Response of fish to the 'Goolwa Channel Water Level Management Plan': 2009-2011




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EXECUTIVE SUMMARY

Over abstraction of water, prolonged drought and subsequently reduced River Murray inflows, resulted in reduced water levels in the Ramsar listed Lower Lakes between 2007 and 2010, with Lake Alexandrina receding to an historical low of approximately -1.0 m AHD in May 2009. Water level recession had many detrimental impacts on the Lower Lakes ecosystem including the exposure of extensive areas of acid sulfate soils which, upon re-wetting, may result in the acidification of water bodies and mobilisation of heavy metals and metalloids.

In order to limit the exposure of acid sulfate soils and reduce the risk of water body acidification in the western region of Lake Alexandrina, the *Goolwa Channel Water Level Management Plan* (GCWLMP) was initiated to maintain higher water levels in the Goolwa Channel through the construction of the Clayton Regulator (completed in August 2009). The construction of the Clayton Regulator isolated the newly created Goolwa weir pool (GWP) from Lake Alexandrina, whilst the GWP remained isolated from the Coorong by the Goolwa Barrage. Water levels 'within' the GWP were then managed independently from Lake Alexandrina, with a combination of pumping and capturing tributary inflows through 2009/10 (water level peaked at +0.74 m AHD), whilst water level in Lake Alexandrina remained below sea level through this period.

Significantly increased flow in the Murray-Darling River system in 2010 resulted in naturally increased water levels in Lake Alexandrina and subsequently the Clayton Regulator was partially removed in September 2010. Furthermore, Lake Alexandrina and the Coorong were hydrologically re-connected for the first time since March 2007. The current project aimed to compare the response of fish species to water level management under the GCWLMP in 2009/10 and naturally increased flows and water levels in 2010/11. The specific objectives were to investigate spatio-temporal variation in (1) fish assemblage structure and (2) recruitment dynamics between sites 'within' and 'outside' the GWP and between sampling events.

Fish assemblages 'within' the GWP (n = 4 sites) and 'outside' the GWP (n = 3 sites) were sampled in August 2009 (prior to water level rise), December 2009 (after water level peaked) and in April 2010 (after water level 'within' the GWP had receded to ~0.0 m AHD). Correspondingly, all sites were again sampled in December 2010 and

March/April 2011. All sites were sampled with single-winged fyke nets (n = 4) and multi-panel gill nets (n = 3), which were set overnight.

A total of 66,408 fish were sampled, from 25 species. Fish assemblages did not differ significantly between locations in August 2009, but after isolation of the GWP and water level management, fish assemblages differed significantly between sites 'within' the GWP and 'outside' the GWP in both December 2009 and April 2010. Following natural increases in water level and partial removal of the Clayton Regulator, fish assemblages remained significantly different between locations in December 2010 but were not significantly different in March/April 2011.

Spatial variation in fish assemblage structure in 2009/10, was primarily due to substantial recruitment of young-of-year (YOY) non-native common carp 'within' the GWP, that was not observed at sites 'outside' of the GWP. Contrastingly, several native freshwater species (e.g. carp gudgeon, flat-headed gudgeon, Australian smelt) exhibited no evidence of enhanced recruitment 'within' the GWP and abundances were similar between locations or indeed greater 'outside' of the GWP. Furthermore, several estuarine species (e.g. small-mouthed hardyhead, bridled goby, blue-spot goby) were present and abundant and characterised assemblages (indicator species analysis) at both locations.

In 2010/11, there was a spatial homogenisation of fish assemblage structure, with assemblages at both locations significantly different from 2009/10 (PERMANOVA: p < 0.003) and increasingly characterised by obligate freshwater species and catadromous species (congolli). Homogenisation of fish assemblages in 2010/11 and variation from assemblage patterns detected in 2009/10 was likely due to variation in several abiotic (i.e. connectivity, salinity) and biotic factors (i.e. habitat availability, productivity and species' recruitment patterns) as a result of significant natural inflows in 2010/11. The increased characterisation of fish assemblages by obligate freshwater species reflected observed decreases in salinity in the region and spatial homogenisation of assemblages reflected the re-connection of the Goolwa Channel and Lake Alexandrina and subsequent fish movement. Additionally, increased abundance of the catadromous congolli was due to the re-connection of Lake Alexandrina with the Coorong. Variation in the abundance of other species, namely the native golden perch and non-native common carp and redfin perch, was related to conspicuous YOY recruitment events.

Significant recruitment of common carp was detected 'within' the GWP under managed water levels in 2009/10 and was detected at both locations in 2010/11 under natural 'high flow' conditions, reflecting the flexible and opportunistic nature of common carp spawning and their capacity to recruit under different flow conditions. Non-native redfin perch and native golden perch, however, exhibited significantly greater recruitment in 2010/11, relative to 2009/10. Reproduction in redfin perch is thought to occur independently of flow but was likely facilitated by decreased salinity, increased habitat availability and increased productivity in 2010/11. Contrastingly, spawning in the native golden perch is flow-dependent and increased flows in the Murray-Darling River system likely resulted in the enhanced recruitment of this species observed in Lake Alexandrina in 2010/11.

The GCWLMP in 2009/10 provided conditions optimal for the spawning and recruitment of non-native common carp but did not enhance native freshwater fish populations. Contrastingly, conditions experienced in 2010/11 resulted in the increased dominance of obligate freshwater species and facilitated the spawning and recruitment of both native and non-native freshwater fish species. This study highlights that engineered solutions, decoupled from broader-scale hydrological processes, may result in a trade-off between achieving positive environmental outcomes (e.g. mitigation of ASS) and potential negative impacts, such as providing a recruitment 'hotspot' for non-native species and inhibiting fish movement. Additionally, river management approaches involving restoration of the natural flow regime may also involve similar trade-offs (i.e. recruitment of native and non-native species), however, ecological benefits are likely to outweigh impacts.

1. BACKGROUND & INTRODUCTION

The Ramsar listed Lower Lakes (i.e. Lake Alexandrina and Lake Albert) and Coorong, located at the terminus of the Murray-Darling River system, are heavily impacted by river regulation and over abstraction of water. Post regulation, mean annual discharge from the Murray Mouth is just ~39% (4723 GL) of natural, pre-regulation discharge (12, 233 GL) (CSIRO 2008). Compounding this situation, drought in the past decade resulted in diminished run-off to the Murray-Darling Basin (MDB) (Murphy and Timbal 2007) and subsequently reduced flows to the Lower Lakes, with River Murray inflows of < 600 $GL.yr^{-1}$ in 2007, 2008 and 2009 (DFW 2011). With the high rates of evaporation experienced in the Lower Lakes (typically > 750 $GL.yr^{-1}$) (CSIRO 2008), inflows were insufficient to maintain typical regulated water levels (approximately 0.75 m AHD (Australian Height Datum)) and the lakes subsequently receded to an historical low (approximately -1.0 m AHD in Lake Alexandrina in May 2009).

Accompanying water level recession, there was a substantial loss of off-channel wetland habitats and submerged vegetation, and remaining water was largely disconnected from fringing emergent vegetation (Marsland and Nicol 2009). Furthermore, the Lower Lakes were hydrologically and physically disconnected from the Coorong and Southern Ocean in March 2007, and salinities (measured as electrical conductivity) in some areas of Lake Alexandrina increased to ≥ 20,000 $\mu S.cm^{-1}$ (DFW 2011). Water level recession also resulted in the exposure of extensive areas of soils with high sulfidic content, which upon oxidation form acid sulfate soils (ASS) (Pons 1973; Fitzpatrick *et al.* 2008). Upon rewetting, these soils have the potential to acidify remaining water and mobilise toxic heavy metals and metalloids, and thus represented a significant threat to the Lower Lakes ecosystem (Fitzpatrick *et al.* 2008). The potential threat posed by ASS was of great concern and consequently several management options were proposed and/or implemented to mitigate the risk to the Lower Lakes, including bioremediation (through the revegetation of key areas of exposed lake bed), limestone addition and maintaining higher water levels with freshwater inflows or seawater intrusion (DEH 2009).

In order to limit the exposure and formation of ASS and reduce the risk of water body acidification in the western region of Lake Alexandrina, the *Goolwa Channel Water Level Management Plan* (GCWLMP) was initiated to maintain higher water levels within the Goolwa Channel (SA Water Corporation 2009). Whilst this intervention was undertaken with the primary objective of mitigating the threat of water body acidification, it secondarily aimed to provide an area of adequate freshwater habitat for freshwater dependent biota to mitigate the impact of low water levels on the ecology of the region (SA Water Corporation 2009). The use of such structures to isolate and manage water levels in a main river channel is a novel and unprecedented approach to the mitigation of acid sulfate soils and habitat conservation.

A large earthen regulator (length = 375 m, width = 40 m, height = 3 m) was constructed across the Goolwa Channel near Clayton, creating an impounded area between the regulator and the Goolwa Barrage (hereafter referred to as the Goolwa Weir Pool (GWP); ~16 km in length and 0.3-1.5 km wide), and physically disconnected this area from Lake Alexandrina. A further low-level regulator was also constructed across the lower reach of Currency Creek to 'pool' early season inflows and thus restrict the inflow of potentially acidified water into the Goolwa Channel. Following construction of the Clayton Regulator, water level within the GWP was then raised to > 0.7 m AHD through a combination by pumping water from Lake Alexandrina and seasonal inflows from tributaries between August and November 2009. Water level then began to recede as pumping and tributary inflows ceased and evaporation increased over summer, and as of May 2010 was approximately -0.1 m AHD. Water level 'outside' of the GWP in Lake Alexandrina ranged from -0.95 to -0.5 m AHD throughout this period.

In 2009/10, fish assemblages were monitored at sites subject to water level management 'within' the GWP and sites not subject to water level management in Lake Alexandrina 'outside' of the GWP to determine the response of fish to the management of water levels (Bice *et al.* 2010a). Following the raising of water levels 'within' the GWP, the abundance of young-of-year (YOY) non-native common carp 'within' the GWP was significantly greater than 'outside' of the GWP, indicating that water level management 'within' the GWP provided conditions favourable for recruitment. Conversely, native freshwater species showed limited positive response to water level management with abundances and recruitment similar between locations or indeed greater 'outside' of the GWP.

In mid-2010, significant increases in flow in the Murray-Darling River system resulted in rapidly increasing water levels in Lake Alexandrina. By September 2010, water level in Lake Alexandrina had risen to within the range of normal regulated levels (approximately 0.75 m AHD) and a portion of the Clayton Regulator was removed, re-connecting the GWP with greater Lake Alexandrina. Furthermore, releases of freshwater to the Coorong commenced in September 2010, resulting in the re-connection of Lake Alexandrina and the Coorong for the first time since March 2007. As such, the disparity in environmental conditions between 2009/10 and 2010/11 allowed a comparison of the response of fish species to a managed increase in water level and a natural increase in water level in Lake Alexandrina following significant inflows.

To achieve positive ecological outcomes and mitigate risks from management interventions, an understanding of the response of aquatic biota is essential. Fish are an integral and conspicuous component of aquatic ecosystems and the fish community of the Lower Lakes is the most diverse in the MDB (Wedderburn and Hammer 2003; Bice 2010a). The assemblage includes species of national conservation significance; namely Murray Cod (*Maccullochella peelii*), Yarra pygmy perch (*Nannoperca obscura*) and Murray hardyhead (*Craterocephalus fluviatilis*), listed as *vulnerable* under the *EPBC Act* (Environment Protection and Conservation Act 1999); species of commercial importance (e.g. golden perch, *Macquaria ambigua*) and iconic diadromous species (e.g. congolli, *Pseudaphritis urvillii*) not found elsewhere in the MDB.

This project aimed to compare the response of fish to water level management as part of the GCWLMP in 2009/10 and naturally increased flows and water levels in 2010/11. Specifically, the objectives were to:

1. Investigate spatial and temporal variation in fish assemblage structure (species composition and abundance) between sites ‘within’ and ‘outside’ the GWP and across sampling events, and
2. Investigate spatial and temporal variation in the recruitment of selected fish species ‘within’ and ‘outside’ the GWP via length-frequency distribution analysis.

This will enable the investigation of several hypotheses and questions generated from monitoring in 2009/10, including

1. Fish communities will continue to be dominated by common carp
    a. Are conditions in the Goolwa Channel suitable for further expansion of the common carp population?
    b. Was there significant survival of newly recruited young-of-year common carp from 2009/10?
2. Fish recruitment and growth rates will continue to be greater at sites outside of the GWP
    a. Is competition limiting growth rates ‘within’ the GWP?
3. Are Murray hardyhead persisting within the Goolwa Channel?

These hypotheses and question were generated under the assumption of continued low River Murray inflows and the continued presence of the Clayton Regulator. The partial removal of the regulator and subsequent capacity for movement of fish throughout the region renders investigation of fish growth rates irrelevant. Nonetheless, hypotheses and questions related to carp populations, recruitment and the presence of Murray hardyhead remain relevant and applicable.

2. METHODS

2.1. Fish sampling

Baseline data was collected from four sites (three 'within' and one 'outside' the GWP) from 20th-22nd August 2009, prior to the raising of water levels (Figure 1 and Table 1). Seven sites (four 'within' and three 'outside' the GWP) were subsequently sampled immediately after water level peaked 'within' the GWP (15th-19th December 2009) and again after the water level had receded (19th-23rd April 2010) (Figure 1 and Table 1). Following the partial removal of the Clayton Regulator, fish assemblages were again sampled at the same seven sites from 13th – 17th December 2010 and 28th March – 1st April (Figure 1 and Table 1).

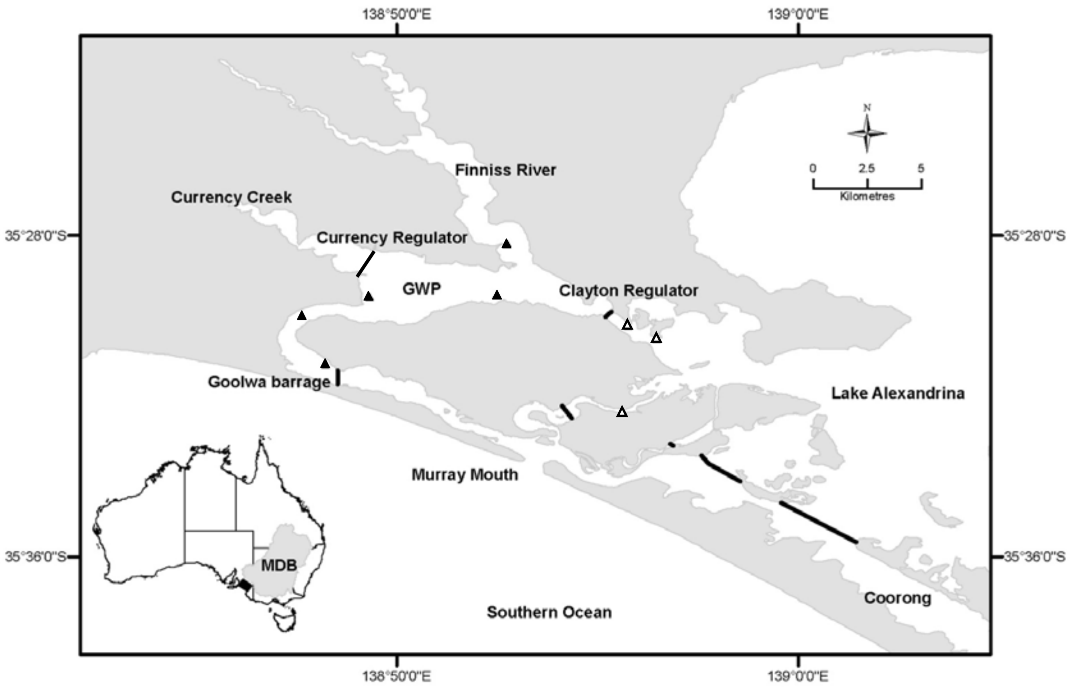

Figure 1. Map of the western side of Lake Alexandrina showing the locations of the Murray Barrages, Clayton and Currency Regulators (solid black), and newly created Goolwa Weir Pool (GWP). Sampling sites 'within' the GWP (solid triangles) and 'outside' the GWP are indicated.

Table 1. Sampling site number, name, location (i.e. within GWP or 'outside'), geographical position (i.e. easting and northing) and when sampled.

Site No.	Site name	Location	Easting	Northing	Sampling event				
					Aug 09	Dec 09	Apr 10	Dec 10	Apr 11
1	Goolwa Barrage	GWP	300998	6066924	Yes	Yes	Yes	Yes	Yes
2	Captain Sturt Rd	GWP	301575	6069591	Yes	No	No	No	No
3	Goolwa Channel	GWP	306063	6070252	Yes	Yes	Yes	Yes	Yes
4	Clayton West	Outside	312149	6069180	Yes	Yes	Yes	Yes	Yes
5	Clayton East	Outside	313049	6068575	No	Yes	Yes	Yes	Yes
6	Holmes Creek	Outside	311654	6065315	No	Yes	Yes	Yes	Yes
7	Finniss arm	GWP	307724	6072896	No	Yes	Yes	Yes	Yes
8	Currency Creek	GWP	302904	6070571	No	Yes	Yes	Yes	Yes

All sites were sampled with single-winged fyke nets (6 m wing length, 0.6 m entry diameter and 0.003 m mesh: *n* = 4) and multi-panel gill nets (three panels: 0.076, 0.102 and 0.127 m stretched mesh x 5 m length x 1.5 m height: *n* = 3), which were set overnight. Fyke nets were set perpendicular to the bank, where possible, in habitat that was representative of the site being sampled (Figure 2). Gill nets were also set perpendicular to the bank but further out from shore where water depth was sufficient to allow the nets to fish efficiently (> 1 m) (Figure 2).

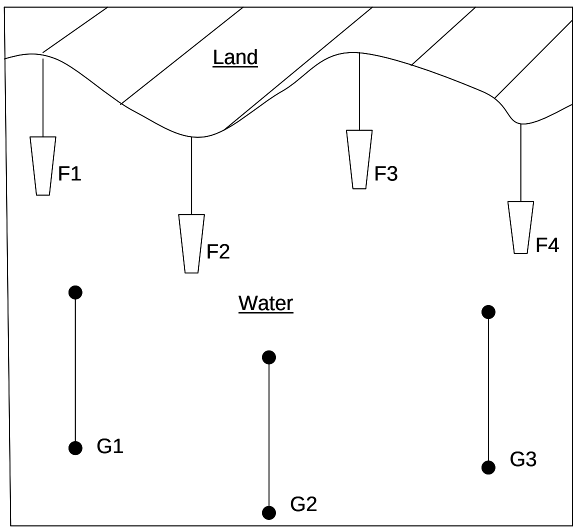

Figure 2. Generalised schematic of sampling method used at each site, showing orientation of fyke nets (F1 – F4) and gill nets (G1 – G3).

All fish captured were identified and enumerated. Length measurements (caudal fork length (FL) or total length (TL) mm, depending on tail morphology) were recorded for up to 50 individuals per species per sampling gear type at each site. Fish condition (i.e. the presence of parasites, lesions, ulcers, wounds, diseases and/or deformities) was assessed for each fish that was measured following the methods used in the *MDB Sustainable Rivers Audit* (Davies *et al.* 2008).

2.2. Water level and salinity

Time-series data for water level (m, AHD) and salinity (measured as electrical conductivity ($\mu S.cm^{-1}$)), over the study period, was obtained from the Department for Water monitoring stations at Signal Point ('within' the GWP) and Milang ('outside' the GWP) (DFW 2011).

2.3. Data analysis

Two-factor PERMANOVA (permutational ANOVA and MANOVA) (Anderson *et al.* 2008) was used to investigate spatial differences in fish assemblages between sites 'within' the GWP and 'outside' the GWP over time using the software package PRIMER v. 6.1.12 (Clarke and Gorley 2006). To allow for multiple comparisons, a Bonferroni correction was adopted (corrected $\alpha = 0.05/n_{comparions}$). Relative abundance data, generated from fyke net catches ($fish.net^{-1}.hr^{-1}$), was transformed using a fourth root transformation and Bray-Curtis similarities (Bray and Curtis 1957) were used to calculate similarity matrices. Non-Metric Multi-Dimensional Scaling (MDS) generated from the same similarity matrices were used to visualise assemblages from different locations and sampling events in two dimensions. SIMPER (similarity percentages) analysis was used to determine species contributing to differences between locations and a 40% cumulative contribution cut-off was applied.

Indicator species analysis (ISA) (Dufrene and Legendre 1997) was used to calculate the indicator value (site fidelity and relative abundance) of species between locations during sampling events using the package PCOrd v 5.12 (McCune and Mefford 2006). ISA was also used to calculate the indicator value of species between sampling events at each location. This analysis may indicate species that characterise particular assemblages without significantly contributing to the differences between assemblages. A perfect indicator (indicator value (IV) = 100) remains exclusive to a particular group and exhibits strong site fidelity during sampling (Dufrene and Legendre 1997). Statistical significance was determined for each species indicator value using the Monte Carlo (randomisation) technique.

The Kolmogorov-Smirnov (K-S) ‘goodness of fit test’ was used to investigate differences in length-frequency distributions of selected species between locations.

3. RESULTS

3.1. Water level and salinity

Water level within the GWP was approximately -0.9 m AHD after construction of the Clayton Regulator and was then raised to a peak of 0.74 m AHD in early November 2009 by a combination of pumping water from Lake Alexandrina 'outside' of the GWP (~27 GL) and capturing seasonal inflows from the Finniss River and Currency Creek (Figure 3a). Water level receded as pumping and tributary inflows ceased and evaporation increased over summer, and by April 2010 was approximately -0.1 m AHD. Water level 'outside' of the GWP in Lake Alexandrina remained approximately -0.9 m AHD throughout this period but began rising in April 2010 in response to increased River Murray flows (Figure 3a). Levels 'within' the GWP also began rising in June 2010 in association with winter tributary inflows. In September 2010, with predictions of significant River Murray inflows, the Clayton Regulator was partially removed, re-instating hydrological connectivity between the Goolwa Channel and Lake Alexandrina. Water levels increased rapidly at both locations and fluctuated between 0.4 and 0.9 m AHD for the remainder of the study (Figure 3a).

Salinity 'within' the GWP (data obtained from the DFW Signal Point monitoring station) ranged from 23,000 – 33,000 $\mu S.cm^{-1}$ from January – June 2009 and was ~20,000 $\mu S.cm^{-1}$ by the completion of the Clayton Regulator and commencement of sampling in August 2009 (Figure 3b). Salinity decreased to ~11,000 $\mu S.cm^{-1}$ after water level peaked in November 2009 but rose as water levels decreased, and was >20,000 $\mu S.cm^{-1}$ by April 2010 (Figure 3b). As a result of increased flows into the system initiating management triggers, the Clayton regulator was breached in September 2010 resulting in a sharp reduction in salinity 'within' the GWP (Figure 3b). Salinity 'outside' of the GWP (data obtained from the DFW Milang monitoring station) ranged from 5500 – 9200 $\mu S.cm^{-1}$ through 2009 and early 2010 (Figure 3b). Following increased water levels and partial removal of the Clayton Regulator in September 2010, salinity decreased rapidly at both locations, reaching ~1000 $\mu S.cm^{-1}$ by December 2010 and remaining <1000 $\mu S.cm^{-1}$ for the remainder of the study (Figure 3b).

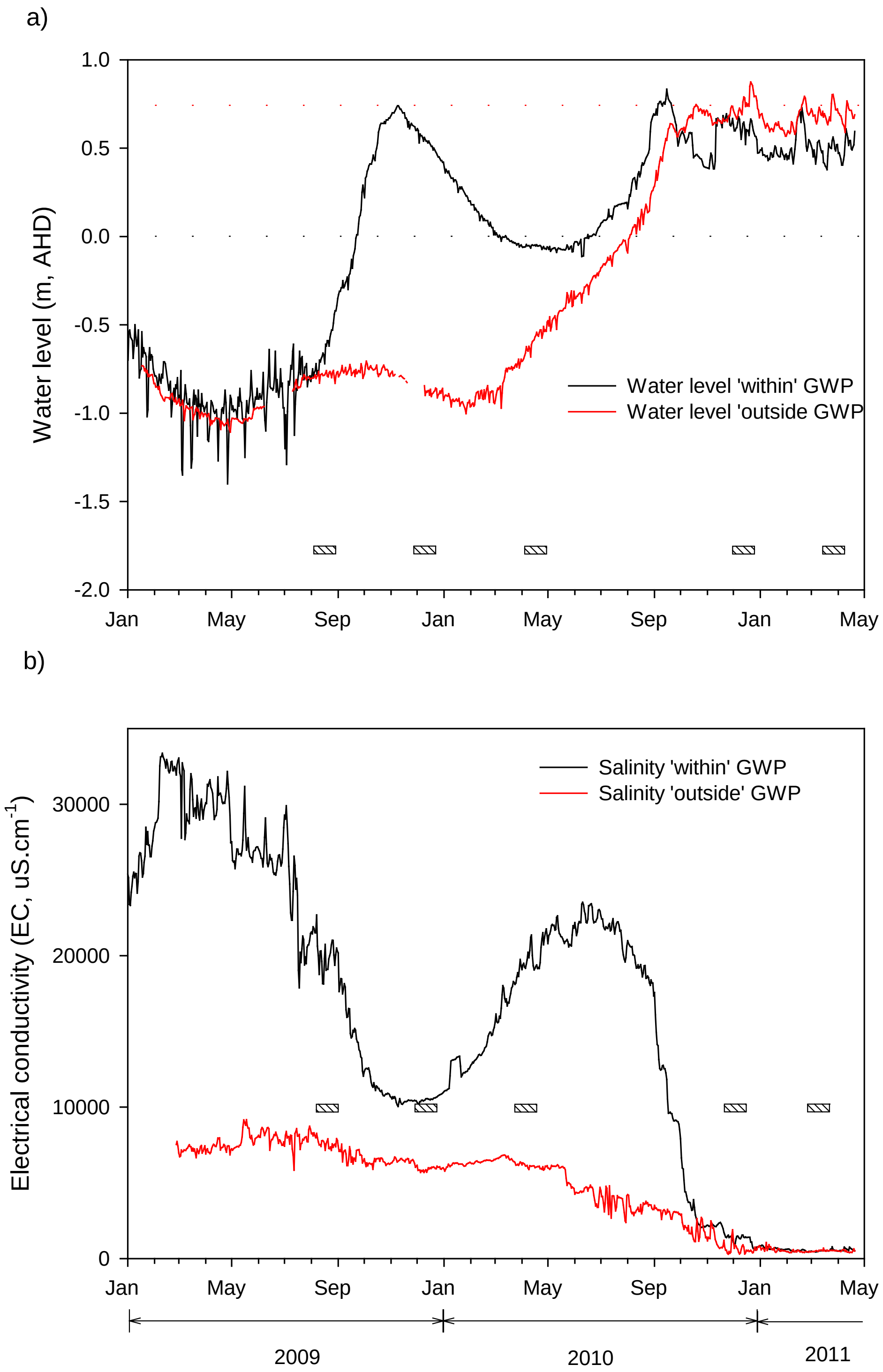

Figure 3. a) Water level and b) salinity 'within' the GWP and 'outside' the GWP from January 2009-May 2011. Time of sampling events is indicated by hatched bars. Red dashed line = normal regulated lake level (0.75 m AHD). Black dashed line = sea level (0.0 m AHD). Data was obtained from the Department for Water, water quality monitoring stations (DFW 2011).

3.2. Catch composition

From 2009 – 2011, a total of 66,408 fish were captured from 25 species, representing a diverse range of life history strategies including obligate freshwater, catadromous, estuarine resident and marine migrant species (Table 2). Species richness was greatest in April 2011 (23), whilst overall abundance was greatest in December 2009 (total fish = 32,147). The most abundant species, in descending order, were small-mouthed hardyhead, common carp, bony herring, flat-headed gudgeon, redfin perch, Australian smelt, and lagoon goby, which collectively contributed > 90% of all fish sampled. A diverse range of species were captured in fyke nets (22), whilst gill nets selectively captured large-bodied freshwater (i.e. adult common carp, bony herring, golden perch and redfin perch) and estuarine/marine species (i.e. black bream, Australian salmon and flat-tailed mullet).

Murray hardyhead, nationally listed as *vulnerable* under the *EPBC Act* (1999), were sampled in low numbers from 'within' and 'outside' the GWP between December 2009 and April 2011 (Table 2).

Table 2. Numbers of fish species sampled at sites 'within' and 'outside' the GWP in August 2009, December 2009, April 2010, December 2010 and March/April 2011. Species are classified following Elliott *et al.* (2007).

Species	Scientific name	August 2009		December 2009		April 2010		December 2010		March/April 2011		Total
		No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	
Golden perch^	*Macquaria ambigua*	1	0	1	0	1	1	2	3	32	12	**53**
Freshwater catfish	*Tandanus tandanus*	0	0	0	0	0	0	0	0	0	1	**1**
Bony herring^	*Nematalosa erebi*	2	1	665	631	632	451	1854	631	1281	388	**6536**
Murray hardyhead^	*Craterocephalus fluviatilis*	0	0	1	0	11	1	4	4	2	0	**23**
Unspecked hardyhead^	*Craterocephalus stercusmuscarum fulvus*	0	0	0	2	0	0	0	0	0	0	**2**
Australian smelt^	*Retropinna semoni*	529	694	1166	823	193	363	727	1037	34	50	**4393**
Flat-headed gudgeon^	*Philypnodon grandiceps*	23	59	415	416	638	1228	1129	1299	725	447	**6379**
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	0	0	0	0	0	0	2	0	1	0	**3**
Carp gudgeon complex^	*Hypseleotris* spp.	1	0	24	33	4	21	19	98	27	14	**241**
Common carp[@]	*Cyprinus carpio*	34	11	8555	26	1235	13	133	335	394	270	**11003**
Redfin perch[@]	*Perca fluviatilis*	1	4	1	174	21	22	4288	496	172	167	**5343**
Goldfish[@]	*Carrasius auratus*	0	0	0	0	2	0	2	2	70	30	**106**
Eastern gambusia[@]	*Gambusia holbrooki*	0	0	0	0	136	0	0	0	151	4	**291**
Common galaxias*	*Galaxias maculatus*	9	10	253	198	66	42	45	47	35	13	**718**
Congolli*	*Pseudaphritis urvillii*	26	10	5	2	0	3	59	69	16	7	**197**
Small-mouthed hardyhead[e]	*Atherinosoma microstoma*	1089	201	15326	1188	2748	2375	1749	292	176	6	**25146**

*^freshwater species, *catadromous species, [e]estuarine resident species, [m] marine migrant species, [@]alien species*

Table 2 continued.

Species	Scientific name	August 2009		December 2009		April 2010		December 2010		March/April 2011		Total
		No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	No. GWP	No. outside	
Tamar goby[e]	*Afurcagobius tamarensis*	11	15	64	159	108	90	331	71	2	0	**852**
Blue-spot goby[e]	*Pseudogobius olorum*	23	0	77	16	51	107	73	27	1	0	**377**
Lagoon goby[e]	*Tasmanogobius lasti*	67	544	749	530	47	253	82	31	8	17	**2328**
Bridled goby[e]	*Arenogobius bifrenatus*	10	4	394	153	343	71	148	31	12	1	**1167**
River garfish[e]	*Hyporhamphus regularis*	0	0	0	3	0	0	0	0	1	0	**4**
Sandy sprat[e]	*Hyperlophus vittatus*	1	0	0	66	54	7	0	0	2	0	**129**
Black bream[e]	*Acanthopagrus butcheri*	1	0	2	0	0	0	0	0	1	0	**4**
Western Australian salmon[m]	*Arripis truttaceus*	0	0	6	0	0	0	0	0	0	0	**6**
Flat-tailed mullet[m]	*Liza argentea*	0	0	16	0	2	0	0	0	2	0	**20**
Totals		**1823**	**1553**	**27720**	**4427**	**6156**	**5038**	**10647**	**4473**	**3145**	**1426**	**66,408**

*^freshwater species, *catadromous species, [e]estuarine resident species, [m] marine migrant species, [@]alien species*

3.3. Spatial and temporal variation in fish assemblages

Non-metric multi-dimensional scaling (MDS) ordination (based on fyke net data) showed distinct groupings of fish assemblages by sampling event and location (i.e. 'within' GWP or 'outside') (Figure 4). This was supported by two-factor PERMANOVA which indicated there were significant differences in fish assemblages between sites 'within' and 'outside' the GWP (sampling events pooled; $Pseudo\text{-}F_{1,\ 127} = 9.16$, $p < 0.001$), and between sampling events (locations pooled; $Pseudo\text{-}F_{4,\ 127} = 39.22$, $p < 0.001$). There was a significant interaction between location and sampling event ($Pseudo\text{-}F_{4,\ 127} = 4.06$, $p < 0.001$) indicating fish assemblages at both locations changed over time but not in a uniform pattern.

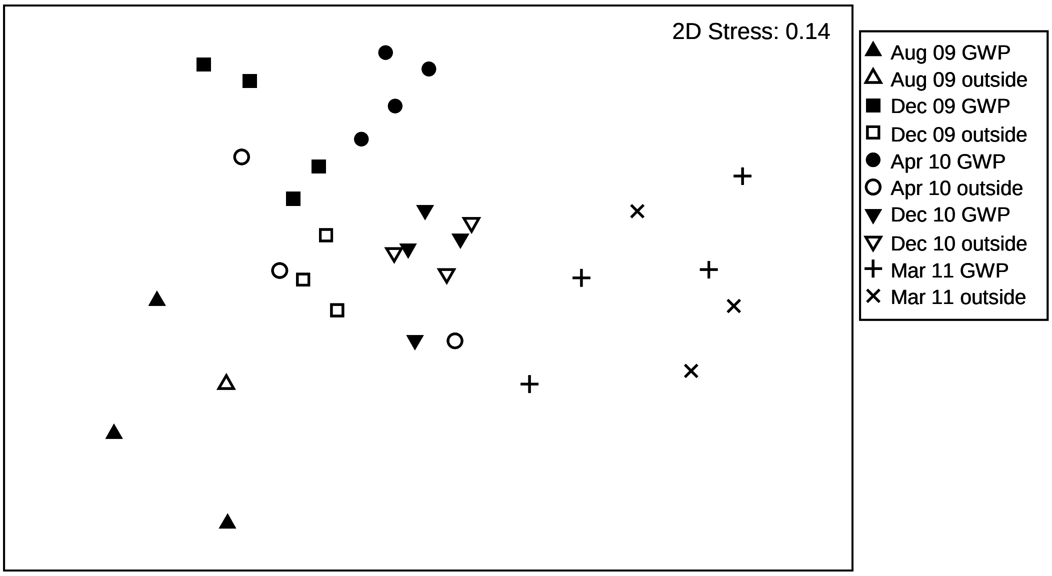

Figure 4. Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from sites within the GWP and outside the GWP in August 2009, December 2009, April 2010, December 2010 and March/April 2011.

3.1.2. Spatial variation

PERMANOVA pairwise comparisons of fish assemblages between locations during each sampling event were undertaken. Immediately after the construction of the Clayton regulator, fish assemblages did not differ between sites 'within' and 'outside' of the GWP ($t = 1.21$, $p = 0.24$). Following the managed rise in water level, however, fish assemblages differed significantly (Bonferroni corrected $\alpha = 0.01$) between sites 'within' and 'outside' of the GWP in December 2009 ($t = 4.99$, $p < 0.001$), April 2010 ($t = 2.86$, $p < 0.001$) and December 2010 ($t = 2.17$, $p = 0.003$) but not in March/April 2011 ($t = 1.54$, $p = 0.05$).

Both ISA (indicator species analysis) and SIMPER (similarity of percentages; adopting a cumulative contribution cut-off of 40%) were used in conjunction to determine species that i) characterise different assemblages (ISA) and ii) contribute to differences between assemblages (SIMPER) where significant differences were detected by PERMANOVA. Differences in fish assemblages between locations in December 2009 were primarily due to greater abundances of non-native common carp and the estuarine small-mouthed hardyhead 'within' the GWP and greater abundance of non-native redfin perch 'outside' the GWP (Figure 5a). Common carp (Indicator Value (IV) = 99.9, $p < 0.001$) and small-mouthed hardyhead ($IV = 91.9$, $p < 0.001$), together with the estuarine blue-spot goby ($IV = 73.7$, $p = 0.005$), also characterised the assemblage 'within' the GWP in December 2009 (Figure 5a). Conversely the fish assemblage 'outside' of the GWP was characterised by greater abundances of estuarine Tamar River goby ($IV = 74.7$, $p = 0.003$) and sandy sprat ($IV = 83.3$, $p < 0.001$), and redfin perch ($IV = 99.6$, $p < 0.001$).

In April 2010, differences in assemblages were again primarily due to greater abundance of common carp 'within' the GWP and greater abundance of estuarine lagoon goby and freshwater Australian smelt 'outside' the GWP (Figure 5b). Common carp ($IV = 99.4$, $p < 0.001$), estuarine bridled goby ($IV = 78.4$, $p = 0.005$) and non-native eastern gambusia ($IV = 50$, $p = 0.007$) characterised the assemblage 'within' the GWP, whilst the assemblage 'outside' of the GWP was characterised by greater abundances of freshwater and estuarine species; namely carp gudgeon ($IV = 59.7$, $p = 0.003$), flat-headed gudgeon ($IV = 73.1$, $p = 0.013$), redfin perch ($IV = 33.3$, $p = 0.025$) and lagoon goby ($IV = 82.1$, $p < 0.001$) (Figure 5b).

In December 2010, the difference in fish assemblage between locations was due to greater abundances of redfin perch, small-mouthed hardyhead and bony herring 'within' the GWP and greater abundance of Australian smelt 'outside' the GWP (Figure 5c). Furthermore, the assemblage 'within' the GWP was characterised by redfin perch ($IV = 62.3$, $p < 0.001$) and the assemblage 'outside' of the GWP was characterised by greater abundances of common carp ($IV = 57.4$, $p = 0.019$) and carp gudgeon ($IV = 71.1$, $p < 0.001$).

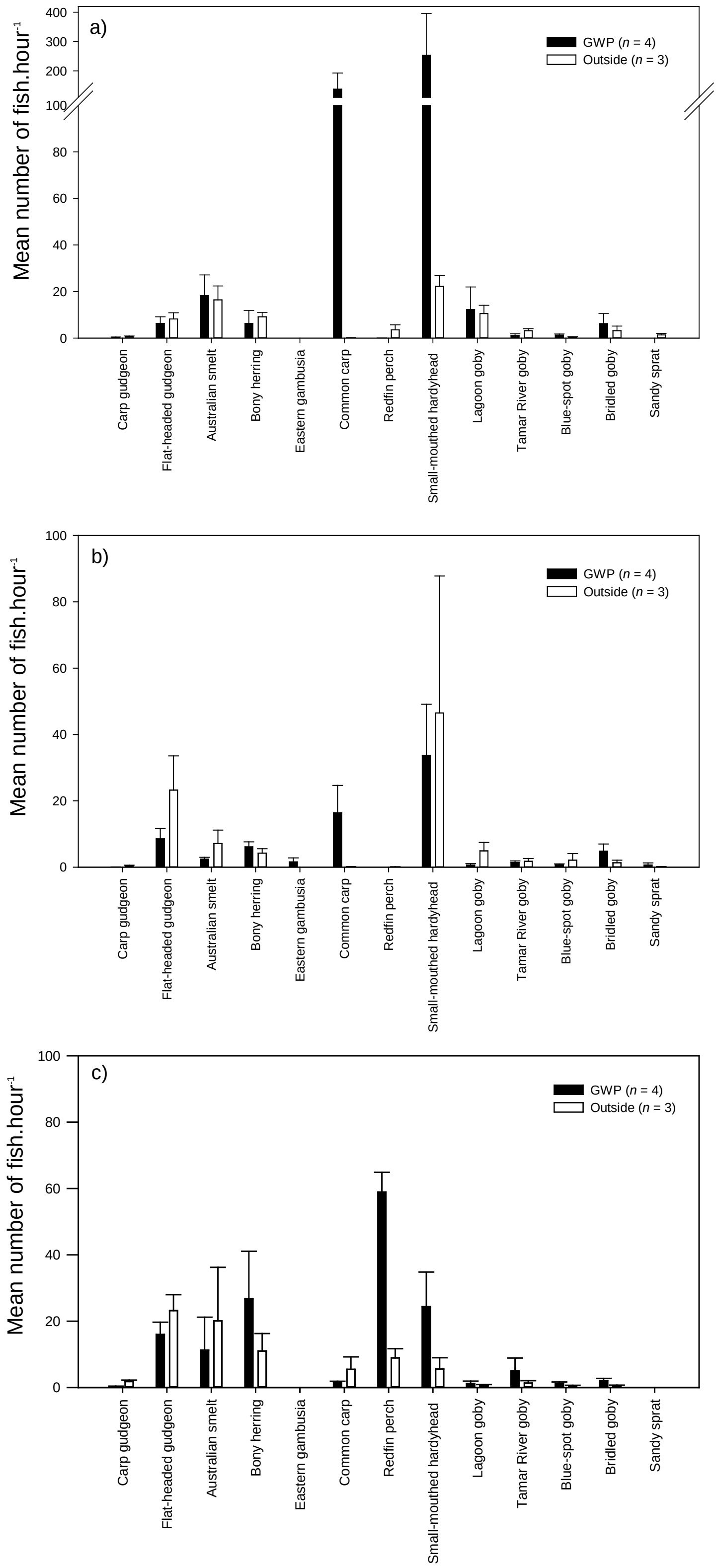

Figure 5. Relative abundances (mean number of fish.hour^{-1}) of species determined to significantly contribute to differences between fish assemblages (by SIMPER) and/or are significant indicators (ISA) of the fish assemblage at a given location (i.e. GWP or outside GWP) in (a) December 2009, (b) April 2010 and (c) December 2010.

3.3.2. Temporal variation

PERMANOVA pairwise comparisons of fish assemblages between sampling events were undertaken for each location (i.e. 'within' GWP and 'outside' GWP). Fish assemblages 'within' the GWP differed significantly between all sampling events ($p < 0.001$; Bonferroni corrected $\alpha = 0.005$). Fish assemblages 'outside' of the GWP also differed significantly between all sampling events ($p < 0.003$) except for December 2009 and March/April 2010 ($t = 1.35$, $p = 0.16$).

'Within' the GWP, there were no significant indicators of the assemblage in August 2009, however, following water level management in December 2010, the assemblage was characterised by a combination of freshwater, estuarine and catadromous species, including common carp, carp gudgeon, lagoon goby, blue-spot goby and common galaxias (Table 3; Figure 6). In April 2010, the assemblage was characterised by bridled goby and eastern gambusia (Table 3; Figure 6). Following, partial removal of the Clayton regulator, fish assemblages in December 2010 were characterised by the catadromous congolli and freshwater bony herring, flat-headed gudgeon and redfin perch (Table 3; Figure 6). In March/April 2011, the assemblage was characterised by greater abundances of two freshwater species, namely golden perch and goldfish (Table 3; Figure 6).

'Outside' of the GWP in August 2009, the fish assemblage was characterised by catadromous congolli and estuarine lagoon goby (Table 3; Figure 7). In December 2009, the assemblage was characterised by three estuarine species; bridled goby, Tamar River goby and sandy sprat (Table 3; Figure 7). There were no significant indicators of the assemblage in April 2010, however, in December 2010, following increased water levels, the assemblage was characterised by four freshwater species; carp gudgeon, flat-headed gudgeon, common carp and redfin perch (Table 3; Figure 7). Again in March/April 2011 the assemblage 'outside' of the GWP was characterised by greater abundances of two freshwater species, namely golden perch and goldfish (Table 3; Figure 7).

Table 3. Summary of indicator species analysis (ISA) showing species that were determined to be significant indicators (p < 0.05) characterising assemblages 'within' the GWP and 'outside' the GWP in August 2009, December 2009, April 2010, December 2010 or March/April 2011. *IV* = indicator value. Obligate freshwater species are shaded in green, catadromous species in orange and estuarine species in blue.

GWP										
	Aug 09		**Dec 09**		**Apr 10**		**Dec 10**		**Mar/Apr 11**	
Species	***IV***	***P***	***IV***	***P***	***IV***	***P***	***IV***	***P***	***IV***	***P***
Carp gudgeon			23.9	0.04						
Flat-headed gudgeon							26.1	<0.001		
Bony herring							31.8	<0.001		
Golden perch									45.2	<0.001
Common carp[@]			31	<0.001						
Redfin perch[@]							67.7	<0.001		
Eastern gambusia[@]					33.1	0.001				
Goldfish[@]									62	0.002
Common galaxias			26.9	0.02						
Congolli							32.2	0.001		
Lagoon goby			30.8	0.001						
Blue-spot goby			31.8	0.002						
Bridled goby					31.1	<0.001				
Outside										
	Aug 09		**Dec 09**		**Apr 10**		**Dec 10**		**Mar/Apr 11**	
Species	***IV***	***P***	***IV***	***P***	***IV***	***P***	***IV***	***P***	***IV***	***P***
Carp gudgeon							34.8	<0.001		
Flat-headed gudgeon							26.2	<0.001		
Golden perch									50	0.003
Common carp[@]							41.1	<0.001		
Redfin perch[@]							32.5	<0.001		
Goldfish[@]									76.2	<0.001
Congolli	45.2	0.001								
Lagoon goby	30.1	0.004								
Tamar River goby			31.9	0.003						
Bridled goby			35.7	<0.001						
Sandy sprat			57.3	<0.001						

[@]*denotes non-native species*

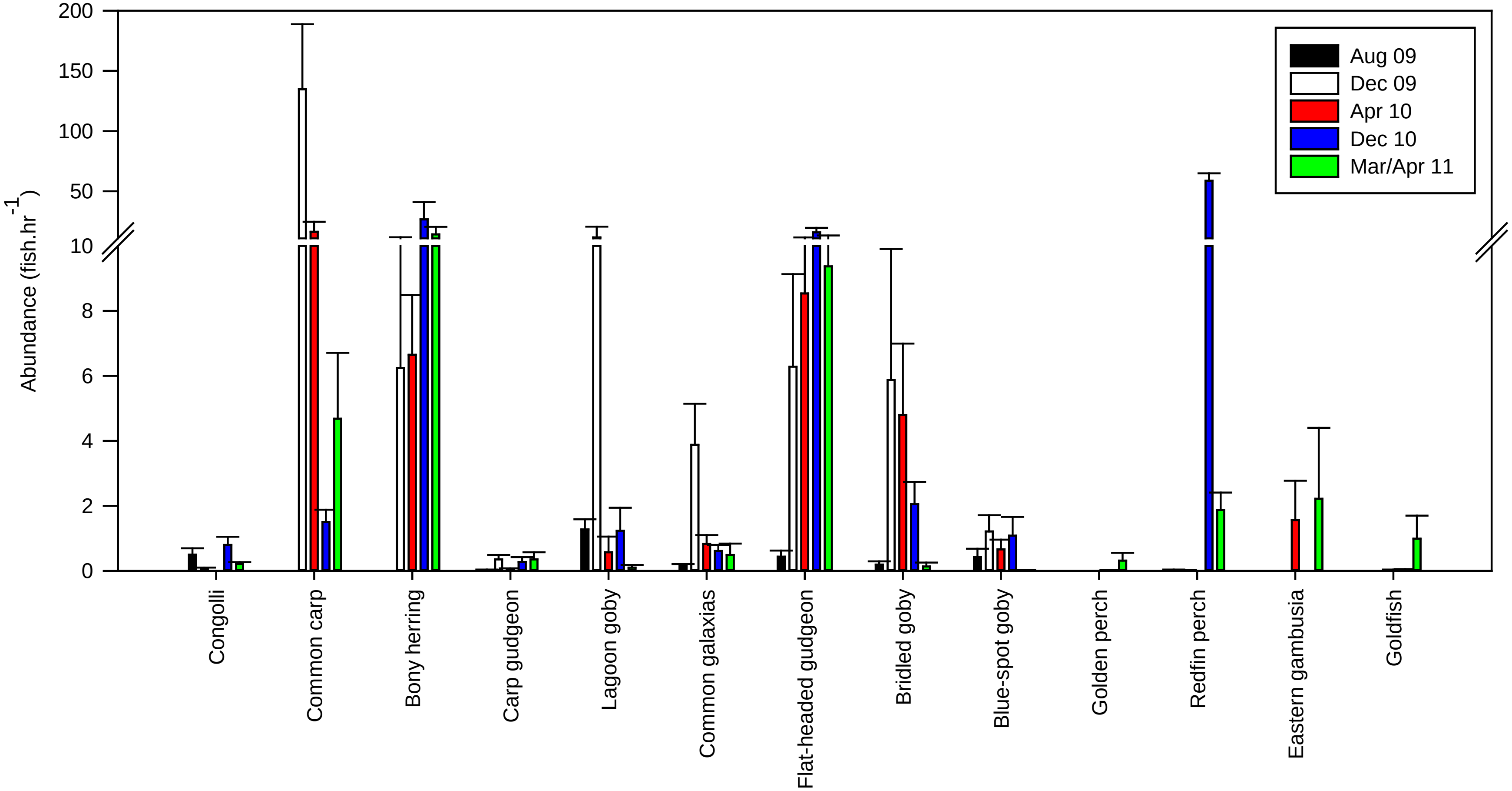

Figure 6. Relative abundances (mean number of fish.hour^{-1}) of species that were significant indicators (ISA) of fish assemblages 'within' the GWP during sampling in August 2009, December 2009, April 2010, December 2010 or March/April 2011.

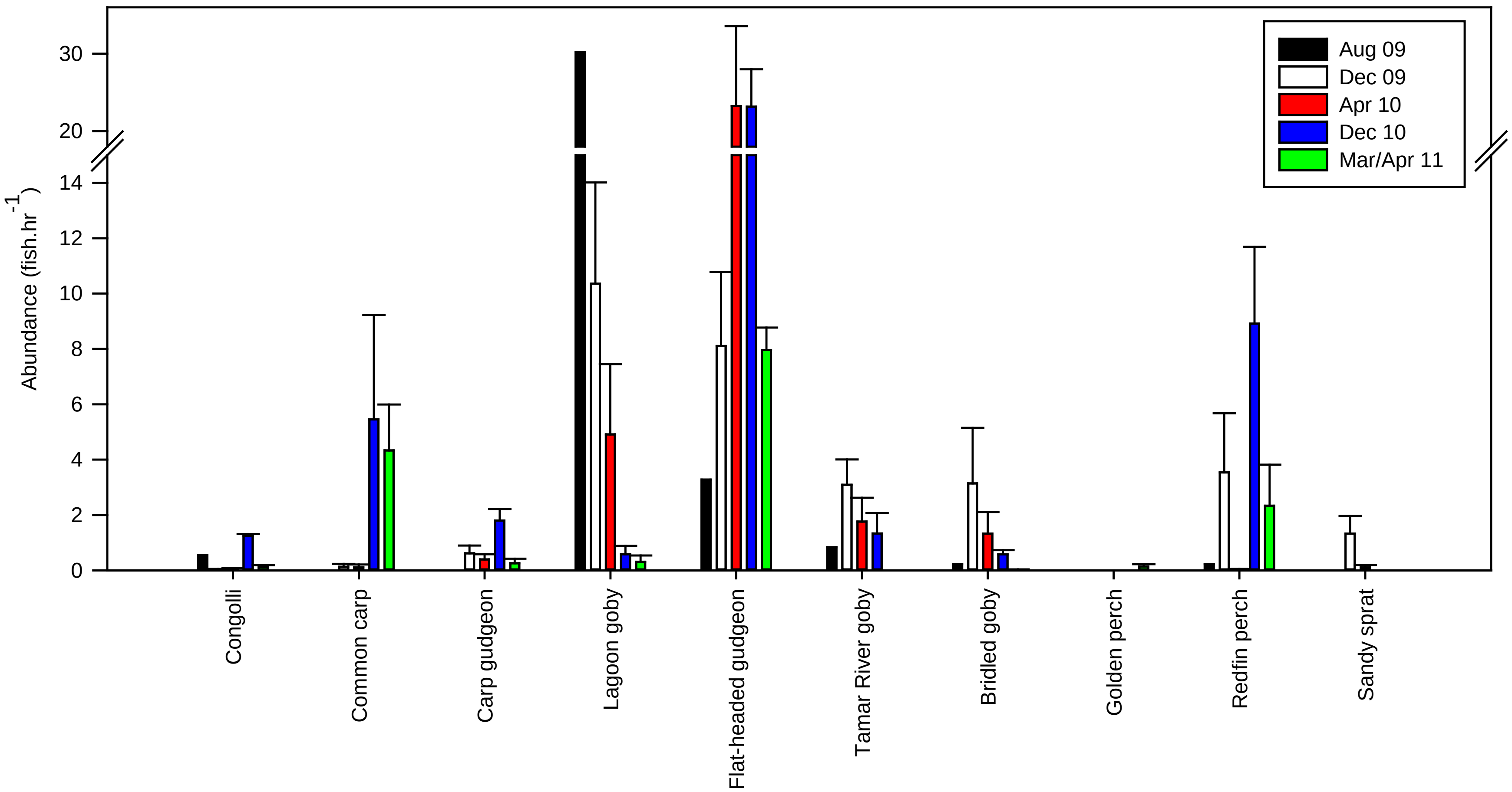

Figure 7. Relative abundances (mean number of fish.hour^{-1}) of species that were significant indicators (ISA) of fish assemblages 'outside' of the GWP during sampling in August 2009, December 2009, April 2010, December 2010 or March/April 2011.

3.4. Spatial and temporal variation in recruitment patterns

Spatial differences in the recruitment of eight selected species in 2010/11 (i.e. small-mouthed hardyhead, flat-headed gudgeon, common galaxias, Australian smelt, bony herring, golden perch, common carp and redfin perch), was investigated using length-frequency analysis. The Kolmogorov-Smirnov (K-S) ‘goodness of fit’ test was used to assess the statistical significance of differences in length-frequency distributions between locations during each sampling event.

Small-mouthed hardyhead

Length-frequency distributions of small-mouthed hardyhead differed significantly between locations in December 2010 ($D = 0.26$, $p < 0.001$) but were not sampled in sufficient numbers ‘outside’ of the GWP in March/April 2011 to allow statistical comparisons (Figure 8a). In December 2010, length distributions at both locations were bi-modal, with adult cohorts at >40 mm FL and likely young-of-year (YOY) cohorts at <35 mm FL. Progression of the YOY cohort was evident at both locations in March/April 2011 but the population ‘within’ the GWP was dominated by fish 45-54 mm FL (>65%) compared with 35-44 mm FL (>70%) ‘outside’ of the GWP.

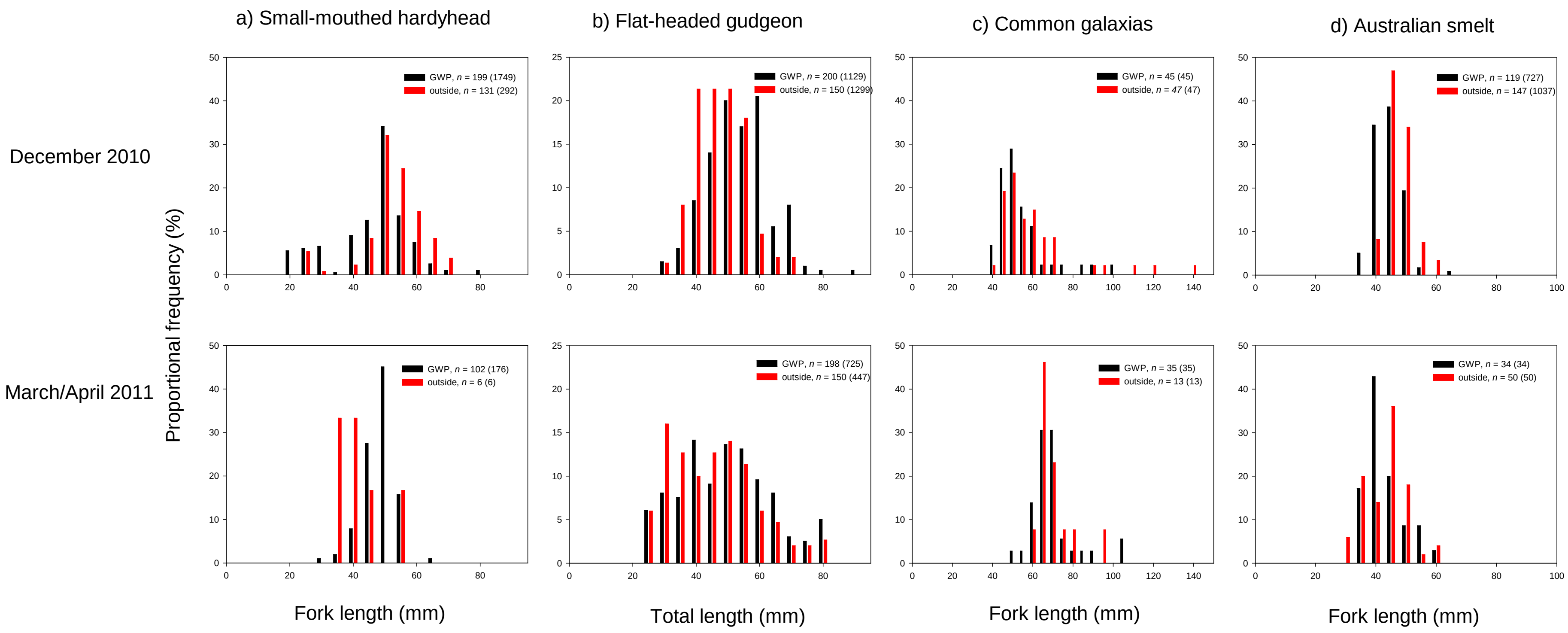

Figure 8. Length-frequency distributions of (a) small-mouthed hardyhead, (b) flat-headed gudgeon, (c) lagoon goby and (d) Australian smelt sampled from sites ‘within’ and ‘outside’ the GWP in December 2010 and March/April 2011. Sample sizes indicate the number of fish measured for length and the total number of fish sampled (in brackets). Note variation in y-axis scaling for different species.

Flat-headed gudgeon

Length-frequency distributions appear similar in December 2010, with uni-modal distributions at both locations, however, distributions differed significantly (D = 0.27, p < 0.001) likely due to a greater proportion of fish >75 mm TL 'within' the GWP (Figure 8b). In March/April 2011, length-frequency distributions were not significantly different (D = 0.13, p = 0.12) with fish ranging 25-83 mm TL and 26-84 mm TL 'outside' the GWP and 'within' the GWP respectively. Recruitment was evident at both locations with similar proportions of individuals <40 mm TL (Figure 8b).

Common galaxias

Length-frequency distributions of common galaxias were not significantly different between locations in December 2010 (D = 0.18, p = 0.44) (Figure 8c). A YOY cohort (<60 mm FL) was present and represented >50% of the population at both locations (Figure 8c). Length-frequency distributions appear similar between locations in March/April 2011 but statistical analysis was not possible due to the small sample size from 'outside' of the GWP. Nonetheless, growth of YOY was evident with individuals' 65-74 mm FL comprising similar proportions of the population (~60%) at both locations.

Australian smelt

Length-frequency distributions were uni-modal at both locations in December 2010 but were significantly different (D = 0.31, p < 0.001) with fish 40-49 mm FL dominating the catch 'within' the GWP and fish 45-54 mm FL dominating the catch 'outside' of the GWP (Figure 8d). In March/April 2011, length-frequency distributions were similar and not significantly different between locations (D = 0.2, p = 0.39) with recruitment of YOY (<40 mm FL) evident at both locations.

Bony herring

Length-frequency distributions for bony herring were uni-modal and not significantly different between locations in December 2010 (D = 0.15, p = 0.21) with catches dominated by newly recruited YOY (<80 mm FL) (Figure 9a). Very few large adult fish (>200 mm FL) were sampled at either location in December 2010. Conversely in March/April 2011, bony herring from both locations exhibited similar (D = 0.07, p =

0.73) bi-modal distributions, with a broad YOY cohort (27-138 mm FL) and a larger adult cohort (>200 mm FL) (Figure 9a).

Golden perch

Golden perch were sampled in low numbers in December 2010; however, a potential YOY individual (95 mm TL) was sampled ‘within’ the GWP (Figure 9b). In March/April 2011, whilst sampled in insufficient numbers to allow statistical comparisons, golden perch length-frequency distributions appeared similar between locations, with a YOY cohort (<60 mm TL) dominating the catch (>70%) at both locations, with smaller proportions of adult fish (>250 mm TL) also present (Figure 9b).

Common carp

The length-frequency distribution of common carp differed significantly between locations in December 2010 ($D = 0.87$, $p < 0.001$) (Figure 9c). Whilst the distribution of lengths was similar between locations, newly recruited YOY (<100 mm FL) were more abundant ‘outside’ of the GWP (>65% of catch) compared to ‘within’ the GWP (~30%) and conversely, larger (120-220 mm FL) and likely older fish were more abundant ‘within’ the GWP (>40%) compared to ‘outside’ the GWP (~10%) (Figure 9c). Small proportions of adult fish were also present at both locations. In March/April 2011, length-frequency distributions again differed significantly between locations ($D = 0.21$, $p = 0.002$). Nonetheless, newly recruited YOY (<160 mm FL) dominated the catch at both locations, with sub-adult fish (160-300 mm FL) also contributing substantially to populations (Figure 10a) and only small proportions of adult fish (>400 mm FL) (Figure 9c).

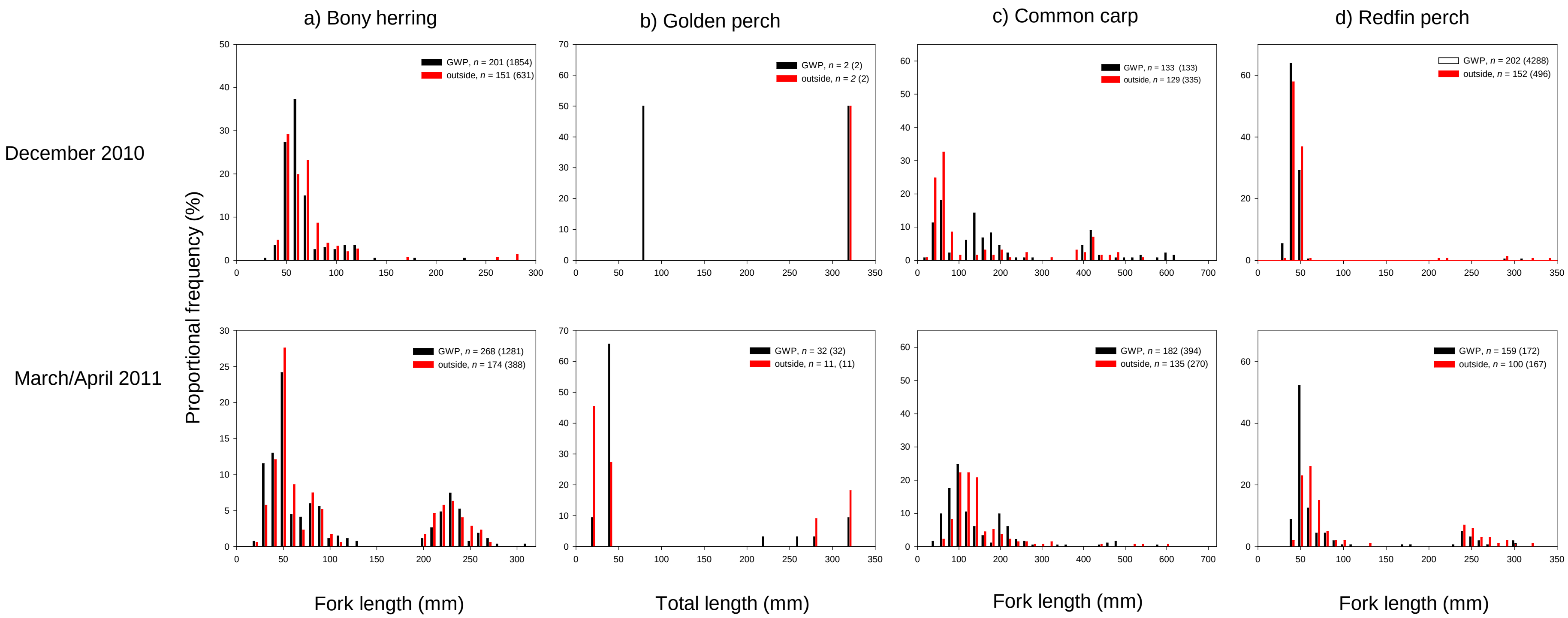

Figure 9. Length-frequency distributions of (a)bony herring, (b) golden perch (c) common carp and (d) redfin perch, sampled from sites within the GWP and outside the GWP in December 2010 and March/April 2011. Sample sizes indicate the number of fish measured for length and the total number of fish sampled (in brackets). Note variation in y-axis scaling for different species.

(a) (b)

Figure 10. (a) A mixture of YOY and larger sub-adult common carp captured ‘outside’ of the GWP in March/April 2011 and (b) a range of different sized (40 – 100 mm FL) YOY redfin perch from ‘outside’ the GWP in March/April 2011.

Redfin perch

In December 2010, length-frequency distributions of redfin perch were similar and non-significantly different between locations (D = 0.11, p = 0.27), with the population dominated (>95% at both locations) by newly recruited YOY (<70 mm FL) (Figure 9d). In March/April 2011, length-frequency distributions exhibited similar patterns but differed significantly (D = 0.36, p < 0.001) (Figure 9d). Both locations were again dominated by the YOY cohort (40 - 120 mm FL) (Figure 10b) but smaller fish (<60 mm FL) were more abundant ‘within’ the GWP. Adult fish (>230 mm FL) were sampled in similar proportions at both locations.

3.5. Fish condition

Very few fish exhibited evidence of parasites, ulcers, wounds, poor fin condition or deformity in December 2010. Small numbers of common carp (n = 3) and redfin perch (n = 2) were observed with deformities and an individual bony herring was observed with an ulcer. Whilst low sample sizes from December 2010 did not allow statistical comparisons between sampling events, there appeared to be an increase in the frequency of fish observed in ‘poor condition’ in March/April 2011 (n = 46; Table 3). Individuals from nine different species exhibited symptoms ranging across five different health categories (Table 3). Poor health affected different species to varying degrees, with the copepod parasite *Lernaea cyprinacea* (anchorworm) most prevalent in golden perch (13.6% of individuals), particularly YOY (Figure 11a) and common galaxias (20.8%), and ulcers particularly prevalent in goldfish (11%) (Figure 11b).

Table 4. Numbers of fish sampled with symptoms of ‘poor condition’ in March/April 2011.

Species	Number of fish presenting with symptoms									
	Lernaea		Ulcer		Poor fin condition		Wound		Deformity	
	GWP	Out	GWP	Out	GWP	Out	GWP	Out	GWP	Out
Golden perch	5	1								
Murray hardyhead	1									
Flat-headed gudgeon	1	1				1	1			
Common galaxias	8	2			1			1		1
Congolli				1						
Tamar River goby	2									
Redfin perch		1		1		1			1	
Common carp					1					
Goldfish	2		9	2	2					

a) b)

Figure 11. a) YOY golden perch exhibiting parasitism by the hookworm *Lernaea cyprinacea* at the base of the caudal fin and (b) a goldfish exhibiting a severe ulcer.

4. DISCUSSION

In response to the risk posed by large areas of ASS in the lower reaches of the Finniss River and Currency Creek, the *Goolwa Channel Water Level Management Plan* (GCWLMP) was initiated with the construction of the Clayton Regulator in August 2009. The GCWLMP aimed primarily to maintain higher water levels and limit further exposure and formation of ASS, and secondarily to provide an adequate area of freshwater habitat for freshwater dependent biota in the face of broadly deteriorating conditions in the Lower Lakes (SA Water 2009). In August 2010, however, increased River Murray inflows resulted in naturally increased water levels in Lake Alexandrina and the Clayton Regulator was partially removed, thus re-connecting the Goolwa Channel with Lake Alexandrina. The aim of the current project was to investigate spatio-temporal variation in fish assemblage structure and recruitment in 2010/11 in comparison to 2009/10 during the GCWLMP (Bice *et al.* 2010a). This allowed the investigation of hypotheses and questions generated following monitoring in 2009/10, including,

1. Fish communities will continue to be dominated by common carp
   a. Are conditions in the Goolwa Channel suitable for further expansion of the common carp population?
   b. Was there significant survival of newly recruited young-of-year common carp from 2009/10?
2. Are Murray hardyhead persisting within the Goolwa Channel?

Results suggest that whilst common carp did not numerically dominate the fish assemblage in 2010/11, as in 2009/10, the species was still abundant and likely dominated the fish biomass. Whilst there was not a numerical expansion in the common carp population in 2010/11, there was significant recruitment of YOY over a greater area (i.e. both 'within' and 'outside' of the GWP) than 2009/10, suggesting that conditions in 2010/11 were also suitable for spawning and recruitment. Furthermore, there was significant survival of the YOY cohort detected in 2009/10, with a substantial proportion of the population comprised of fish 160-300 mm TL.

Murray hardyhead (nationally listed as *vulnerable* under the *EPBC Act* (1999)) continued to persist in the Goolwa Channel and were sampled in low numbers in both December 2010 and March/April 2011. Nevertheless, only two individuals were sampled from a single site (Goolwa Barrage) in March/April 2011 and several other monitoring programs failed to detect the species in the region in autumn 2011 (Bice *et al.* In Prep; Wedderburn and Barnes In Prep). Increased water levels and habitat availability, and potential dispersal, may have decreased the catchability of this species.

4.1. General catch

A diverse range of species with various life-history strategies were captured over the study period, including obligate freshwater, catadromous, estuarine and marine migrant species. Species richness (25) was greater than that observed in other recent monitoring in the Lower Lakes including Wedderburn and Hammer (2003) (21), Bice *et al* (2008) (20), Wedderburn and Barnes (2009) (20) and Wedderburn and Hillyard (2010) (20). This was primarily due to the presence of freshwater catfish (protected under the *Fisheries Act* (2007) and considered endangered in South Australia (Hammer *et al.* 2009)) and several estuarine/marine species not commonly sampled in the Lower Lakes; namely black bream, flat-tailed mullet, river garfish and Australian salmon. The use of gill nets in the current study and not in the previous studies increased the likelihood of sampling several of these species.

Importantly, the continued absence of Yarra pygmy perch, despite extensive sampling in this and several other monitoring programs in the past three years (Bice *et al.* 2009; Wedderburn and Barnes 2009; Bice *et al.* 2010b; Wedderburn and Hillyard 2010), suggests the local extirpation of the sole wild population of this species in the MDB. Southern pygmy perch were also not collected in the current project but were sampled at Black Swamp, at the confluence of the Finniss River and Tookayerta Creek, by Bice *et al.* (In Prep) in spring 2010, indicating the species is potentially persisting in low abundances in the region.

4.2. Spatial and temporal variation in fish assemblages

Fish assemblages both ‘within’ and ‘outside’ the GWP differed significantly between sampling events but temporal variation in assemblages was not consistent between locations. Fish assemblages were similar between locations in August 2009, but differed significantly during water level management in December 2009 and April 2010, reflecting the response of fish species to the isolation of the GWP and varying hydrological conditions between locations. Fish assemblages differed spatially in the short-term (December 2010) following naturally increased water levels and the partial removal of the Clayton Regulator but were not significantly different by March/April 2011. Homogenisation of fish assemblages between sites 'within' the GWP and 'outside' the GWP in March/April 2011 reflects the hydrological and physical re-connection of the Goolwa Channel and Lake Alexandrina, and a combination of the subsequent potential for movement of fish and similarity of hydrological conditions between locations.

Comparing the temporal variation in fish assemblage structure between sampling events at each location indicates clear patterns of fish response, firstly to water level management under the GCWLMP in 2009/10 and secondly, increased River Murray inflows and water levels, and partial removal of the Clayton Regulator in 2010/11. Water level management 'within' the GWP facilitated spawning and recruitment of common carp that resulted in significantly greater abundances than 'outside' of the GWP and primarily drove the spatial variation in fish assemblages during this period. At the same time, several freshwater species (i.e. carp gudgeon, flat-headed gudgeon, Australian smelt) were more abundant 'outside' of the GWP, whilst several small-bodied estuarine species (small-mouthed hardyhead, blue-spot goby, bridled goby, sandy sprat and lagoon goby) were present and abundant in one or both locations. Following the partial removal of the Clayton Regulator, temporal variation in fish assemblage structure was more consistent between sites 'within' and 'outside' the GWP. The abundance of common carp increased significantly at sites 'outside' of the GWP with substantial recruitment of YOY in spring/summer 2010/11 and likely dispersal of sub-adult fish from 'within' the GWP following breaching of the regulator. Recruitment of YOY common carp from spawning in 2010/11 was also evident at sites 'within' the GWP. Furthermore in 2010/11, fish assemblages both 'within' and 'outside' of GWP were consistently characterised by decreasing abundances of the aforementioned estuarine species and high abundances of the catadromous congolli, several native freshwater species (golden perch, bony herring, flat-headed gudgeon and carp gudgeon) and non-native redfin perch and goldfish.

The occurrence of significant natural inflows to the Lower Lakes was undoubtedly the overarching driver structuring fish assemblages in 2010/11. More specifically, subsequent variation in a number of abiotic and biotic factors, including salinity, productivity, aquatic habitat availability and quality, connectivity and species' recruitment patterns, likely directly influenced fish assemblage patterns. Nonetheless, different species varied in their response to these factors. Reductions in salinity at both locations (from >20,000 µS.cm^{-1} down to <1000 µS.cm^{-1}) potentially resulted in the reduced abundance or indeed absence of several estuarine species and increased abundance of obligate freshwater species in March/April 2011. Significantly greater abundance of congolli, an obligate catadromous species, in December 2010, of which >95% of the total catch were YOY (<70 mm TL), reflected the re-connection of the Lower Lakes with the Coorong and successful upstream migration of these individuals (authors unpublished data). Temporal variation in the abundance of some species, most notably common carp, redfin perch and golden perch, were related to conspicuous YOY recruitment events.

4.3. Spatial and temporal variation in recruitment patterns

During the management of water levels in 2009/10, spatial variation in recruitment patterns between sites ‘within’ the GWP and ‘outside’ the GWP was exhibited by several species, most notably common carp, which exhibited enhanced recruitment ‘within’ the GWP (Bice *et al.* 2010a). In 2010/11, however, consistent with the homogenisation of fish assemblages following increased inflows and partial removal of the Clayton Regulator, recruitment patterns of most species were consistent between locations. Nevertheless, there was substantial temporal variation in the recruitment patterns of some species between 2009/10 and 2010/11.

The recruitment of YOY common carp was facilitated by water level management ‘within’ the GWP in 2009/10 (Bice *et al.* 2010a). The progression of this cohort was evident in 2010/11, with individuals 160-300 mm FL comprising a substantial proportion of the population at both locations. This suggests the continued survival of this cohort of fish and presence ‘outside’ of the GWP indicates likely dispersal of these individuals from the GWP upon breaching of the regulator. In addition, a new cohort of YOY individuals spawned in the spring/summer 2010/11, was also present and dominated the population in the region.

Increased water level ‘within’ the GWP in 2009/10 resulted in the re-inundation of edge habitats and a positive response from aquatic vegetation, which was largely absent from the area prior to the GCWLMP (Nicol and Gehrig 2010), providing favourable conditions for common carp spawning and recruitment (see Crivelli 1981; Koehn *et al.* 2000). In Lake Alexandrina in 2009/10, water levels remained low, edge habitats were not inundated and aquatic vegetation was largely absent (Nicol and

Gehrig 2010), and recruitment of common carp was significantly less than 'within' the GWP (Bice *et al.* 2010a). Increased water levels in Lake Alexandrina in 2010/11 resulted in a re-inundation of edge habitats and positive response of aquatic vegetation (Gehrig *et al.* 2011) albeit under vastly different hydrological conditions from the GWP in 2009/10. The response of common carp to increased water level, both 'within' the GWP in 2009/10 and in Lake Alexandrina in 2010/11 reflected the flexible spawning strategy of common carp and ability to recruit under different flow conditions, concurring with the finding of other studies that have observed spawning and recruitment in the absence of flooding (Smith and Walker 2004) and upon increased flows and floodplain inundation (King et al. 2003; Stuart and Jones 2006; King *et al.* 2010).

Another non-native species, redfin perch, exhibited significantly greater recruitment in 2010/11 relative to 2009/10, with YOY comprising >95% of the total catch in December 2010 and >75% in March/April 2011. Contrastingly, no recruitment of YOY redfin perch was detected 'within' the GWP during water level management in 2009/10, suggesting that conditions provided by natural inflows and increased water levels (e.g. reduced salinities) were more conducive to spawning and recruitment. Several studies have investigated the spawning and recruitment of redfin perch in the northern hemisphere (Hargeby *et al.* 2005; Langangen *et al.* 2011) but the majority have been made in lentic (still) waters, and the few that have investigated populations in riverine or lotic (flowing) environments (Mann 1978; Nunn *et al.* 2007) have neglected to link spawning and recruitment to flow conditions. Nonetheless, evidence suggests spawning and recruitment in redfin perch is not typically flow-related. The species spawns annually, which has been demonstrated in Lake Albert (Bice 2010b), and in the northern hemisphere timing of spawning is believed to be dictated by photoperiod and temperature (Gillet and Dubois 2007). Many populations exhibit inter-annual recruitment variation (Paxton *et al.* 2004) with temperature during the larval and juvenile stages typically positively correlated with recruitment (Kjellman *et al.* 2003; Paxton *et al.* 2004). Nonetheless, resource availability in the larval and juvenile stages could influence recruitment.

Increased inflows and water levels in Lake Alexandrina in 2010/11 would likely have resulted in enhanced primary and secondary productivity. Redfin perch typically undergo two dietary shifts during ontogeny whereby larvae and early juveniles are planktivorous before becoming benthivorous and finally piscivorous at a length of about 120-180 mm (Persson 1993; Mittelbach and Persson 1998). Both planktonic and benthic prey items were potentially abundant in Lake Alexandrina in 2010/11 and may have facilitated recruitment of YOY redfin perch. Interestingly, it has been suggested the dietary shift to piscivory may be an ontogentic bottleneck for redfin perch, particularly when there is significant inter- and intra-specific competition, and thus growth, survival and future year class contribution may be impacted (Persson 1993; Persson 1986). Nonetheless, it remains unknown if the strong YOY recruitment observed in redfin perch in Lake Alexandrina in 2010/11 will translate to year class strength and increased adult abundance in following years.

Native golden perch also exhibited greater recruitment in 2010/11, relative to 2009/10. Whilst only sampled in low numbers in March/April 2011 (*n* = 43), ~75% of individuals sampled were newly recruited YOY (<60 mm TL), which are rarely sampled in Lake Alexandrina (Wedderburn and Hammer 2003; Bice and Ye 2007; Wedderburn and Hillyard 2010; authors unpublished data). Golden perch reproduction is believed to be flow-dependent, with the species spawning and recruiting in association with within-channel flow increases and floods during spring-summer in the mid-Murray (Mallen-Cooper and Stuart 2003; King et al*.* 2009). It is likely that increased flows in the lower River Murray in 2010/11 facilitated successful spawning and recruitment of YOY golden perch in Lake Alexandrina. Indeed, preliminary data suggests that significant recruitment of YOY golden perch has occurred throughout the South Australian MDB in 2010/11 (authors unpublished data).

4.4. Fish condition

The presence of parasites, deformities, wounds, ulcers and other gross indicators of poor health was negligible in 2009/10 (Bice *et al.* 2010a) and December 2010. In March/April 2011, however, parasitism by the copepod *Lernaea cyprinacea* (anchor worm) was evident on seven fish species and was most prevalent on common galaxias and YOY golden perch. Nonetheless, infection rates still remained well below those reported by other studies (e.g. Pérez-Bote (2010)). The attachment organ of *Lernaea cyprinacea* penetrates beneath the skin of hosts and causes haemorrhaging, muscle necrosis, an inflammatory response and can lead to secondary infection (Lester and Haywood 2006) that may be detrimental to fish health (Pérez-Bote 2010). Medeiros and Maltchik (1999) suggest that dispersal of fish and spread of their pathogens may increase parasitism by *Lernaea cyprinacea* during flows and floods. Prevalence of *Lernaea cyprinacea* is typically highest during summer due to elevated water temperatures (Pérez-Bote 2010) and thus prevalence in Lake Alexandrina is likely to decrease through autumn and winter.

Additionally, several goldfish exhibited severe ulcers and ‘red spots’, which may be indicators of epizootic ulcerative syndrome (EUS), a notifiable disease known to cause fish kills. Observation of fish with signs consistent with EUS was greater in Mar/April 2011 than previous seasons, albeit without statistical significance, following increased flows, water levels and partial removal of the Clayton Regulator. Several studies (Sammut *et al.* 1995; Choongo *et al.* 2009) have associated increased prevalence of EUS with contamination of surface waters following acid sulfate soil drainage. Indeed, Choongo *et al.* (2009) associated increased prevalence of EUS in the Zambezi River, Zambia, with the acidification of ground water following several years of drought and subsequent contamination of surface waters following significant flows. This association was not investigated directly in this study, however, general hydrological conditions were similar to those of Choongo *et al.* (2009) and thus the re-inundation of ASS in Lake Alexandrina may have created conditions that predispose fish to EUS infections. Nonetheless, the prevalence of signs in this study was very low, even in March/April 2011, when compared to ‘outbreaks’ reported in other studies.

4.5. Conclusions and management recommendations

The monitoring of fish assemblages in 2009/10, during the GCWLMP (Bice *et al.* 2010a), and in 2010/11, following naturally increased flows and water levels, and partial removal of the Clayton Regulator, provided an opportunity to compare the influence of a managed increase in water level and a natural increase in flow and water level on fish assemblage structure and recruitment. Other factors also potentially influenced fish assemblage patterns, including antecedent conditions and re-connection of Lake Alexandrina and the Coorong, and such factors were also considered.

In 2009/10, the GCWLMP provided conditions optimal for the spawning and recruitment of non-native common carp but did not enhance native fish populations. Additionally, the Clayton Regulator further fragmented an already highly regulated system and represented a significant barrier to fish movement. This intervention highlights that an engineered solution decoupled from broader-scale hydrological processes may result in a trade-off between achieving positive environmental outcomes (e.g. mitigation of ASS) and potential negative impacts, such as providing a recruitment 'hotspot' for non-native species and inhibiting fish movement.

Contrastingly, increased natural flows and water levels, and partial removal of the Clayton Regulator in 2010/11 resulted in a homogenisation of fish assemblage structure and recruitment patterns between sites 'within' and 'outside' of the GWP, and significant recruitment events of both native (golden perch) and non-native species (redfin perch and common carp). The increased dominance of obligate freshwater species and increased abundance of catadromous congolli reflect the re-connection of the Goolwa Channel with greater Lake Alexandrina, re-connection of Lake Alexandrina with the Coorong and the influence of broad-scale hydrological conditions on the region (e.g. reduced salinity).

The results of this study suggest that river management, involving restoration of the natural flow regime rather than engineered water level manipulation, has a greater capacity to illicit a positive response from native fish species. Nonetheless, approaches involving restoration of the natural flow regime may also involve a trade-off between achieving positive environmental outcomes (i.e. recruitment of native species) and potential negative impacts (i.e. recruitment of non-native species). The ecological benefits of re-instating a 'near-natural' flow regime, however, are likely to outweigh ecological impacts, particularly after prolonged and ongoing flow restoration.

In 2011/12, variable water levels are likely to be managed in Lake Alexandrina, with the aim of decreasing salinities in Lake Albert (Jason Higham pers. comm.). This will initially involve the closure of barrage gates (fishways will remain open) and an increase in water levels in Lake Alexandrina (>0.75 m AHD), to allow freshwater to flow into Lake Albert, before a re-opening of barrage gates to allow freshwater releases to the Coorong, 'drawing down' levels in Lake Alexandrina (<0.6 m AHD) and 'pulling' saline water out of Lake Albert. This pattern may be repeated several times to achieve reduced salinities in Lake Albert. The actual hydrological regime (i.e. water level variation), however, will be dependent upon several factors including a potential environmental flow in spring 2011, Coorong water levels and barrage releases, and possible variation in River Murray inflows due to rainfall and broader catchment inflows. Nonetheless, elevated water levels are likely to occur in late winter (i.e. August) and through spring 2011.

Elevated water level (>0.75 m AHD) during spring 2011 may influence the fish community by increasing available spawning and nursery habitat, and thus facilitating recruitment in both native and non-native species. Many native species spawn in spring (Lintermans 2007) and it has been suggested that 'surcharged' water levels in the Lower Lakes at this time of year may facilitate the movement and utilisation of newly inundated habitat and subsequently facilitate the recruitment of fish species, including Murray hardyhead, Yarra pygmy perch and southern pygmy perch (Wedderburn and Hammer 2003; Bice and Ye 2007; Hammer 2007). Common carp in the lower River Murray also exhibit a peak in spawning activity in spring, from mid-October – December (Smith and Walker 2004a, b) and the flexible nature of spawning and recruitment observed in the current study, suggests that elevated water levels in Lake Alexandrina in spring 2011 may facilitate further spawning and recruitment in this species. Murray hardyhead and southern pygmy perch are now rare in the region and Yarra pygmy perch have likely been extirpated but a captive population awaits re-introduction with the return of favourable conditions to Lake Alexandrina. As such, the management of water levels to facilitate native species recruitment likely takes precedence over management to disadvantage non-native species (i.e. lowering water levels to limit access to spawning and nursery habitats). Nonetheless, common carp may spawn over a protracted period of 7-9 months in the lower River Murray, with a second spawning peak from early January – March (Smith and Walker 2004a, b) and the maintenance of lower water levels and thus limited access to spawning and nursery habitats during this period would likely disadvantage common carp spawning and recruitment, with limited impact on native species.

5. REFERENCES

Anderson, M. J., Gorley, R. N. and Clarke, K. R. (2008). 'PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods.' (PRIMER-E: Plymoth, UK.)

Bice, C. (2010a). 'Literature review on the ecology of fishes of the Lower Murray, Lower Lakes and Coorong. Report to the South Australian Department for Environment and Heritage.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 81pp. SARDI Publication Number F2010/000031-1.

Bice, C. (2010b). 'Biological information and age structure analysis of large-bodied fish species captured during the Lake Albert trial fish-down, October 2009.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 27pp. SARDI Publication Number F2010/000159-1.

Bice, C., Hammer, M., Wilson, P. and Zampatti, B. (In Prep). 'Fish monitoring for the 'Drought Action Plan for South Australian Murray-Darling Basin threatened freshwater fish populations': Summary for 2010/11.' South Australian Research and Development Institute, (Aquatic Sciences), Adelaide.

Bice, C., Hammer, M., Leigh, S. and Zampatti, B. (2010b). 'Fish monitoring for the 'Drought Action Plan for South Australian Murray-Darling Basin threatened freshwater fish populations': Summary for 2009/10.' South Australian Research and Development Institute, (Aquatic Sciences), Adelaide, 156pp. SARDI Publication No. F2010/000647-1.

Bice, C., Hammer, M., Wilson, P. and Zampatti, B. (2009). 'Fish monitoring for the 'Drought Action Plan for South Australian Murray-Darling Basin threatened freshwater fish populations': Summary for 2008/09. Report to the South Australian Department for Environment and Heritage.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 110pp. SARDI Publication No. F2009/000451-1.

Bice, C., Wilson, P. and Ye, Q. (2008). 'Threatened fish populations in the Lower Lakes of the River Murray in spring 2007 and summer 2008.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 32pp. SARDI Publication number F2008/000801-1.

Bice, C. and Ye, Q. (2007). 'Monitoring threatened fish communities on Hindmarsh Island, in the Lower Lakes of the River Murray, South Australia, in the summers of 2006 and 2007 with reference to baseline data from 2005.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 47pp. SARDI Publication Number F2007/000551-2.

Bice, C., Zampatti, B. and Short, D. (2010a). 'Response of fish to the 'Goolwa Channel Water Level Management Plan' in 2009/10. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 44pp. SARDI Publication number F2010/000703-1.

Bray, J. and Curtis, J. (1957). An ordination of the upland forest communities of Southern Wisconsin. *Ecological Monographs* **27**, 325-349.

Choongo, K., Hang'ombe, B., Samui, K. L., Syachaba, M., Phiri, H., Maguswi, C., Muyangaali, K., Bwalya, G. and Mataa, L. (2009). Environmental and climatic factors associated with epizootic ulcerative syndrome (EUS) in fish from the Zambezi floodplains, Zambia. *Bulletin of Environmental Contamination and Toxicology* **83**, 474-478.

Clarke, K. R. and Gorley, R. N. (2006). 'PRIMER v6: User manual/tutorial.' (PRIMER-E Ltd, Plymouth, UK)

Crivelli, A. J. (1981). The biology of the common carp, *Cyprinus carpio* L. in the Camargue, southern France. *Journal of Fish Biology* **18**, 271-290.

CSIRO (2008). 'Water availability in the Murray-Darling Basin.' Report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. CSIRO, Australia, 67pp.

Davies, P. E., Harris, J. H., Hillman, T. J. and Walker, K. F. (2008). 'SRA Report 1: A Report on the Ecological Health of Rivers in the Murray-Daling Basin, 2004-2007.' Prepared by the Independent Sustainable Rivers Audit Group for the Murray-Darling Basin Ministerial Council.

DEH (2009). 'The Coorong Lower Lakes and Murray Mouth: Managing for a Healthy Future, August 2009.' The Department for Environment and Heritage, Adelaide. ISBN 978-1-921466-47-2.

Dufrene, M. and Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs* **67**, 345-366.

DFW (2011). 'DFW Unpublished Data'. Department for Water.

Elliott, M., Whitfield, A. K., Potter, I. C., Blaber, S. J. M., Cyrus D. P., Nordlie, F. G. and Harrison, T. D. (2007). The guild approach to categorizing estuarine fish assemblages: a global review. *Fish and Fisheries* **8**, 241-268.

Fitzpatrick, R., Shand, P., Marvanek, S., Merry, R., Thomas, M., Raven, M., Simpson, S. and McClure, S. (2008). 'Acid sulfate soils in subaqueous, waterlogged and drained soil environments in Lake Albert, Lake Alexandrina and River Murray below Blanchtown (Lock 1): properties, distribution, genesis, risks and management.' CSIRO Land and Water Science. Report 46/08.

Gehrig, S., Nicol, J. and Bucater, L. (2011). Aquatic and littoral vegetation monitoring of Goolwa Channel 2009-11. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 46 pp.

Gillet, C. and Dubois, J. P. (2007). Effect of water temperature and size of females on the timing of spawning of perch *Perca fluviatilis* L. in Lake Geneva from 1984 to 2003. *Journal of Fish Biology* **70**, 1001-1014.

Hammer, M. (2007). Distribution, status and urgent conservation measures for Yarra pygmy perch in the Murray-Darling Basin. Report to the Department for Environment and Heritage. Aquasave Consultants, Adelaide. 29 pp.

Hammer, M., Wedderburn, S. and Van Weenen, J. (2009). 'Action Plan for South Australian Freshwater Fishes.' Native Fish Australia (SA).

Hargeby, A., Blom, H., Blindow, I. and Andersson, G. (2005). Increased growth and recruitment of piscivorous perch, *Perca fluviatilis*, during a transient phase of expanding submerged vegetation in a shallow lake. *Freshwater Biology* **50**, 2053-2062.

Jennings, P., Zampatti, B. and Bice, C. (2008). 'Fish movement and recruitment in the Coorong and Lower Lakes 2007/08 Progress Report.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 47pp.

King, A. J., Humphries, P. and Lake, P. S. (2003). Fish recruitment on floodplains: the roles of patterns of flooding and life history characteristics. *Canadian Journal of Fisheries and Aquatic Sciences* **60**, 773-786.

King, A. J., Tonkin, Z. and Mahoney, J. (2009). Environmental flow enhances native fish spawning and recruitment in the Murray River, Australia. *River Research and Applications* **25**, 1205-1218.

King, A. J., Ward, K. A., O'Connor, P., Green, D., Tonkin, Z. and Mahoney, J. (2010). Adaptive management of an environmental watering event to enhance native fish spawning and recruitment. *Freshwater Biology* **55**, 17-31.

Kjellman, J., Lappalainen, J., Urho, L. and Hudd, R. (2003). Early determination of perch and pikeperch recruitment in the northern Baltic Sea. *Hydrobiologia* **495**, 181-191.

Koehn, J., Brumley, A. and Gehrke, P. (2000). 'Managing the impacts of carp.' Bureau of Rural Sciences (Department of Agriculture, Fisheries and Forestry - Australia), Canberra.

Langangen, Ø., Edeline, E., Ohlberger, J., Winfield, I. J., Fletcher, J. M., James, J. B., Stenseth, N. C. and Vøllestad, L. A. (2011). Six decades of pike and perch population dynamics in Windermere. *Fisheries Research* **109**, 131-139.

Lester, R. J. G. and Haywood, C. J. (2006). 'Phylum Arthropoda.' In '*Fish Diseases and Disorders. Protozoan and Metazoan Infections*,' Vol. 1 (Woo, PTK ed.), pp 466-565. CAB International, Wallingofrd.

Lintermans, M. (2007). 'Fishes of the Murray-Darling Basin.' (Murray-Darling Basin Commission, Canberra).

Mallen-Cooper, M. and Stuart, I. G. (2003). Age, growth and non-flood recruitment of two potamodromous fishes in a large semi-arid/temperate river system. *River Research and Applications* **19**, 697-719.

Mann, R. H. K. (1978). Observations on the biology of the perch, *Perca fluviatilis*, in the River Stour, Dorset. *Freshwater Biology* **8**, 229-239.

Marsland, K. B. and Nicol, J. M. (2009). 'Lower Lakes vegetation condition monitoring - 2008/09.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 45pp. SARDI Publication Number F2009/000370-1.

Medeiros, E. S. F. and Maltchik, L. (1999). The effects of hydrological disturbance on the intensity of infestation of *Lernaea cyprinacea* in an intermittent stream fish community. *Journal of Arid Environments* **43**, 351-356.

McCune, B. and Mefford, M. (2006). 'PC-ORD. Multivariate Analysis of Ecological Data, Version 5.12.' (MjM Software Design, Glendon Beach, Oregon).

Mittlebach, G. and Persson, L. (1998). The ontogeny of piscivory and its ecological consequences. *Canadian Journal of Fisheries and Aquatic Sciences* **55**, 1454-1465.

Murphy, B. F. and Timbal, B. (2007). A review of recent climate variability and climate change in southeastern Australia. *International Journal of Climatology* **28**, 859-879.

Nicol, J. and Gehrig, S. (2010). 'Aquatic and littoral vegetation monitoring of Goolwa Channel 2009-10.' South Australian Research and Development Institute (Aquatic Sciences), Adelaide, 21 pp.

Nunn, A. D., Harvey, J. P. and Cowx, I. G. (2007). Variations in the spawning periodicity of eight fish species in three English lowland rivers over a 6 year period, inferred from 0+ year fish length distributions. *Journal of Fish Biology* **70**, 1254-1267.

Paxton, C. G. M., Winfield, I. J., Fletcher, J. M., George, D. G. and Hewitt, D. P. (2004). Biotic and abiotic influences on the recruitment of male perch in Windermere, U.K. *Journal of Fish Biology* **65**, 1622-1642.

Pérez-Bote, J. L. (2010). *Barbus comizo* infestation by *Lernaea cyprinacea* (Crustacea: Copepoda) in the Guidiana River, southwestern Spain. *Journal of Applied Icthyology* **26**, 592-595.

Persson, L. (1986). Effects of reduced interspecific competition on resource utilization in perch (*Perca fluviatilis*). *Ecology* **67**, 355-364.

Persson, L. (1993). Predator-mediated competition in prey refuges, the importance of habitat dependent prey resources. *Oikos* **68**, 12-22.

Pons, L. J. (1973). Outline of the genesis, characteristics, classification and improvement of acid sulphate soils. In 'Proceedings of the 1972 International Acid Sulphate Soils Symposium'. Wageningen, Netherlands. (Ed. H Dost) pp. 3-27. (International Land Reclaimation Institute: Wageningen, Netherlands).

SA Water Corporation (2009). 'Goolwa Channel Water Level Management Project: Report to the Public Works Committee.' South Australian Water Corporation, Adelaide. 12525/08.

Sammut, J., Melville, M. D., Callinan, R. B. and Fraser, G. C. (1995). Estuarine Acidification: Impacts on Aquatic Biota of Draining Acid Sulphate Soils. *Australian Geographic Studies* **33**, 89-100.

Smith, B. B. and Walker, K. F. (2004). Reproduction of the common carp in South Australia, shown by young-of-the-year samples, gonadosomatic index and the histological staging of ovaries. *Transactions of the Royal Society of South Australia* **128**, 249-257.

Stuart, I. G. and Jones, M. (2006). Large, regulated forest floodplain is an ideal recruitment zone for non-native carp (*Cyprinus carpio* L.). *Marine and Freshwater Research* **57**, 333-347.

Wedderburn, S. and Barnes, T. (2009). 'Condition monitoring of threatened fish species at Lake Alexandrina and Lake Albert (2008-2009). Report to the Murray-

Darling Basin Authority and the South Australian Murray-Darling Basin Natural Resources Management Board.' The University of Adelaide, Adelaide.

Wedderburn, S. and Barnes, T. (In Prep). 'Condition monitoring of threatened fish species at Lake Alexandrina and Lake Albert (2010-2011). Report to the Murray-Darling Basin Authority and the South Australian Murray-Darling Basin Natural Resources Management Board.' The University of Adelaide, Adelaide.

Wedderburn, S. and Hammer, M. (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) Inc., Adelaide.

Wedderburn, S. and Hillyard, C. (2010). 'Condition monitoring of threatened fish species at Lake Alexandrina and Lake Albert (2009-2010). Report to the Murray-Darling Basin Authority and the South Australian Murray-Darling Basin Natural Resources Management Board.' The University of Adelaide, Adelaide, 42pp.