


Condition Monitoring of Threatened Fish Populations in Lake Alexandrina and Lake Albert

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

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Summary

The objective of this condition monitoring was to assess the status of three threatened fish populations in Lake Alexandrina and Lake Albert, namely Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscura*) and southern pygmy perch (*N. australis*). The assessment was made partly by relating current distributions to the 2003 baseline when healthy threatened fish populations were present, and by comparing with the populations in March 2016. The project aimed to make the assessment by (1) determining the Relative Abundance Index (RAI) for each threatened fish species at the icon site level, (2) determining the Young-of-the-Year Index (YOYI) for each threatened fish species at the icon site level, and (3) combining the RAI and YOYI to determine a Whole of Icon Site Score (WOISS) for populations of each threatened fish species.

The repeated sample technique was extended from two to three sampling events in March 2017 based on the results from March 2016 condition monitoring, which found further sampling was required to account for probability of detection (i.e. to account for false absences) of southern pygmy perch. The third sample was necessary to gain the level of statistical robustness required for monitoring by the MDBA as determined in the refinement of the condition monitoring methods several years ago. Fish were sampled using a seine net on two occasions (samples A and B) at 20 sites and on three occasions using fyke nets (samples A, B and C) in March 2017. Key habitat variables were also measured.

A total of 18,537 fish were captured, represented by 19 native and four alien species. Murray hardyhead was recorded in both repeated samples using the seine method, but in very low abundances. Southern pygmy perch was recorded in all three repeated samples using fyke nets, with numbers substantially higher than in March 2016. Southern pygmy perch was associated with well-vegetated channel sites. Murray hardyhead showed no correlation with any particular habitat type, possibly due to the low numbers sampled or because it was widely dispersed in March 2017. Yarra pygmy perch was undetected. Alien fish dominated the catch – extremely high abundances of eastern gambusia (*Gambusia holbrooki*) were recorded, especially in habitats that were suitable for the pygmy perches. When co-occurring, southern pygmy perch and eastern gambusia inhabited well-vegetated drainage channels and wetlands.

Murray hardhead and southern pygmy perch each had a RAI value of 1.00, which indicates that current populations have a distribution similar to the 2003 baseline condition, and the Condition Monitoring RAI target was met. The YOYI value of 0.94 met the target and indicates that Murray hardyhead underwent suitable recruitment over 2016–17. The YOYI value of 0.30 for the southern pygmy perch (0.30) population failed the target and suggests recruitment over 2016–17 was limited (unknown factors). The WOISS of 0.97 ±0.19 for Murray hardyhead meets the target (i.e. WOISS >0.5). The WOISS of 0.65 ±0.38 for southern pygmy perch may be acceptable, but fails the target if the true value lies at the lower end of the tolerance. The WOISS for Yarra pygmy perch is zero, which fails the target.

Introduction

Lake Alexandrina and Lake Albert (the 'Lower Lakes') are shallow waterbodies covering over 75,000 hectares at the terminus of the Murray–Darling Basin (MDB) (Eastburn 1990). A range of habitats fringe the Lower Lakes, including stream, river, swamp, wetland, lake and brackish water areas (estuarine conditions). The broad characteristics (e.g. salinities) of Lake Albert differ somewhat from Lake Alexandria because it is has no flow through to the Coorong lagoons. The Lower Lakes harbour the most diverse fish community in the MDB, because they are inhabited by estuarine, diadromous and freshwater fishes. Also of particular interest are three threatened small-bodied (<8 cm long), short-lived species, namely Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscura*) and southern pygmy perch (*N. australis*) (Wedderburn and Hammer 2003; Wedderburn et al. 2012). The status of the threatened fishes has been assessed since 2007–08 under The Living Murray (TLM) initiative of the Murray–Darling Basin Authority (MDBA).

The genetically distinct population of Yarra pygmy perch occurs nowhere else in the MDB (Hammer et al. 2010). The species was extirpated from Lake Alexandrina during the 1997–2010 drought in south-eastern Australia (Wedderburn et al. 2014; Wedderburn et al. 2012). Yarra pygmy perch 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. 2013; Wager and Jackson 1993). An attempt to reintroduce Yarra pygmy perch to the MDB in 2012–13 appears unsuccessful (Bice et al. 2014; Wedderburn 2014). A second attempt to reintroduce Yarra pygmy perch in November 2015 also had limited success, but on this occasion factors potentially associated with recovery (e.g. water levels, food availability, predation, competition) were examined through an intervention monitoring project (Wedderburn et al. 2016). Findings of the study suggest the proliferation of alien eastern gambusia (*Gambusia holbrooki*) may be a significant factor impacting on the recovery of Yarra pygmy perch because they consume many of the same prey.

Southern pygmy perch is 'Endangered' in South Australia (Hammer et al. 2009). Importantly, the southern pygmy perch population in Lake Alexandrina is genetically unique from other populations in Australia (Unmack et al. 2013). The species was extirpated from the lake during the Millennium Drought (Wedderburn et al. 2014). Populations persisted in tributaries of the lake (Hammer et al. 2012; Whiterod et al. 2015), thereby providing the possibility of natural recovery. Southern pygmy perch reintroduced to the Hindmarsh Island region in 2011 and 2012 persist with limited wild recruitment (Bice et al. 2014; Wedderburn and Barnes 2014). The distribution and abundance of southern pygmy perch has increased in recent years (Wedderburn and Barnes 2016).

Murray hardyhead is 'Critically Endangered' in South Australia (Hammer et al. 2009) and 'Endangered' under the EPBC Act due to severe population decline and localised extinctions during the Millennium Drought. Substantial effort was made during the drought to maintain each genetic management unit in a captive breeding program and surrogate refuge dams (Ellis et al. 2013). Likewise, a population of Murray hardyhead was conserved in a drought refuge of the lakes using environmental water allocations through the TLM initiative (Wedderburn et al. 2013). The abundance of Murray hardyhead has increased in the Lower Lakes over recent years, but its distribution is still limited to Lake Alexandrina (Wedderburn and Barnes 2016).

The current monitoring program relates to the Lower Lakes, Coorong and Murray Mouth (LLCMM) Environmental Water Management Plan (MDBA 2014), and the refined LLCMM Condition Monitoring Plan (CMP) objective (F2) to "*Ensure recruitment success of threatened small-bodied fish species in the Lower Lakes to maintain or establish self-sustaining populations*". The sampling and measures of condition for each of the threatened small-bodied fish populations in March 2017 are similar to the last assessment by Wedderburn and Barnes (2016), except they have been improved to optimise the estimate of occupancy of southern pygmy perch. Specifically, there are three instead of two repeated samples using fyke nets, which were undertaken at 17 sites in March 2017 in habitats fringing Lake Alexandrina. Analyses of the data from March 2016 showed that two repeated samples using seine netting was adequate to gain an estimate of occupancy for Murray hardyhead. Therefore, two repeated samples using seine netting were conducted at the same 17 sites in Lake Alexandrina and three sites in Lake Albert.

The objective of the condition monitoring was to assess the status of each of the three threatened fish populations using three scores. First, recruitment success of the threatened fishes in the Lower Lakes was assessed using a Young-of-the-Year Index (YOYI). Second, the current extent of each threatened fish population was also assessed against the 2003 baseline (Wedderburn and Hammer 2003) using a Relative Abundance Index (RAI), which took into account the estimate of occupancy from the repeated samples. Third, the YOYI and RAI values were formulated to determine the Whole of Icon Site Score (WOISS) for each threatened fish species. Ultimately, the WOISS value determines if the CMP objective (F2) has been achieved.

The project also records the distribution and abundances of other cohabiting fish species, partly to identify potential threats. For example, the presence and abundance of alien fishes are discussed, including the aggressive and prolific eastern gambusia (*Gambusia holbrooki*) and the piscivorous redfin perch (*Perca fluviatilis*). Habitat characteristics were also measured, to identify patterns between threatened fish populations and the environmental conditions.

Materials and methods

Fish sampling

Twenty sites were sampled three times in March 2017, herein referred to as samples A, B and C (Table 1). Subsequent samples at each site occurred within seven days of the last sample. Three single-leader fyke nets (5-mm half mesh) were set overnight at 17 sites in Lake Alexandrina on three occasions (samples A, B and C), and placed 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 seine shots were taken at each of 20 sites, which included the 17 fyke netting sites and three sites in Lake Albert, within 10 m of the shoreline (seine net: 7 m long × 1.5 m deep; 5-mm half mesh) on two occasions (samples A and B). Fish were identified to species and counted. Total lengths (TL) of threatened fish were measured to the nearest millimetre.

Table 1. Sites sampled in March 2017 (UTM zone 54H, WGS84).

Site	Site description	Easting	Northing	Habitat type
2	Wyndgate (early reintroduction site)	309485	6066535	Drainage line
3	Hunters Creek (upstream Denver Rd)	309489	6066309	Natural channel
5	Channel off Steamer Drain	310426	6066005	Modified channel
10	Dunn Lagoon	312568	6070380	Wetland
16*	Narrung (Lake Albert)	334667	6068532	Wetland
22	Mundoo Island	311065	6064130	Drainage line
25	Dog Lake	329963	6084901	Wetland
26	Old Clayton	310519	6070104	Natural channel
30	Mundoo Island–Boundary Creek	313752	6063750	Drainage line
31	Boggy Creek	312194	6067197	Modified channel
32	Mundoo Island	312275	6064403	Drainage line
34	Shadows Lagoon	311165	6067555	Wetland
38	Black Swamp	304679	6076719	Wetland
48*	Waltowa (Lake Albert)	352876	6058248	Wetland
62*	Belcanoe (Lake Albert)	337274	6052900	Wetland
68	Shadows Lagoon–Hunters Creek	310784	6067009	Wetland
71	Shadows Lagoon channel (S)	311250	6067348	Artificial channel
73	Hunters Creek–Steamer Drain	310038	6066429	Natural channel
75	Currency Creek	302267	6071370	Wetland
86	Goolwa Channel (upstream of barrage)	300622	6066308	Natural channel

* Seine sampling method used only.

Habitat measures

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

- Salinity as Total Dissolved Solids (TDS)
- Electrical Conductivity units (EC)
- pH
- Temperature (°C)

Several other habitat variables were recorded, chosen based on their potential importance to threatened fish populations:

- 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
- Riparian vegetation: estimated percentage covering ground
- Aquatic plant cover: estimated percentage covering sediment
- Habitat type: natural channel (usually >10 m wide), modified channel (<10 m wide; includes natural drainage lines that have been excavated), lake, wetland

Data analyses and interpretation

To examine the links between fish assemblages and habitat, fyke net sampling data was analysed by Non-metric Multi-dimensional Scaling (NMS) ordination using the Relative Sørensen distance metric in PC-ORD (ver. 6: McCune and Mefford 2011). Therefore, the ordination includes only the 17 sites fringing Lake Alexandrina where fyke nets were used, and excludes the three sites in Lake Albert which were sampled only using seine netting.

The first use of the refined condition monitoring method demonstrated that a repeated sample strategy provided an estimate for occupancy that was more accurate than naïve occupancy obtained in single sample monitoring (Wedderburn and Barnes 2016). In the March 2016 condition monitoring, the analysis for southern pygmy perch showed that the optimal strategy is three repeated samples with fyke netting to accurately estimate occupancy (Guillera-Arroita et al. 2010). The sampling design used in March 2016 was optimal for Murray hardyhead, with three seine shots at 20 sites in two repeated samples, so has been maintained in the March 2017 condition monitoring.

Estimation of occupancy, defined as the proportion of sites occupied by a species, was based on data from repeated samples at each site. The repeated sampling approach was necessary because species detection is generally imperfect, which can lead to the incorrect classification of occupied sites as empty. If imperfect detection is not accounted for, bias is induced in the occupancy estimator. The data were analysed using occupancy models based on zero-inflated binomial models (Mackenzie et al. 2006; Royle and Dorazio 2008). These models aim to estimate site occupancy while accounting for imperfect detection, and provide more rigorous comparisons among sites, or between sampling times at each site. The models allow the separate estimation of occupancy and detectability on a logit scale. Estimates of each parameter (and 95% confidence intervals) were then back-transformed to the probability scale.

Condition indicators of threatened fish populations

Values for condition indicators of threatened fish populations were calculated based on the methods detailed in the Condition Monitoring Refinement Project (Robinson 2015; Wedderburn 2015) and used for the March 2016 condition monitoring assessment (Wedderburn and Barnes 2016).

Relative Abundance Index

The Relative Abundance Index (RAI) assesses the extent of a threatened fish population in relation to the 2003 baseline condition when healthy fish populations occurred before the impacts of the Millennium Drought (Wedderburn and Hammer 2003). The RAI uses the proportion of sites recorded in the baseline for Yarra pygmy perch (8/43 sites = 0.19), southern pygmy perch (6/43 sites = 0.14), and Murray hardyhead (10/43 sites = 0.23).

RAI = proportion of sites recorded /proportion of sites recorded in baseline

The RAI is ceiled at 1.0 to correspond with the maximum of 1.0 for the YOYI, for the purpose of aggregating the values of both indices (see below). The CMP target is RAI >0.7 for all threatened fish populations in the lakes.

Young-of-the-Year Index

Young-of-the-Year (YOY) is defined as fish in their first year of life, and total length is recorded as a surrogate measure of age: Murray hardyhead YOY <50 mm TL; southern pygmy perch YOY<40 mm TL; Yarra pygmy perch YOY<40 mm TL.

The Young-of-the-Year Index (YOYI) taken in March indicates the level of successful recruitment within a threatened fish population (breeding occurs in spring for all species). The CMP target is YOYI >0.5 for Murray hardyhead (annual life cycle) and YOYI >0.3 for the pygmy perches (live for up to 4 years).

YOYI = number of YOY/total number of fish

Whole of Icon Site Score

A Whole of Icon Site Score (WOISS) with a tolerance (95% confidence intervals) will be determined for each threatened fish species by averaging the RAI and YOYI:

WOISS = (RAI + YOYI)/2

The tolerance of the WOISS is calculated using the variances of the RAI and YOYI:

WOISS Variance = VAR(RAI) + VAR(YOYI)

Tolerance = $t \times \sqrt{\mathrm{Var(WOISS)}}$, where $t = t_{0.05,\ n\ \mathrm{df}}$

The CMP target is WOISS >0.5 for each threatened fish species.

Results

Water quality

In March 2017, salinities of sites fringing Lake Albert ranged from 1354 EC at Belcanoe to 15,330 EC at Narrung (Table 2). At the same time, salinities at sites fringing Lake Alexandrina varied from 508 EC at Dunn Lagoon to 1741 EC at Shadows Lagoon, with higher readings of up to 6620 EC in the Goolwa Channel above the Goolwa Barrage. In sample A, the mean salinities of sites in Lake Albert and Lake Alexandrina were 2206 EC and 829 EC, respectively. In sample B, the mean salinities at sites in Lake Albert and Lake Alexandrina were 6843 EC and 1208 EC, respectively. In sample C, the mean salinity at sites in Lake Alexandrina was 1104 EC. Sites in Lake Albert were not sampled a third time.

In March 2017, readings ranged from pH 6.82 in the channel off Hunters Creek on Hindmarsh Island to pH 9.42 at Narrung. Secchi depth varied substantially, ranging from 15 cm where Shadows Lagoon meets Hunters Creek to >73 cm in an artificial channel off Shadows Lagoon. Water temperatures at sites ranged between 17.6ºC and 26.6ºC throughout the sampling.

Processing fyke net catch in Hunters Creek (site 3) in March 2017 (Photos: Owen Love).

Table 2. Water quality for samples A, B and C in March 2017 condition monitoring of threatened fishes in the Lower Lakes (NS = not sampled).

Site	Salinity (TDS)			Conductivity (µS/cm)			pH			Secchi (cm)			Temperature (ºC)		
	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
2	526	578	643	764	878	967	6.82	6.74	6.94	>64	42	31	19.1	18.8	19.5
3	466	392	403	728	604	616	7.2	7.27	7.58	41	35	>53	20.1	20.7	18.8
5	344	361	377	527	553	577	7.02	7.02	7.22	48	61	55	19.7	18.9	20.4
10	332	355	362	508	538	546	8.61	8.49	8.98	35	31	29	23.8	20.4	23.5
16	8950	10140	NS	1368	15330	NS	9.42	8.44	NS	23	27	NS	24.9	24.7	NS
22	382	425	465	586	647	730	6.88	6.91	7.05	25	33	15	18.5	18.5	21.5
25	470	477	501	718	729	732	7.79	8.27	6.94	28	20	23	23.6	21.4	26.2
26	332	356	364	515	557	558	8.45	8.48	8.68	38	29	38	22.1	18.9	22.3
30	426	459	583	652	708	902	7.42	7.46	7.49	49	49	36	21.9	19.8	22.4
31	608	643	496	940	984	767	7.93	7.76	7.6	25	55	46	22.4	19.5	20.4
32	421	434	435	646	668	662	7.84	7.94	8.01	33	33	31	19.3	18.7	22
34	925	997	1131	1423	1528	1741	8.08	7.91	7.86	42	42	53	22.5	21.7	20.3
38	885	908	887	1358	1375	1358	8.32	8.28	7.82	52	49	51	21.5	19.6	17.9
48	1656	1615	NS	2547	2535	NS	7.55	7.24	NS	12	>19	NS	23.5	23.3	NS
62	1769	1747	NS	2702	2663	NS	8.31	8.17	NS	28	20	NS	25	26.6	NS
68	897	954	1168	1354	1438	1797	7.41	7.36	7.2	18	15	28	19.8	18.8	19.8
71	908	941	685	1382	1449	1058	7.44	7.87	7.62	>66	35	>73	20.1	20.9	19.1
73	351	381	391	539	600	600	7.57	7.42	6.96	40	24	29	21.4	21.6	20.3
75	439	430	440	679	660	674	8.31	8.75	8.57	24	20	24	19.9	18.6	17.9
86	513	4140	2970	782	6620	4480	7.87	8.34	8.64	20	33	31	21.4	17.6	18.8

Physical habitat

As reflected by the proportions of aquatic plants, most sites were well-vegetated in March 2017 (Table 3). All sites were inhabited by cumbungi (*Typha domingensis*) at the fringes, where river club rush (*Scheonoplectus validus*) often occurred. Hornwort (*Ceratophyllum demersum*) was the predominant submerged plant, and was recorded at most sites. Hornwort was especially thick in channel sites on Hindmarsh Island, where it sometimes congested most of the volume of water (sites 2, 31, 38 and 73). Water milfoil (*Myriophyllum* spp) was recorded at numerous sites, including all three sites in Lake Albert. Ribbon weed (*Vallisneria americana*) was common in shallow wetland sites on Hindmarsh Island, and was particularly abundant at site 34 Shadows Lagoon.

Mean water depth ranged between 19 cm at Waltowa to 109 cm at Black Swamp in March 2017. The channel sites generally were deeper than wetland habitats, except the deeper wetland habitat in Black Swamp is a reflection the site's proximity to the channel of the Finniss River. Wetland sites in other areas of the lakes had a mean water depth of <71 cm in March 2017.

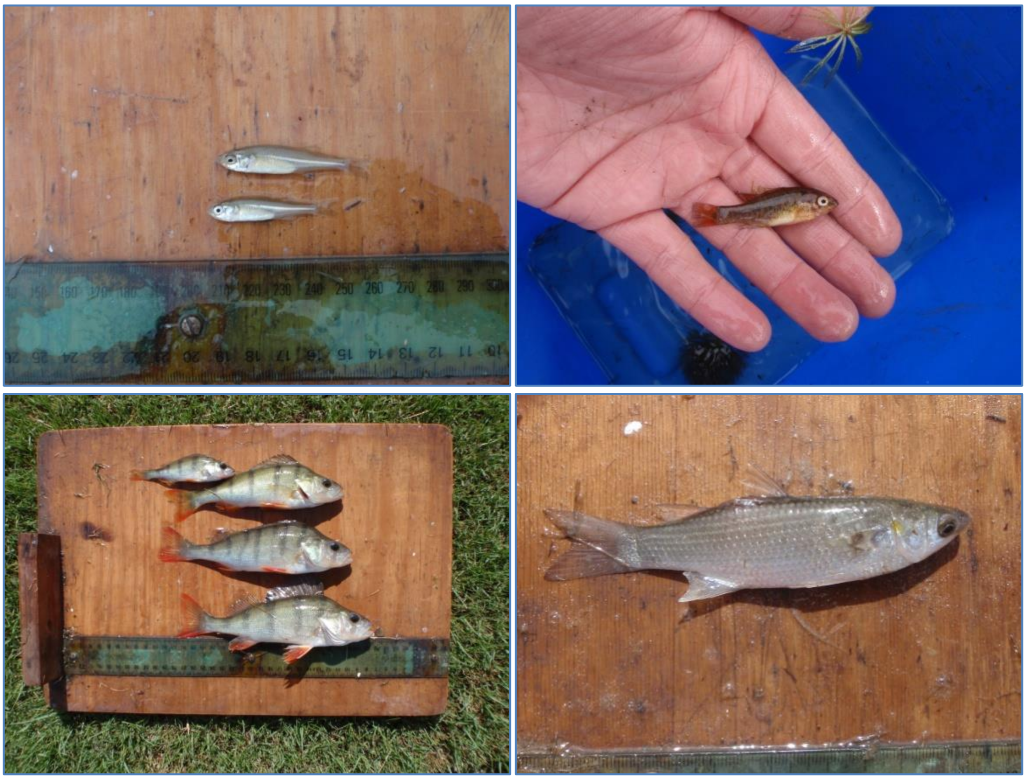
Table 3. Physical habitat readings for samples A, B and C in March 2017 (NS = not sampled).

Site	Mean depth (cm)			Aquatic plants (%)			Habitat type
	A	B	C	A	B	C	
2	56	52	51	100	90	95	Drainage line
3	42	44	39	85	90	95	Natural channel
5	56	62	66	97	100	60	Modified channel
10	35	39	29	70	47	40	Wetland
16	68	70	NS	82	75	NS	Wetland
22	38	53	61	70	81	90	Drainage line
25	36	27	40	33	27	22	Wetland
26	29	30	36	32	30	50	Natural channel
30	63	52	45	44	32	21	Drainage line
31	56	88	65	85	66	82	Modified channel
32	61	59	53	25	40	40	Drainage line
34	54	42	41	60	41	60	Wetland
38	93	104	109	90	95	95	Wetland
48	21	19	NS	90	80	NS	Wetland
62	38	42	NS	58	60	NS	Wetland
68	40	40	54	72	80	75	Wetland
71	51	62	62	97	91	96	Artificial channel
73	102	98	96	100	100	100	Natural channel
75	38	30	33	40	55	40	Wetland
86	28	33	41	50	50	25	Natural channel

Fish assemblages

Condition monitoring undertaken in March 2017 recorded a total of 18,537 fish comprising of 19 native and four alien species (Table 4). Murray hardyhead was recorded at four sites in samples A and B. Southern pygmy perch was recorded at six sites in sample A and five sites in samples B and C. Yarra pygmy perch was undetected. Alien fish dominated the catch in March 2017 (75% of total catch) more so than any other year since 2009 (Figure 1). The high proportion of alien fish in March 2017 is predominantly due to high abundances of eastern gambusia (88% of alien fish). Common carp, goldfish and redfin perch constituted only 6%, 2% and 1.4% of the total fish captured. Overall, eastern gambusia comprised 66% of the total catch of fish in March 2017, and was the only fish species captured at all sites.

Estuarine fishes were a considerable proportion of the catch (~60%) at the end of drought in 2010, but constituted only <1% of the total catch in March 2017 due to the much lower salinities. Diadromous fishes have been a considerable component of the fish assemblage since 2013. Since then, the proportion of common galaxias gradually increased to 14% of the total catch in March 2016 but was only 7% in March 2017. Congolli (*Pseudaphritis urvillii*) comprised 0.8% of the total catch in March 2017, which is comparable to the 0.5% in March 2016.



A selection of fish recorded in March 2017 condition monitoring: Murray hardyhead from Boggy Creek (top left); southern pygmy perch from Black Swamp (top right); redfin perch from Shadows Lagoon (bottom left); jumping mullet from the Goolwa Channel (bottom right).

Table 4. Number of sites recorded and total abundance of each fish species captured during condition monitoring in March 2017 (Samples A and B with fyke at 17 sites and seine at 20 sites; sample C with fyke only at 17 sites in Lake Alexandrina).

Common name	Scientific name	Sample A		Sample B		Sampled C	
Native fishes		Number of sites	Total abundance	Number of sites	Total abundance	Number of sites	Total abundance
Southern pygmy perch	*Nannoperca australis*	6	71	5	17	5	26
Yarra pygmy perch	*Nannoperca obscura*	0	0	0	0	0	0
Murray hardyhead	*Craterocephalus fluviatilis*	4	9	4	19	0	0
Unspecked hardyhead	*Craterocephalus fulvus*	8	419	8	249	4	75
Bony herring	*Nematalosa erebi*	11	545	11	568	9	273
Flathead gudgeon	*Philypnodon grandiceps*	13	119	12	144	11	52
Dwarf flathead gudgeon	*Philypnodon macrostomus*	6	23	6	45	4	17
Carp gudgeon	*Hypseleotris* spp.	8	51	6	16	2	8
Australian smelt	*Retropinna semoni*	6	81	5	118	2	4
Golden perch	*Macquaria ambigua ambigua*	5	25	7	27	5	21
Congolli	*Pseudaphritis urvillii*	11	52	8	62	7	35
Common galaxias	*Galaxias maculatus*	15	515	16	445	12	356
Smallmouth hardyhead	*Atherinosoma microstoma*	3	104	2	10	1	1
Blue-spot goby	*Pseudogobius olorum*	4	5	4	9	1	1
Tamar River goby	*Afurcagobius tamarensis*	1	3	0	0	0	0
Lagoon goby	*Tasmanogobius lasti*	1	1	0	0	0	0
Sandy sprat	*Hyperlophus vittatus*	1	1	1	19	0	0
Yellow-eye mullet	*Aldrichetta forsteri*	1	2	0	0	0	0
Jumping mullet	*Liza argentea*	0	0	1	1	0	0
Alien fishes							
Common carp	*Cyprinus carpio*	18	417	17	358	15	331
Goldfish	*Carassius auratus*	13	120	16	132	13	104
Redfin perch	*Perca fluviatilis*	11	106	13	86	11	64
Eastern gambusia	*Gambusia holbrooki*	20	5063	20	3977	15	3135

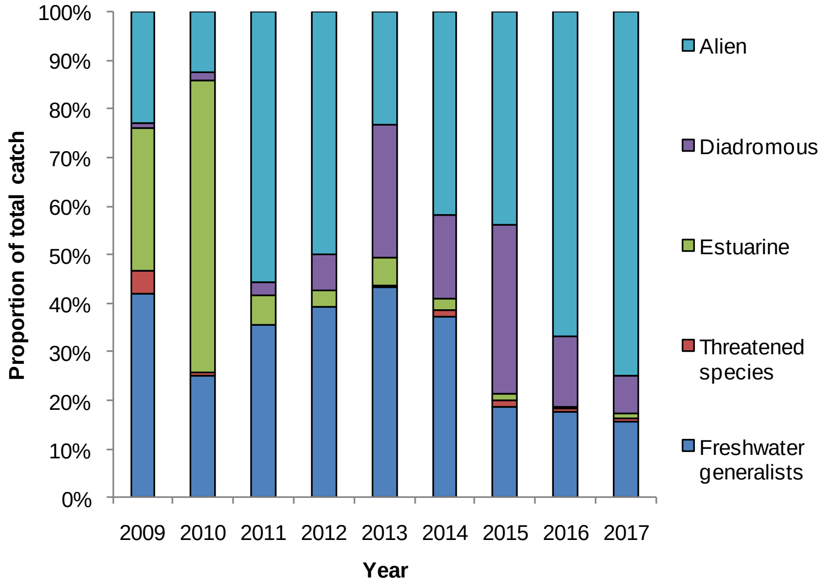
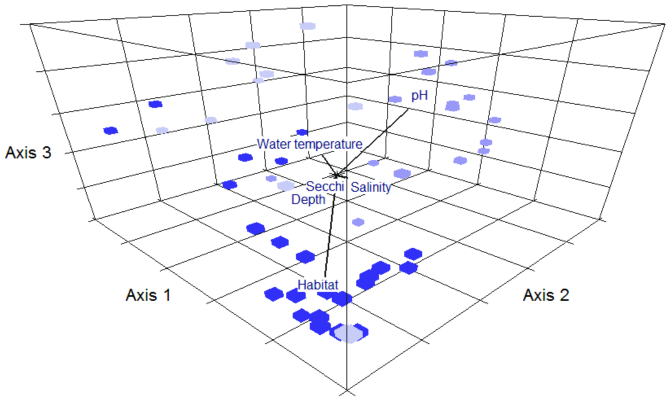


Figure 1. Proportion of major fish groups in condition monitoring each March from 2009 to 2017.

The alien eastern gambusia was prolific in March 2017, comprising 66% of all fish captured.

The three-dimensional ordination highlights the relationship between habitat complexity ('Habitat') and the abundance of eastern gambusia (GAMHOL) mostly in sites on Hindmarsh Island indicated in dark blue points at the bottom of the plot (Figure 2). The ordination also shows that sites near the Goolwa Channel, at the top right of the plot, have higher pH values.

The relatively strong positive correlation for eastern gambusia on Axis 1 suggests an association with sites of high habitat complexity on Hindmarsh Island, of which southern pygmy perch is correlated. Murray hardyhead is not represented in the ordination due to the lack of correlation with any particular group of sites in 2017.



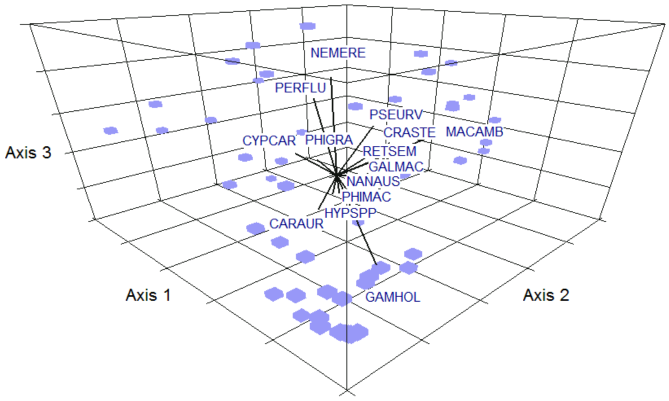


Figure 2. Three-dimensional NMS ordination (stress = 6.9%) of sites based on similarities between fish species composition and abundance. Habitat (top plot) and fish species (bottom plot) are overlaid with the vector length proportional to, and directed towards, their correlation with sites. In the top plot, sites are represented by points with four shades of blue from darkest to lightest associated with Hindmarsh Island, Goolwa Channel, Mundoo Island and Dog Lake, respectively. Fish codes are overlayed in the bottom plot as follows: NEMERE bony bream; PERFLU redfin perch; PSEURV congolli; CRASTE unspecked hardyhead; MACAMB golden perch; CYPCAR common carp; PHIGRA flathead gudgeon; RETSEM Australian smelt; GALMAC common galaxias; NANAUS southern pygmy perch; CARAUR goldfish; HYPSP carp gudgeon; GAMHOL eastern gambusia.

Condition indicators of threatened fish populations

Repeated sample analysis

The estimated values for detection and occupancy for Murray hardyhead using two repeated sample events at 20 sites in March 2016 determine that the survey design was optimum. Based on analysis of two repeated samples using seine netting at 20 sites in the March 2017 condition monitoring, however, the estimate of detection for Murray hardyhead was only 0.333 and has a high level of variation as indicated by the standard error (Table 5). The estimate of occupancy 0.450 for Murray hardyhead in 2017 is higher than the previous year, but the high standard error of 0.320 provides a low level of confidence in the result.

Table 5. Estimates of detection and occupancy of Murray hardyhead in March 2016 and March 2017 condition monitoring from two repeated samples using seine netting at 20 sites.

Year	Detection	±SE	Occupancy	±SE
2016	0.750	0.171	0.267	0.106
2017	0.333	0.248	0.450	0.320

The estimated values for detection and occupancy of the two repeated sample events at 17 sites for southern pygmy perch in March 2016 were used to determine the optimum number of sampling events (there is no value in seine netting to monitor southern pygmy perch: Wedderburn and Barnes 2016). The March 2017 data verify that three replicate fyke netting surveys minimise the variance of the estimate of occupancy and increase the detection of southern pygmy perch (Table 6). By conducting three repeated samples in March 2017 the probability of detection was increased from 0.5 in 2016 to 0.75 in 2017, with a corresponding improvement in variation (reduction in standard error) within the data.

Table 6. Estimates of detection and occupancy of southern pygmy perch in March 2016 and March 2017 from two and three repeated samples, respectively, using fyke nets at 17 sites in Lake Alexandrina.

Year	Detection	±SE	Occupancy	±SE
2016	0.500	0.217	0.400	0.179
2017	0.750	0.101	0.418	0.122

Condition scores

The YOYI value for Murray hardyhead exceeds the minimum target of YOYI >0.7, and the low variation (±SE) suggests this reading is reliable (Table 7). The target of RAI >0.7 was met for Murray hardyhead in March 2017. This value, however, was determined from the prediction of occupancy which had a high level of variation, and where probability of detection was low (see above). This aside, the icon site target is a WOISS >0.5 for the Murray hardyhead population, so the value of 0.97 meets the target in March 2017. A comparison of results between years shows the WOISS for Murray hardyhead in March 2017 is similar to March 2016. The narrower tolerance in March 2017 relates to the increase in RAI resulting from a higher predicted occupancy.

The target of RAI >0.7 was met for southern pygmy perch in March 2017. This is a more reliable result, compared to that obtained for Murray hardyhead, because probability of detection used to calculate RAI was relatively high with low variation. The YOYI value is relatively low for southern pygmy perch, and just fails the minimum target of YOYI >0.3. The icon site target is a WOISS >0.5 for the southern pygmy perch population. The WOISS of 0.65 meets the target. The wide tolerance, however, suggests the true value for the WOISS might be as low as 0.27 for southern pygmy perch. Southern pygmy perch shows no improvement in the WOISS from March 2016 to March 2017. In this case the lack of improvement appears to be mostly related to a low YOYI (low level of recruitment).

The RAI and YOYI values for Yarra pygmy perch were not determined, because the species was not captured in the March 2017 condition monitoring. The icon site target is a WOISS >0.5 for the Yarra pygmy perch population. The WOISS for Yarra pygmy perch is zero, which fails to meet the target.

Table 7. Values for relative abundance index (RAI), Young-of-the-Year Index (YOYI) and Whole of Icon Site Score (WOISS) for the threatened fish populations in March 2016 and March 2017.

	RAI	±SE	YOYI	±SE	WOISS ±tolerance
Murray hardyhead					
March 2016	1.00	0.209	0.99	0.011	1.00 ±0.42
March 2017	1.00	0.092	0.94	0.041	0.97 ±0.19
Southern pygmy perch					
March 2016	1.00	0.101	0.40	0.157	0.70 ±0.39
March 2017	1.00	0.097	0.30	0.132	0.65 ±0.38
Yarra pygmy perch					
March 2016	N/A	N/A	N/A	N/A	0
March 2017	N/A	N/A	N/A	N/A	0

Discussion

Threatened fish populations

The objective of this condition monitoring project was to determine the status of Murray hardyhead, southern pygmy perch and Yarra pygmy perch populations in the Lower Lakes by relating current population condition to the 2003 baseline (Wedderburn and Hammer 2003). Murray hardyhead and southern pygmy perch show signs of population recovery following decline during the Millennium Drought, with range expansions and recruitment by March 2016 which have carried to March 2017. Yet the abundance of Murray hardyhead in the March 2017 condition monitoring is substantially less than the previous year (Wedderburn and Barnes 2016). Conversely, the abundance of southern pygmy perch in sampling has increased considerably due largely to a third repeated sample at each site. A concern, however, is that the species was not detected on Mundoo Island where it occurred for the last several years. Yarra pygmy perch was not detected in March 2016 and March 2017, thereby supporting the proposition that the species is extinct in the MDB (Hammer et al. 2010; Wedderburn et al. 2014).

<u>Relative Abundance Index</u>

The first aim of the condition monitoring project was to determine the Relative Abundance Index (RAI) for each threatened fish species at the icon site level, as a measure of their current distribution. Specifically, the RAI value is the extent of a species' occurrence in 2017, while accounting for probability of detection in sampling (i.e. false absences), as it relates to occupancy in the 2003 baseline (Wedderburn and Hammer 2003).

The RAI of 0.97 for Murray hardyhead meets the icon site target, but must be treated with caution because the value is obtained from a predicted occupancy with high variation, and it was derived from a low level of detection. Another factor also not considered in the RAI value is that Murray hardyhead has not returned to its full range to include Lake Albert (last recorded in 2008: Wedderburn and Barnes 2009). This is despite the reintroduction of 1000 Murray hardyhead at three sites in Lake Albert in November 2016 by the South Australian Murray–Darling Basin Natural Resource Management Board and Aquasave.

Southern pygmy perch appears to be recovering in the south-western parts of Lake Alexandrina (Hindmarsh Island, Mundoo Island, Black Swamp) since the Millennium Drought, but has yet to establish self-sustaining populations in the formerly occupied northern region of Lake Alexandrina (e.g. Turvey's Drain, Angas River mouth: N. Whiterod, Aquasave, unpublished data). Nevertheless, the RAI of 1.00 for southern pygmy perch meets the target, and suggests the species now has a similar level of distribution as in 2003. The RAI value obtained for southern pygmy perch is more reliable than that of Murray hardyhead due to the minimised variation of probability of occupancy achieved by including a third repeated sample at the 17 sites. Of particular concern, however, is that southern pygmy perch was not detected on Mundoo Island for the first time in several years.

<u>Young-of-the-Year Index</u>

The second aim of the condition monitoring project was to determine the Young-of-the-Year Index (YOYI) for each threatened fish population to provide a measure of recruitment success at the icon site level.

The high YOYI value of 0.94 for Murray hardyhead meets the target. There were, however, much lower numbers of Murray hardyhead captured in March 2017 compared to the previous year, which suggests either a lower level of recruitment in the current year or the fish are widely dispersed throughout the region. The latter scenario seems plausible given the high RAI value. The reasons for the wide dispersal of Murray hardyhead in March 2017, as reflected in the RAI, are unknown. Based on previous studies on Murray hardyhead, the changes in its distribution and abundance are likely to be related to salinity (Hammer and Wedderburn 2008; Wedderburn and Hammer 2003; Wedderburn et al. 2007). For example, salinities were lower at the sampling sites in March 2017 compared to March 2016, and were generally below the physiological optimum (approx. 2000–5000 EC) for Murray hardyhead (Wedderburn et al. 2008).

The YOYI value of 0.3 is relatively low for southern pygmy perch, and just falls short of the target. Despite more southern pygmy perch being captured and measured in the March 2017 sampling, due to the extra sampling effort, the YOYI value is substantially lower than that obtained in March 2016. This suggests there was some limitation to recruitment for the species over 2016–17, but the factors are unknown. A possible explanation is that the extreme high numbers of the alien eastern gambusia impacted on the recruitment success of southern pygmy perch, either through competition for food or aggressive exclusion (see Pyke 2008; Wedderburn et al. 2016).

<u>Whole of Icon Site Score</u>

The third aim of the condition monitoring project was to determine the Whole of Icon Site Score (WOISS) for each threatened fish species, by formulating the RAI and YOYI.

As with the RAI, the WOISS for Murray hardyhead does not consider that the species is yet to recolonise Lake Albert. The WOISS of 0.97 for Murray hardyhead shows the species has recovered well in Lake Alexandrina, and meets the target for the icon site. The high WOISS for Murray hardyhead reflects its wide range. For example, the continued presence of Murray hardyhead in Dog Lake (northern Lake Alexandrina) contributes towards meeting the WOISS target.

The WOISS of 0.65 for southern pygmy perch meets the target, but fails if the true value lies at the lower end of the tolerance. The likely reason for the relatively low WOISS value and wide tolerance relates to the low level of recruitment recorded over 2016–17 (YOYI value). The absence of southern pygmy perch from sampling on Mundoo Island may also be a factor lowering the WOISS.

Threatened fish habitats

There was no distinct preference by Murray hardyhead for any particular habitat in the study, unlike in March 2016 when it showed a preference for the shallow fringes of natural channels. The species was detected in a wider range of habitats in March 2017, including modified channels (site 31), natural channels (sites 26 and 86), and wetlands (site 25). This finding, combined with its low abundances at sites, suggests the species is now sparsely but widely dispersed in Lake Alexandria and its associated waters. It is difficult to speculate about the reasons for the differences between Murray hardyhead abundances in March 2016 and March 2017. The differences are unlikely to be directly related to the water levels of Lake Alexandrina because they were similar at the time of sampling (~0.55–0.65 in March of each year: DEWNR, unpublished data). Similarly, mean water depth at sampling sites of Lake Alexandrina in March 2016 and March 2017 were comparable (52 cm and 57 cm in sample A, respectively). A key determinant of distribution and abundance of Murray hardyhead is salinity, where the species' preference is for slightly elevated to moderate salinities (Wedderburn et al. 2007). There was a notably lower difference in salinity at the sampling sites of Lake Alexandrina in March 2017 (mean 829 EC in sample A) compared to March 2016 (mean 1711 EC in sample A). Salinity, therefore, may have been a factor leading to the lower abundance of Murray hardyhead at sites in March 2017.

Murray hardyhead was recorded at the same condition monitoring sites in Lake Albert prior to the impacts of drought (Wedderburn and Hammer 2003). As in March 2016, sites sampled in Lake Albert in March 2017 fit the typical habitat description for Murray hardyhead, including elevated salinities, but the species was unrecorded. Indeed, salinities at sites in Lake Albert were optimal for Murray hardyhead (approximately 2000–6000 EC). Therefore, other unknown factors are restricting its ability to colonise Lake Albert following its extirpation from the lake during drought.

There was distinct preference by southern pygmy perch for channel habitats with water levels slightly at the higher range at study sites. Most often the preferred sites had a muddy, detritus-rich substrate, with abundant hornwort and cumbungi (i.e. high habitat complexity). Southern pygmy perch also tended to be associated with habitats where alien eastern gambusia was prolific, and low numbers of alien redfin perch were recorded. As with Murray hardyhead, it is undetermined if water level recessions leading up to the March 2017 sampling influenced recruitment success of southern pygmy perch. Eastern gambusia was prolific in all well-vegetated drainage channel habitats, however, so the alien species might be a factor influencing the recruitment of southern pygmy perch because the volume of water reduces in their obligate habitat and fish became more concentrated (increased competition for food and space leading to reduced level of survivorship of YOY pygmy perch).

Repeated sample method

The first use of the refined condition monitoring method demonstrated that a repeated sample strategy provided an estimate for occupancy that was more accurate than naïve occupancy obtained in single sample monitoring (Wedderburn and Barnes 2016). The findings also showed that sampling in March 2016 was inadequate to monitor the southern pygmy perch population due to the low probability of detection with two repeated samples at 17 sites. Accordingly, an optimal sampling design for southern pygmy perch was executed in March 2017, which involved three repeated samples using fyke nets at 17 sites in Lake Alexandrina (Lake Albert was excluded from this aspect because there are no records of pygmy perches ever inhabiting the lake). The extra sampling effort to target southern pygmy perch in March 2017 improved the reliability of the WOISS because the probability of detection was increased from 0.5 to 0.75, and variation was reduced in the probability of occupancy.

The sampling design used in March 2016 was optimal for Murray hardyhead at the time, with three seine shots in each of two repeated samples at 20 sites (Wedderburn and Barnes 2016). The results of sampling using the same methods in March 2017, however, were inadequate due to the low probability of detection and the high variation of probability of occupancy. This relates to the lower abundance of Murray hardyhead at the sampling sites, which reduced the chance of capture (i.e. more false absences recorded). Therefore, three repeated samples using seine netting at 20 sites are required to be able to state with an acceptable degree of certainty whether Murray hardyhead is present or absent at the monitoring sites (Guillera-Arroita et al. 2010).

The MDBA undertook a refinement of the condition monitoring methods with the objective of making the assessment of threatened fish populations statistically robust (Wedderburn 2015). Thus, sampling of threatened fish populations in the Lower Lakes should aim for a design that accounts for probability of detection and is based on minimising variance of probability of occupancy (Guillera-Arroita et al. 2010; Robinson 2015). Based on results of the March 2017 condition monitoring, three repeated samples (replicate surveys) are required to minimise the variance of prediction of occupancy for southern pygmy perch and Murray hardyhead at 17 and 20 sites, respectively, in March 2018.

Recommendations

1. An increased understanding of the factors that drive and impact on recruitment and dispersal in the threatened fish populations is required to address the failure to meet some of the condition monitoring targets with regard to RAIs, YOYIs and WOISSs. Understanding these issues will assist management of natural fish populations and captive fish for future reintroductions. Based on limited ecological understanding of the populations, especially the pygmy perches, the following are deemed priority actions and themes for investigations, but the list is not exhaustive:

   (1) Further reintroductions of Yarra pygmy perch are necessary if a self-sustaining population is ever to be re-established in Lake Alexandrina, and therefore the MDB.
   (2) Investigate the impacts of redfin perch and eastern gambusia on the three threatened species (especially any reintroduced Yarra pygmy perch), particularly with regards to inhibition of recruitment and population recovery, and undertake management of alien fish accordingly.
   (3) Examine food availability for the three threatened species (especially any reintroduced Yarra pygmy perch) to determine if starvation is impacting on early life survivorship (e.g. in relation to wetland water level management, competition with eastern gambusia).
   (4) Explore the dispersal ability of the three threatened species to gauge their capacity to naturally re-colonise suitable habitat.
   (5) Examine genetic aspects of any captive Yarra pygmy perch that are used for reintroduction to the wild, and how genetic factors influence survival and the establishment of self-sustaining populations.

2. Habitat will strongly influence the factors that drive and impact on recruitment of threatened fishes in the Lower Lakes. Anecdotally, water level fluctuations in fringing habitats appear to substantially benefit threatened fish. Obviously, they are intrinsically linked to Lake Alexandrina water levels. Correct hydrological regimes (water levels, and timing and duration of inundation) in lake-fringing sites will establish aquatic plant assemblages and prey communities necessary for the threatened fishes, and possibly reduce the impacts from alien fishes. Hydrological regimes could be managed at individual sites to establish appropriate macrophyte assemblages (some protection from redfin perch), food resources and habitat connectivity for fish. In this regard, for example, managing flow regimes to enhance zooplankton prey for reproducing adult and young-of-the-year fish is beneficial for fish recruitment. Alternatively, aquatic macrophyte control could be necessary where

hydrological management is unfeasible (e.g. where cumbungi chokes up channels formerly inhabited by the threatened fishes). In this regard, sites on Hindmarsh Island and Mundoo Island, where threatened fish occur or occurred, are applicable for trials and investigations. This includes fish reintroduction sites.

Conclusions

Murray hardhead and southern pygmy perch each had a RAI value of 1.00, which indicates that current populations have a distribution similar to the 2003 baseline condition, and the Condition Monitoring RAI target was met. Southern pygmy perch, however, was not detected on Mundoo Island in March 2017, and Murray hardyhead has yet to re-establish in Lake Albert. The YOYI value of 0.94 met the target and indicates that Murray hardyhead underwent suitable recruitment over 2016–17. The YOYI value of 0.30 for the southern pygmy perch (0.30) population failed the target and suggests recruitment over 2016–17 was limited. The WOISS of 0.97 ±0.19 for Murray hardyhead meets the target. The WOISS of 0.65 ±0.38 for southern pygmy perch may be acceptable, but fails the target if the true value lies at the lower end of the tolerance. Yarra pygmy perch was not detected in March 2017, therefore the WOISS is zero and fails the target.

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