 sites at the lowest priority.

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References

Adams, M., S. D. Wedderburn, P. J. Unmack, M. P. Hammer and J. B. Johnson, (2011). Use of congeneric assessment to reveal the linked genetic histories of two threatened fishes in the Murray–Darling Basin, Australia. *Conservation Biology* **25**: 767–776.

Beesley, L., A. J. King, F. Amtstaetter, J. D. Koehn, B. Gawne, A. Price, D. L. Nielsen, L. Villizzi and S. N. Meredith, (2012). Does flooding affect spatiotemporal variation of fish assemblages in temperate floodplain wetlands? *Freshwater Biology* **57**: 2230–2246.

Beesley, L., A. J. King, B. Gawne, J. D. Koehn, A. Price, D. Nielsen, F. Amtstaetter and S. N. Meredith, 2014. Optimising environmental watering of floodplain wetlands for fish. *Freshwater Biology*: in press.

Bertozzi, T., M. Adams and K. F. Walker, (2000). Species boundaries in carp gudgeons (Eleotrididae: *Hypseleotris*) from the River Murray, South Australia: evidence for multiple species and extensive hybridization. *Marine and Freshwater Research* **51**: 805–815.

Bice, C., P. Wilson and Q. Ye (2008). Threatened fish populations in the Lower Lakes of the River Murray in spring 2007 and summer 2008. SARDI Aquatic Sciences, Adelaide, 39.

Bice, C., M. Hammer, P. Wilson and B. Zampatti, (2011). Fish monitoring for the 'Drought Action Plan for South Australian Murray-Darling Basin threatened freshwater fish populations': summary for 2010/11. SARDI Aquatic Sciences, Adelaide, 214.

Bice, C., N. Whiterod, B. Zampatti and M. Hammer, (2014). The Critical Fish Habitat Project: Assessment of reintroduction success of threatened species in the Coorong, Lower Lakes and Murray Mouth region 2011–2014. SARDI Aquatic Sciences, Adelaide, 39.

Brauer, C. J., P. J. Unmack, M. P. Hammer, M. Adams and L. B. Beheregaray, (2013). Catchment-scale conservation units identified for the threatened Yarra pygmy perch (*Nannoperca obscura*) in highly modified river systems. *PLoS One 8*:e82953.

Cooke, S. J., C. Paukert and Z. Hogan, (2012). Endangered river fish: factors hindering conservation and restoration. *Endangered Species Research* **17**: 179–191.

Ellis, I. and M. Kavanagh, (2014). A review of the biology and status of the endangered Murray hardyhead: streamlining recovery processes. The Murray–Darling Freshwater Research Centre 57.

Ellis, I. M., D. Stoessel, M. P. Hammer, S. D. Wedderburn, L. Suitor and A. Hall, (2013). Conservation of an inauspicious endangered freshwater fish, Murray hardyhead (*Craterocephalus fluviatilis*), during drought and competing water demands in the Murray–Darling Basin, Australia. *Marine and Freshwater Research* **64**: 792–806.

Fratto, Z. W., V. A. Barko and J. S. Scheibe, (2008). Development and efficacy of a bycatch reduction device for Wisconsin-type fyke nets deployed in freshwater systems. *Chelonian Conservation and Biology* **7**: 205–212.

Hammer, M. (2001). Molecular systematics and conservation biology of the southern pygmy perch *Nannoperca australis* (Günther, 1861) (Teleostei: Percichthyidae) in south-eastern Australia. B. Sc. (Honours), The University of Adelaide.

Hammer, M. (2007). Report on urgent conservation measures and monitoring of Southern Purple-spotted Gudgeon on the River Murray, South Australia. Aquasave Consultants, Adelaide, 15.

Hammer, M., T. Barnes, L. Piller and D. Sortino, (2012). Reintroduction Plan for the Purple-spotted Gudgeon in the Southern Murray–Darling Basin. Aquasave Consultants, Adelaide, 52.

Hammer, M. and S. Wedderburn, (2008). The threatened Murray hardyhead: natural history and captive rearing. *Fishes of Sahul* **22**: 390–399.

Hammer, M., S. Wedderburn and J. van Weenan, (2009). Action Plan for South Australian Freshwater Fishes. Native Fish Australia (SA), Adelaide.

Hammer, M. P., C. M. Bice, A. Hall, A. Frears, A. Watt, N. S. Whiterod, L. B. Beheregaray, J. O. Harris and B. P. Zampatti, (2013). Freshwater fish conservation in the face of critical water shortages in the southern Murray–Darling Basin, Australia. *Marine and Freshwater Research* **64**: 807–821.

Hammer, M. P., P. J. Unmack, M. Adams, J. B. Johnson & K. F. Walker, (2010). Phylogeographic structure in the threatened Yarra pygmy perch *Nannoperca obscura* (Teleostei: Percichthyidae) has major implications for declining populations. *Conservation Genetics* **11**: 213–223.

Houde, E. D. (1987). Fish early life history dynamics and recruitment variability. *American Fisheries Society Symposium* **2**: 17–29.

Humphries, P. (1995). Life history, food and habitat of southern pygmy perch, *Nannoperca australis*, in the Macquarie River, Tasmania. Marine and Freshwater Research 46:1159–1169.

Kingsford, R., K. Walker, R. Lester, P. Fairweather, J. Sammut and M. Geddes, (2011). A Ramsar wetland in crisis - the Coorong, Lower Lakes and Murray Mouth, Australia. *Marine and Freshwater Research* **62**: 255–265.

Koehn, J. D. and M. Lintermans, (2012). A strategy to rehabilitate fishes of the Murray–Darling Basin, south-eastern Australia. *Endangered Species Research* **16**: 165–181.

Lintermans, M. (2007). Fishes of the Murray–Darling Basin: An Introductory Guide, MDBC Publication No. 10/07 edn. Murray–Darling Basin Commission, Canberra.

Lintermans, M. (2013). A review of on-ground recovery actions for threatened freshwater fish in Australia. *Marine and Freshwater Research* **64**: 775–791.

Llewellyn, L. C. (1974). Spawning, development and distribution of the southern pigmy perch *Nannoperca australis australis* Günther from inland waters in eastern Australia. *Australian Journal of Marine and Freshwater Research* **25**: 121–149.

Maunsell (2009). Lower Lakes, Coorong and Murray Mouth Condition Monitoring Plan. Report prepared for the South Australian Murray–Darling Basin Natural Resources Management Board. Adelaide.

MDBA (2014). Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan. Murray–Darling Basin Authority, Canberra, 127.

Nicol, J. M., S. L. Gehrig, K. A. Frahn and A. D. Strawbridge, (2013). Resilience and resistance of aquatic plant communities downstream of Lock 1 in the Murray River. Goyder Institute for Water Research, Adelaide, 57.

Robinson, W. (2013). The Living Murray: Towards Assessing Whole of Icon Site Condition. Murray Darling Basin Authority, Canberra, 122.

Saddlier, S. and M. Hammer, (2010). National Recovery Plan for the Yarry Pygmy Perch *Nannoperca obscura*. Department of Sustainability and Environment, Melbourne.

Saddlier, S., J. Koehn and M. Hammer, (2013). Let's not forget the small fishes: conservation of two threatened species of pygmy perch in south-eastern Australia. *Marine and Freshwater Research* **64**: 874–886.

Stoessel, D., I. Ellis and M. Riederer, (in prep). Revised National Recovery Plan for the Murray hardyhead *Craterocephalus fluviatilis*. Department of Environment and Primary Industries, Melbourne.

Tonkin, Z., A. J. King and J. Mahoney, (2008). Effects of flooding on recruitment and dispersal of the Southern Pygmy Perch (*Nannoperca australis*) at a Murray River floodplain wetland. *Ecological Management and Restoration* **9**: 196–201.

Unmack, P. J., M. P. Hammer, M. Adams, J. B. Johnson and T. E. Dowling, (2013). The role of continental shelf width in determining freshwater phylogeographic patterns in south-eastern Australian pygmy perches (Teleostei: Percichthyidae). *Molecular Ecology* **22**: 1683–1699.

Wedderburn, S. and T. Barnes, (2009). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2008–2009). The University of Adelaide, Adelaide, 40.

Wedderburn, S. and T. Barnes, (2011). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2010–2011). The University of Adelaide, Adelaide, 41.

Wedderburn, S. and T. Barnes, (2012). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2011–2012). The University of Adelaide, Adelaide, 64.

Wedderburn, S. and T. Barnes, (2013). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2012–2013). The University of Adelaide, Adelaide.

Wedderburn, S. and T. Barnes, (2014). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2013–2014). The University of Adelaide, Adelaide.

Wedderburn, S. and M. Hammer, (2003). The Lower Lakes Fish Inventory: Distribution and Conservation of Freshwater Fishes of the Ramsar Convention Wetland at the Terminus of the Murray Darling Basin, South Australia. Native Fish Australia (SA), Adelaide, 38.

Wedderburn, S. and K. Hillyard, (2010). Condition Monitoring of Threatened Fish Species at Lake Alexandrina and Lake Albert (2009–2010). The University of Adelaide, Adelaide, 42.

Wedderburn, S., R. Shiel, K. Hillyard and J. Brookes, (2010). Zooplankton Response to Watering of an Off-channel Site at the Lower Lakes and Implications for Murray hardyhead Recruitment. The University of Adelaide, Adelaide, 52.

Wedderburn, S. D. (2008). Population fragmentation in the Murray hardyhead *Craterocephalus fluviatilis* McCulloch, 1912 (Teleostei: Atherinidae): ecology, genetics and osmoregulation. PhD thesis, The University of Adelaide, Adelaide.

Wedderburn, S. D., T. C. Barnes and K. A. Hillyard, (2014). Shifts in fish assemblages indicate failed recovery of threatened species following prolonged drought in terminating lakes of the Murray–Darling Basin, Australia. *Hydrobiologia* **730**: 179–190.

Wedderburn, S. D., M. P. Hammer and C. M. Bice, (2012). Shifts in small-bodied fish assemblages resulting from drought-induced water level recession in terminating lakes of the Murray–Darling Basin, Australia. *Hydrobiologia* **691**: 35–46.

Wedderburn, S. D., K. A. Hillyard and R. J. Shiel, (2013). Zooplankton response to flooding of a drought refuge and implications for the endangered fish species *Craterocephalus fluviatilis* cohabiting with alien *Gambusia holbrooki*. *Aquatic Ecology* **47**: 263–275.

Wedderburn, S. D. and K. F. Walker, (2008). Osmoregulation in populations of an endangered hardyhead (Atherinidae: *Craterocephalus fluviatilis* McCulloch, 1912) from different salinity regimes. *Ecology of Freshwater Fish* **17**: 653–658.

Woodward, G. M. A. & B. S. Malone, (2002). Patterns of abundance and habitat use by *Nannoperca obscura* (Yarra pygmy perch) and *Nannoperca australis* (southern pygmy perch). *Proceedings of the Royal Society of Victoria* **114**: 61–72.

Zampatti, B., C. Bice & P. Jennings, (2010). Temporal variability in fish assemblage structure and recruitment in a freshwater deprived estuary: The Coorong, Australia. *Marine and Freshwater Research* **61**: 1298–1312.

Appendix

Highest priority sites for consideration in future TLM Condition Monitoring in the Lower Lakes.

Site	**Site description**	**Threatened fish species present**		
		2001 to 2005 (Wedderburn and Hammer 2003; Wedderburn 2008)	**2007 to 2013** (TLM Condition Monitoring and CFH sampling)	**Autumn 2014**
1	Boundary Creek	Not sampled	MH, YP, SP	Not sampled
2	Wyndgate, Hindmarsh Island	MH, YP, SP	SP[2]	None
3[1]	Hunter's Creek upstream	MH, YP, SP	None	None
5[1]	Steamer Drain	MH, YP, SP	MH, SP, YP[2]	None
10	Dunn Lagoon 1	MH	MH	None
14[1]	Goolwa Channel–Currency Ck (S)	Not sampled	MH	MH
16	Lake Albert–Narrung	Not sampled	None	None
18[1]	Goolwa Channel–Finniss River (S)	Not sampled	MH	MH
22	Mundoo Island 1	SP	SP	SP
25	Dog Lake	Not sampled	MH	MH
26	Old Clayton	Not sampled	MH	MH
31	Boggy Creek (N)	Not sampled	MH	None
32	Mundoo Island 2	Not sampled	MH, MH[2]	MH
34	Shadows Lagoon	Not sampled	SP, YP[2]	YP[2]
37[1]	Turvey's drain	SP	MH, SP, SP[2]	None
38[1]	Black Swamp	SP, YP	SP	None
48	Lake Albert–Waltowa	MH	None	None
62	Lake Albert–Belcanoe	MH	None	None
71[3]	Shadows Lagoon channel (S)	Not sampled	Not sampled	None
74[3]	Boggy Creek (S)	Not sampled	Not sampled	None
75	Currency Creek (S/W)	Not sampled	Not sampled	MH
84[3]	Boggy Lake–Mosquito Creek	Not sampled	Not sampled	None
86	Goolwa Channel–Goolwa Barrage	Not sampled	Not sampled	MH
87[3]	Lake Albert–Narrows confluence	Not sampled	Not sampled	None
91[3]	Lake Albert–south shore	Not sampled	Not sampled	None
92[3]	Loveday Bay (N)	Not sampled	Not sampled	None
96	Hindmarsh Island–north boat ramp	Not sampled	Not sampled	MH
104[1]	Hunters Creek downstream	SP, YP	SP	None
106[1]	Holmes Creek–Eastick Creek	Not sampled	MH, SP	None

[1] Sites sampled under the CFH project.
[2] Fish re-captured at CFH project reintroduction sites.
[3] Threatened fish not captured but habitat suitable for at least one threatened species.

Moderate priority sites for consideration in future TLM Condition Monitoring in the Lower Lakes.

Site	Site description	Threatened fish species present		
		2001 to 2005 (Wedderburn and Hammer 2003; Wedderburn 2008)	**2007 to 2013** (TLM Condition Monitoring and CFH sampling)	**Autumn 2014**
6	Holmes Creek–Boggy Creek	Not sampled	MH	MH
11	Dunn Lagoon 2	Not sampled	MH	None
15	Angas River mouth	Not sampled	SP	None
19	Bremer River mouth	Not sampled	MH	None
30	Mundoo Island–Boundary Creek	Not sampled	MH	None
35	Mundoo Island (channel junction)	Not sampled	SP	None
49[3]	Lake Albert–Nindethana	Not sampled	None	None
66	Pelican Lagoon 2	None	Not sampled	None
68	Shadows Lagoon (S/W)	Not sampled	Not sampled	None
76	Currency Creek (N/W)	Not sampled	Not sampled	MH
77	Currency Creek (N/E)	Not sampled	Not sampled	MH
78	Goolwa Channel–Currency Ck (N)	Not sampled	Not sampled	MH
79	Goolwa Channel–Hindmarsh Is	Not sampled	Not sampled	MH
85[3]	Clayton Bay	Not sampled	Not sampled	None
93	Loveday Bay–Wamwarrum	MH	Not sampled	None
98	Boggy Lake	MH	Not sampled	None
105[1]	Drain behind Wyndgate	SP, YP	None	None
107[1]	Mundoo Island 3	Not sampled	SP[2]	None

[1] Sites sampled under the CFH project.
[2] Fish re-captured at CFH project reintroduction sites.

Lowest priority sites for consideration in future TLM Condition Monitoring in the Lower Lakes.

Site	Site description	Threatened fish species present		
		2001 to 2005 (Wedderburn and Hammer 2003; Wedderburn 2008)	**2007 to 2013** (TLM Condition Monitoring and CFH sampling)	**Autumn 2014**
4	Holmes Creek–Fish trap Creek	Not sampled	MH	None
9	Finniss River–Wally's Wharf	None	MH	None
20	Nalpa Station	None	None	None
27	Milang	Not sampled	MH	None
28	Point Sturt	Not sampled	None	None
29	Poltalloch	Not sampled	None	None
36	Campbell House (Lake Albert)	Not sampled	MH	None
44	Hindmarsh Island bridge	Not sampled	MH	None
60	Dunn Lagoon 3	Not sampled	None	None
65	Pelican Lagoon 1	Not sampled	Not sampled	None
67[3]	Shadows Lagoon (N/W)	Not sampled	Not sampled	None
69	Shadows Lagoon (N)	Not sampled	Not sampled	None
70	Shadows Lagoon (E)	Not sampled	Not sampled	None
72	Shadows Lagoon channel (N)	Not sampled	Not sampled	None
73	Steamer Drain–Hunters Creek	Not sampled	Not sampled	None
80	Goolwa Channel–Finniss River (N)	Not sampled	Not sampled	None
81	East of Dunn Lagoon	Not sampled	Not sampled	None
82	Hindmarsh Island east shoreline	Not sampled	Not sampled	None
83	Holmes Creek	Not sampled	Not sampled	None
88	Lake Albert–Narrung Narrows 1	Not sampled	Not sampled	None
89	Lake Albert–Narrung Narrows 2	Not sampled	Not sampled	None
90	Lake Albert–Meningie	None	Not sampled	None
94	Loveday Bay (S)	Not sampled	Not sampled	None
95	Goolwa Channel–north boat ramp	Not sampled	Not sampled	None
97	Holmes Creek–Lake Alexandrina	Not sampled	Not sampled	None
101[1]	Blue Lagoon 1	Not sampled	None	None
102[1]	Blue Lagoon 2	Not sampled	None	None
103[1]	Channel off Hunters Creek	Not sampled	None	None

[1] Sites sampled under the CFH project.
[3] Threatened fish not captured but habitat suitable for at least one threatened species.