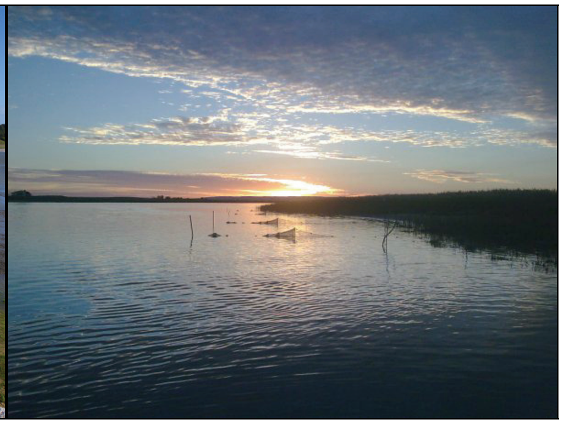
Response of fish to the ‘Goolwa Channel Water Level Management Plan’ in 2009/10



Bice, C., Zampatti, B. and Short, D.

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PO Box 120 Henley Beach SA 5022

December 2010

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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EXECUTIVE SUMMARY

Due to over abstraction, prolonged drought and subsequently reduced River Murray inflows, water levels in the Ramsar listed Lower Lakes have been receding since 2006 and reached an historical low of -1.0 m AHD in May 2009. Water level recession has had many detrimental impacts on the Lower Lakes ecosystem including the exposure of extensive areas of acid sulfate soils (ASS) which, upon re-wetting, may result in the acidification of water bodies and mobilisation of heavy metals and metalloids.

In response to the risk posed by a large area of ASS in the lower reaches of the Finniss River and Currency Creek, the *Goolwa Channel Water Level Management Plan* (GWLMP) was initiated. The aim of the plan was to maintain higher water levels and limit further exposure of ASS. This involved the construction of a large regulator across the Goolwa Channel at Clayton in August 2009 creating the Goolwa Weir Pool (GWP, ~16 km long and 0.3 – 1.5 km wide) between this structure and the Goolwa Barrage. Water was then pumped into the GWP from Lake Alexandrina and winter – spring tributary inflows were captured, raising water levels to ~0.7 m AHD in November 2009. Water level receded again over summer – autumn and was ~-0.1 m AHD in May 2010.

Whilst the GWLMP was primarily an action to mitigate the risk posed by ASS, it secondarily aimed to provide an adequate area of freshwater habitat for freshwater dependent biota in the face of broadly deteriorating conditions in the Lower Lakes. The current project aimed to determine the response of fish species to the GWLMP. 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.

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 had receded to ~0.0 m AHD). 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 46,717 fish were sampled, from 23 species. Fish assemblages did not differ significantly between locations in August 2009 but after water level rise, fish assemblages differed significantly between 'within' the GWP and 'outside' the GWP in both December 2009 and April 2010. Differences in assemblages were primarily due to greater abundances of non-native common carp 'within' the GWP in both December and April 2010, greater abundances of the euryhaline small-mouthed hardyhead and blue-spot goby in December 2009, and greater abundances of the estuarine bridled goby in April 2010. In contrast, greater abundances of the freshwater redfin perch and estuarine sandy sprat were sampled 'outside' of GWP in December 2009 and greater abundances of the freshwater carp gudgeon, flat-headed gudgeon, Australian smelt and redfin perch, and estuarine lagoon goby were sampled 'outside' of the GWP in April 2010.

Spatial variation in recruitment was evident for several species. The increase in common carp abundance 'within' the GWP was due to a large spawning and recruitment event following water level rise. In both December 2009 and April 2010, young-of-year (YOY) common carp comprised >99% of the population. Some native freshwater and estuarine species exhibited earlier spawning and recruitment within the GWP, relative to 'outside' the GWP in December 2009 but greater growth and recruitment success 'outside' the GWP by April 2010. Growth and recruitment of these species 'within' the GWP was likely not enhanced, relative to 'outside' the GWP, due to a combination of factors including; decreasing productivity within the GWP with receding water levels, competitive interactions with juvenile common carp and elevated salinity.

The GWLMP provided conditions optimal for the spawning and recruitment of non-native common carp but did not enhance native fish populations. This project highlights that undertaking engineering interventions 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. Importantly, potential ecological tradeoffs involved in such approaches need to be considered with respect to restoration of native fish populations.

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 Basin (MDB), are heavily impacted by river regulation and over abstraction. Post regulation, mean annual discharge from the Murray Mouth is ~39% (4723 GL) of natural, pre-regulation discharge (12, 233 GL) (CSIRO 2008). Compounding this situation, drought in the past decade has resulted in diminished run-off to the MDB (Murphy and Timbal 2007) and subsequently diminished flows to the Lower Lakes, with River Murray inflows of < 600 $GL.yr^{-1}$ in 2007, 2008 and 2009 (DWLBC 2010). With the high rates of evaporation often experienced in the Lower Lakes (typically > 750 $GL.yr^{-1}$) (CSIRO 2008), inflows have been insufficient to maintain typical regulated water levels (approximately 0.75 m AHD (Australian Height Datum)) and the water level in the lakes has receded to an historical low (-1.0 m AHD in Lake Alexandrina in May 2009) (Figure 1).

Water levels in the Lower Lakes have been receding since mid-2006 and have been < 0.0 m AHD (i.e. sea level) since late 2007. There has been a substantial loss of off-channel wetland habitats, submerged vegetation has vanished and the remaining water has become disconnected from fringing emergent vegetation (Marsland and Nicol 2009). Furthermore the Lower Lakes have been hydraulically disconnected from the Coorong and Southern Ocean since March 2007, and salinities in some areas of Lake Alexandrina have risen to ≥ 20,000 $\mu S.cm^{-1}$ (electrical conductivity) (DWLBC 2010). Nevertheless, perhaps most alarmingly, water level recession has 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 represent a significant threat to the Lower Lakes ecosystem (Fitzpatrick *et al.* 2008). The potential threat posed by ASS is of great concern and consequently several management options have been proposed and/or implemented to mitigate the risk to the Lower Lakes, including bioremediation (e.g. revegetation), limestone addition and maintaining higher water levels with freshwater inflows or seawater intrusion (DEH 2009).

An extensive area of ASS was found in the lower reaches of Currency Creek and the Finniss River, which flow into the Goolwa Channel on the south-western side of Lake Alexandrina (Fitzpatrick *et al.* 2009). These tributaries typically flow seasonally, in winter and spring, and due to the low water levels, a significant risk of acidic 'pore water' and 'pooled' water flowing into Goolwa Channel on the commencement of seasonal flows was deemed to exist. Water levels in the lower reaches of these tributaries are influenced by water levels in Lake Alexandrina and thus the *Goolwa Channel Water Level Management Plan* (GWLMP) was initiated to maintain higher water levels within the Goolwa Channel and limit the inflow of acidic water at the beginning of the flow season (SA Water 2009). Whilst this intervention was undertaken with the primary goal of mitigating the threat posed by acid sulfate soils, it secondarily aimed to provide a significant area of adequate freshwater habitat for freshwater dependent biota in the face of broadly deteriorating conditions in the Lower Lakes (SA Water 2009).

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 disconnecting 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. Following construction of the Clayton Regulator, water level within the GWP was then raised to > 0.7 m AHD by pumping water from Lake Alexandrina and seasonal inflows from tributaries between August and November 2009. Modelling indicated that water level in the GWP would drop to ~0.0 m AHD by autumn 2010 before being refilled to ~0.7 m AHD with winter-spring tributary inflows. As such an operating range of 0.0 – 0.7 m AHD could be achieved without further pumping.

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 2010). The assemblage includes species of national conservation significance; namely Murray Cod (*Maccullochella peelii 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*) (Knight *et al.* 2004) and iconic diadromous species (e.g. congolli, *Pseudaphritis urvillii*) not found elsewhere in the MDB.

This project aimed to determine the response of fish to the raising of water levels within the GWP. Specifically, the objectives were to:

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

The information provided will inform future management of the GWP.

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).

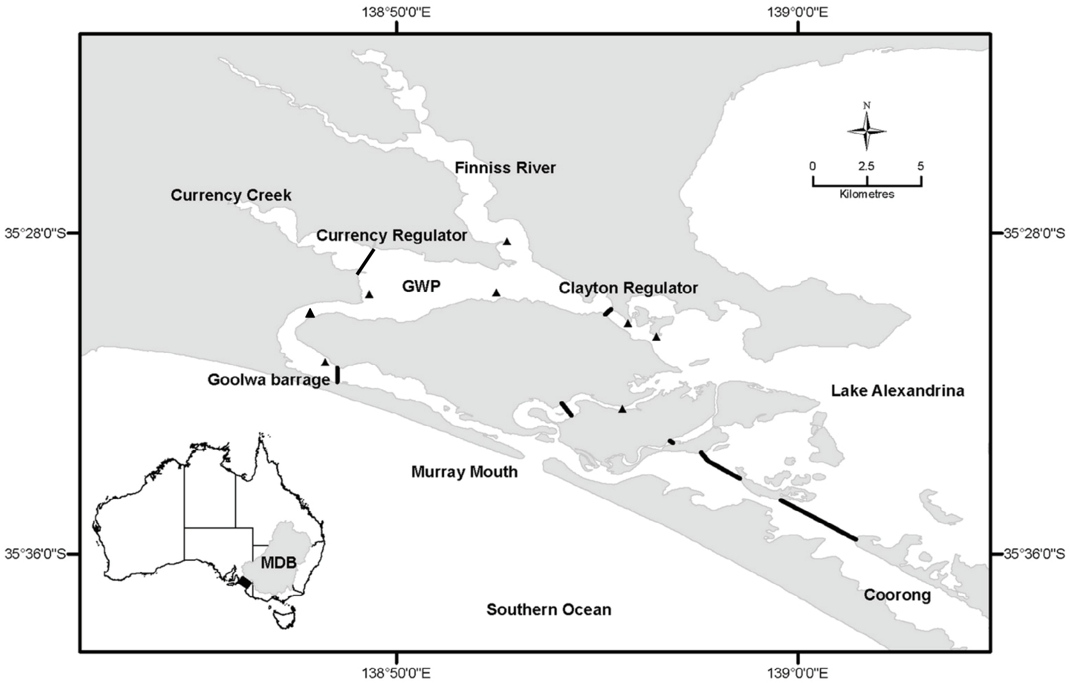

Figure 1. Map of the western side of Lake Alexandrina showing the locations of the Murray Barrages, Clayton and Currency Regulators (solid black), and newly created Goolwa Weir Pool (GWP). Sampling sites are indicated by solid triangles.

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**
1	Goolwa Barrage	GWP	300998	6066924	Yes	Yes	Yes
2	Captain Sturt Rd	GWP	301575	6069591	Yes	No	No
3	Goolwa Channel	GWP	306063	6070252	Yes	Yes	Yes
4	Clayton West	Outside	312149	6069180	Yes	Yes	Yes
5	Clayton East	Outside	313049	6068575	No	Yes	Yes
6	Holmes Creek	Outside	311654	6065315	No	Yes	Yes
7	Finniss arm	GWP	307724	6072896	No	Yes	Yes
8	Currency Creek	GWP	302904	6070571	No	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).

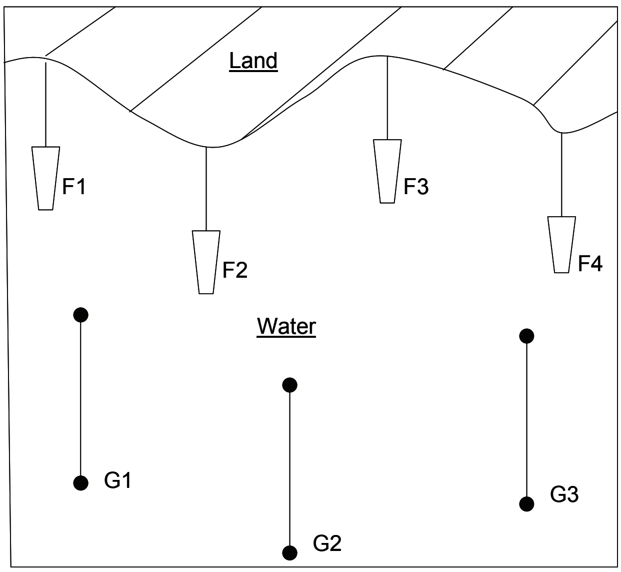

Figure 2. Generalised schematic of sampling method used at each site, showing orientation of fyke nets (F1 – F4) and gill nets (G1 – G3).

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

Approximately 25 common galaxias (*Galaxias maculatus*) and Australian smelt (*Retropinna semoni*) were collected (and frozen) from 'within' and 'outside' the GWP in December 2009 and August 2010 (*n* = 50 individuals per species per sampling event) for ageing via otolith microstructure analysis. Common galaxias are typically a catadromous species, exhibiting downstream migration to estuaries for spawning and marine larval development before upstream migrations of juvenile or 'whitebait' life stages (McDowall *et al.* 1994). Nevertheless, common galaxias possess a flexible life history and may complete their lifecycle entirely in freshwater in land-locked populations (Chapman *et al.* 2006) and there is some evidence that this has occurred in the Lower Lakes in recent years (Jennings *et al.* 2008). Australian smelt is a freshwater species that is common and broadly distributed within the Lower Lakes. As such, these species are potentially good indicators of enhanced/diminished conditions for recruitment within the GWP. Furthermore, the use of daily otolith increments has been validated as a technique for determining age in both of these species (sensu McDowall *et al.* 1994; Tonkin *et al.* 2008a)

2.2. Otolith preparation and analysis

Thawed fish were measured to the nearest millimetre (standard length, SL) and sagittal otoliths were extracted under a dissecting microscope, rinsed in distilled water, cleaned of extraneous tissue and dried by rubbing in silk cloth. Transverse sections of sagittae provide the best plane for resolving microstructure in common galaxias and Australian smelt (McDowall *et al.* 1994; Tonkin *et al.* 2008a). For preparation, sagittae were embedded in crystal bond™, then ground and polished from the anterior side towards the core with 30 µm and 9 µm lapping film. The ground surface was glued to the centre of a microscope slide and then further ground and polished from the posterior side, to produce sections of 50 - 100 µm thickness. Each otolith was examined by a single reader and two counts of the increments were made. Counts were compared and if they differed by more than 10% the otolith was rejected, but if count variation was within 10%, the mean of counts was accepted as the best estimate of daily increment number. This analysis allows interpretation of age and back-calculation to actual spawn or hatch dates.

Pre-hatch increments of common galaxias otoliths are typically laid down at such fine resolution they are difficult to interpret consistently in all otolith sections using standard light microscopy techniques. Alternatively, an easily identifiable hatch mark is evident (McDowall *et al.* 1994), providing a reliable reference point to begin increment counts. Thus in the current study, daily increment counts for common galaxias were made from the hatch mark along the maximum growth axis towards the ventral apex. The estimates of individual age and collection dates were used to calculate the date on which successful recruits were hatched.

The timing of first increment formation (i.e. pre-hatch, hatch or on commencement of exogenous feeding) of Australian smelt has not been validated and thus, following Tonkin *et al.* (2008b), age of Australian smelt is expressed as 'estimated age'. Nonetheless, increment counts are made from the primordium along the maximum growth axis towards the ventral apex. Daily increment counts were subtracted from individual capture dates to identify the date successful recruits were spawned.

2.3. Water quality

A range of water physico-chemical parameters were measured at each site during each sampling event. Water clarity, as expressed by Secchi depth (m), was measured with a Secchi Disk. Electrical conductivity ($\mu S.cm^{-1}$), pH, dissolved oxygen concentration (ppm) and temperature (°C) were measured with a TPS 90-FLT water quality meter. Time-series data for salinity (electrical conductivity) and water level (m, AHD), over the study period, was obtained from the Department of Water Land and Biodiversity Conservation (DWLBC 2010).

2.4. Data analysis

Two-factor PERMANOVA (permutational ANOVA and MANOVA) (Anderson *et al.* 2008) was used to investigate spatial differences in fish assemblages between '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 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 (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). 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 (Nicol *et al.* 2007). 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. The ‘K-S goodness of fit test’ was also used to investigate differences in spawn date frequency distributions of common galaxias and Australian smelt between sites ‘within’ the GWP and ‘outside’ the GWP.

Linear regressions of length-at-age were plotted for common galaxias and Australian smelt from sites ‘within’ and ‘outside’ the GWP (sampling events pooled). Analysis of covariance (ANCOVA) was used to investigate differences in length-at-age relationships between locations. ANCOVA investigates statistical difference by comparing the intercepts and correlation coefficients but most importantly the slopes of linear regressions, which in the case of length-at-age relationships, is synonymous with growth rate.

3. RESULTS

3.1. Water levels 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 (~27 GL) from Lake Alexandrina 'outside' of the GWP and capturing seasonal inflows from the Finniss River and Currency Creek (Figure 3a). Water level then began to recede as pumping and tributary inflows ceased and evaporation increased over summer, and as of May 2009 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 (Figure 3a).

Salinity 'within' the GWP (data obtained from the DWLBC Signal Point monitoring station) ranged from 23,000 – 33,000 µS.cm^{-1} from January – June 2009 and was ~20,000 µS.cm^{-1} by the completion of the Clayton regulator and sampling in August 2009 (Figure 3b). Salinity decreased to ~11,000 µS.cm^{-1} after water level peaked in November 2009 but rose as water levels decreased, and was >20,000 µS.cm^{-1} by April 2010 (Figure 3b). Salinity outside of the GWP (data obtained from the DWLBC Point Macleay monitoring station) ranged from 5500 – 9200 µS.cm^{-1} through 2009 and early 2010 but declined gradually as water levels in Lake Alexandrina increased in March 2010 (Figure 3a & b).

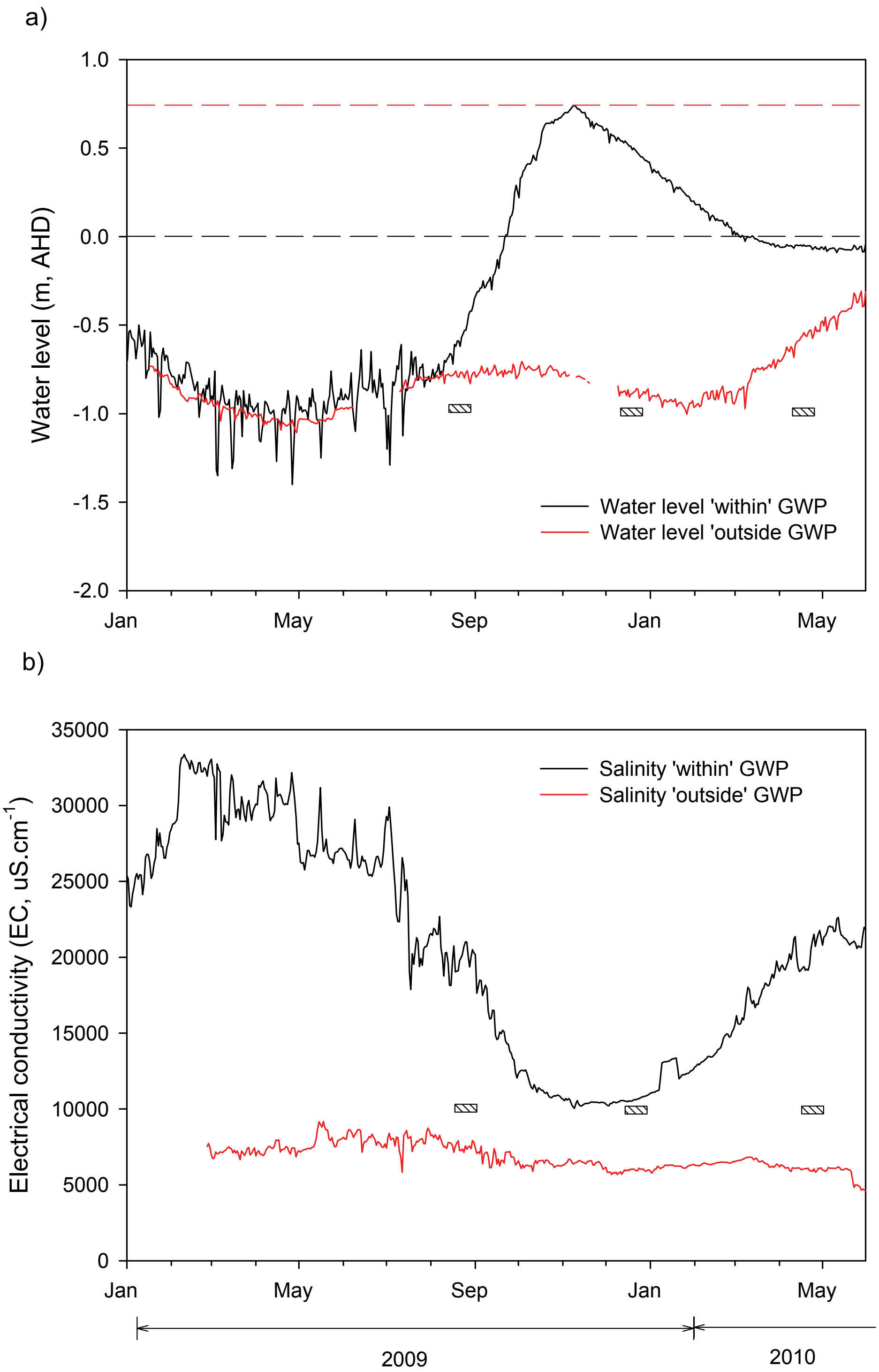

Figure 3. a) Water level and b) salinity within the GWP and 'outside' the GWP from January 2009-May 2010. Time of sampling events is indicated by hatched bars. Red dashed line = normal regulated lake level (0.75 m AHD). Black dashed line = sea level (0.0 m AHD). Data was obtained from the Department of Water, Land and Biodiversity Conservation water quality monitoring stations (DWLBC 2010).

3.2. Catch composition

A total of 46,717 fish were captured from 23 species, representing a diverse range of life history strategies including obligate freshwater, catadromous, estuarine resident and marine migrant species (Table 2). Species richness (*n* = 21) and abundance (total fish = 32,147) were greatest in December 2009. The most abundant species, in descending order, were small-mouthed hardyhead, common carp, flat-headed gudgeon, Australian smelt, bony herring and lagoon goby, which collectively contributed > 90% of all fish sampled. A diverse range of species were captured in fyke nets (*n* = 19), whilst gill nets selectively captured large-bodied freshwater (i.e. common carp, bony herring and golden perch) and estuarine/marine species (i.e. black bream, Australian salmon and flat-tailed mullet).

A single Murray hardyhead, nationally listed as *vulnerable* under the *EPBC Act* (1999), was sampled from 'within' the GWP in December 2010. Furthermore, 11 individuals (including 10 from the Finniss arm site) were sampled 'within' the GWP in April 2010.

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

Species	Scientific name	August 2009		December 2009		April 2010		Total
		No. in GWP	No. outside GWP	No. in GWP	No. outside GWP	No. in GWP	No. outside GWP	
Golden perch^	*Macquaria ambigua*	1	0	1	0	1	1	**4**
Bony herring^	*Nematalosa erebi*	2	1	665	631	632	451	**2382**
Murray hardyhead^	*Craterocephalus fluviatilis*	0	0	1	0	11	1	**13**
Unspecked hardyhead^	*Craterocephalus stercusmuscarum fulvus*	0	0	0	2	0	0	**2**
Australian smelt^	*Retropinna semoni*	529	694	1166	823	193	363	**2545**
Flat-headed gudgeon^	*Philypnodon grandiceps*	23	59	415	416	638	1228	**2779**
Carp gudgeon complex^	*Hypseleotris* spp.	1	0	24	33	4	21	**83**
Common carp[@]	*Cyprinus carpio*	34	11	8555	26	1235	13	**9871**
Redfin perch[@]	*Perca fluviatilis*	1	4	1	174	21	22	**220**
Goldfish[@]	*Carrasius auratus*	0	0	0	0	2	0	**2**
Eastern gambusia[@]	*Gambusia holbrooki*	0	0	0	0	136	0	**137**
Common galaxias*	*Galaxias maculatus*	9	10	253	198	66	42	**578**
Congolli*	*Pseudaphritis urvillii*	26	10	5	2	0	3	**46**
Small-mouthed hardyhead[e]	*Atherinosoma microstoma*	1089	201	15326	1188	2748	2375	**22923**
Tamar goby[e]	*Afurcagobius tamarensis*	11	15	64	159	108	90	**448**
Blue-spot goby[e]	*Pseudogobius olorum*	23	0	77	16	51	107	**276**
Lagoon goby[e]	*Tasmanogobius lasti*	67	544	749	530	47	253	**2190**
Bridled goby[e]	*Arenogobius bifrenatus*	10	4	394	153	343	71	**975**
River garfish[e]	*Hyporhamphus regularis*	0	0	0	3	0	0	**3**
Sandy sprat[e]	*Hyperlophus vittatus*	1	0	0	66	54	7	**127**
Black bream[e]	*Acanthopagrus butcheri*	1	0	2	0	0	0	**3**
Western Australian salmon[m]	*Arripis truttaceus*	0	0	6	0	0	0	**6**
Flat-tailed mullet[m]	*Liza argentea*	0	0	16	0	2	0	**18**
Totals		**1823**	**1553**	**27720**	**4427**	**6156**	**5038**	**46717**

*^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) shows distinct groupings of fish assemblages by sampling event and location (i.e. ‘within’ GWP or ‘outside’) (Figure 4). This is supported by two-factor PERMANOVA (permutational ANOVA and MANOVA) (Anderson *et al.* 2008) which indicated there were significant differences in fish assemblages between sites ‘within’ and ‘outside’ the GWP (sampling events pooled; $Pseudo\text{-}F_{1,\ 66}$ = 14.02, p <0.001), and between sampling events (locations pooled; $Pseudo\text{-}F_{2,\ 66}$ = 16.34, p <0.001). There was a significant interaction between location and sampling event ($Pseudo\text{-}F_{2,\ 66}$ = 3.94, p < 0.001) indicating fish assemblages at both locations changed over time but not in a uniform pattern.

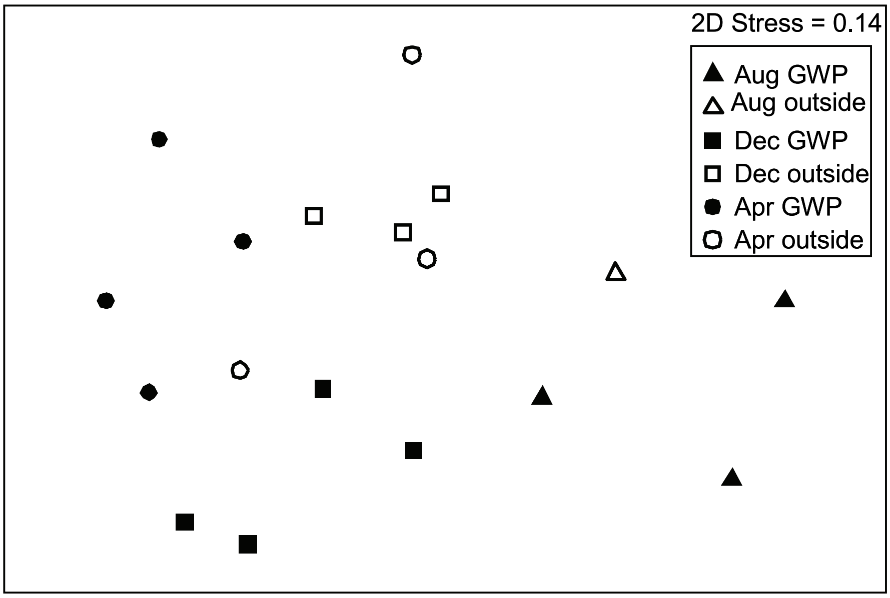

Figure 4. Non-metric multi-dimensional scaling (MDS) plot of fish assemblages sampled from sites within the GWP and outside the GWP in August 2009, December 2009 and April 2010.

PERMANOVA pairwise comparisons of all location x sampling event combinations were undertaken. Fish assemblages both ‘within’ and ‘outside’ of the GWP differed significantly between sampling events for all combinations (p < 0.003; Bonferroni corrected α = 0.003). Fish assemblages ‘within’ and ‘outside’ the GWP differed significantly in December 2009 (t = 4.55, p <0.001) and April 2010 (t = 2.73, p <0.001) but not in August 2009 (t = 1.77, p = 0.02).

SIMPER was used to determine species contributing to differences in assemblages between locations. Adopting a cumulative contribution cut-off of 40%, differences in fish assemblages between locations in December 2009 were primarily due to greater abundances of common carp and small-mouthed hardyhead 'within' the GWP and greater abundance of redfin perch 'outside' the GWP (Figure 5a). In April 2010, differences in assemblages were again primarily due to greater abundance of common carp 'within' the GWP and greater abundance of lagoon goby and Australian smelt 'outside' the GWP (Figure 5b).

Indicator species analysis (ISA) (Dufrene and Legendre 1997) was used to determine the species characterising the different locations during sampling events when significant differences existed between the assemblages. In December 2009, common carp (Indicator Value (IV) = 99.9, $p < 0.001$), small-mouthed hardyhead (IV = 91.9, $p < 0.001$) and blue-spot goby (IV = 73.7, $p = 0.005$) characterised the assemblage 'within' the GWP and were more abundant at this location (Figure 5a). Conversely the fish assemblage 'outside' of the GWP was characterised by greater abundances of Tamar River goby (IV = 74.7, $p = 0.003$), redfin perch (IV = 99.6, $p < 0.001$) and sandy sprat (IV = 83.3, $p < 0.001$). In April 2010, common carp (IV = 99.4, $p < 0.001$), bridled goby (IV = 78.4, $p = 0.005$) and eastern gambusia (IV = 50, $p = 0.007$) were more abundant 'within' the GWP (Figure 5b) and characterised the assemblage. The assemblage 'outside' of the GWP in April 2010 was characterised by greater abundances of 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).

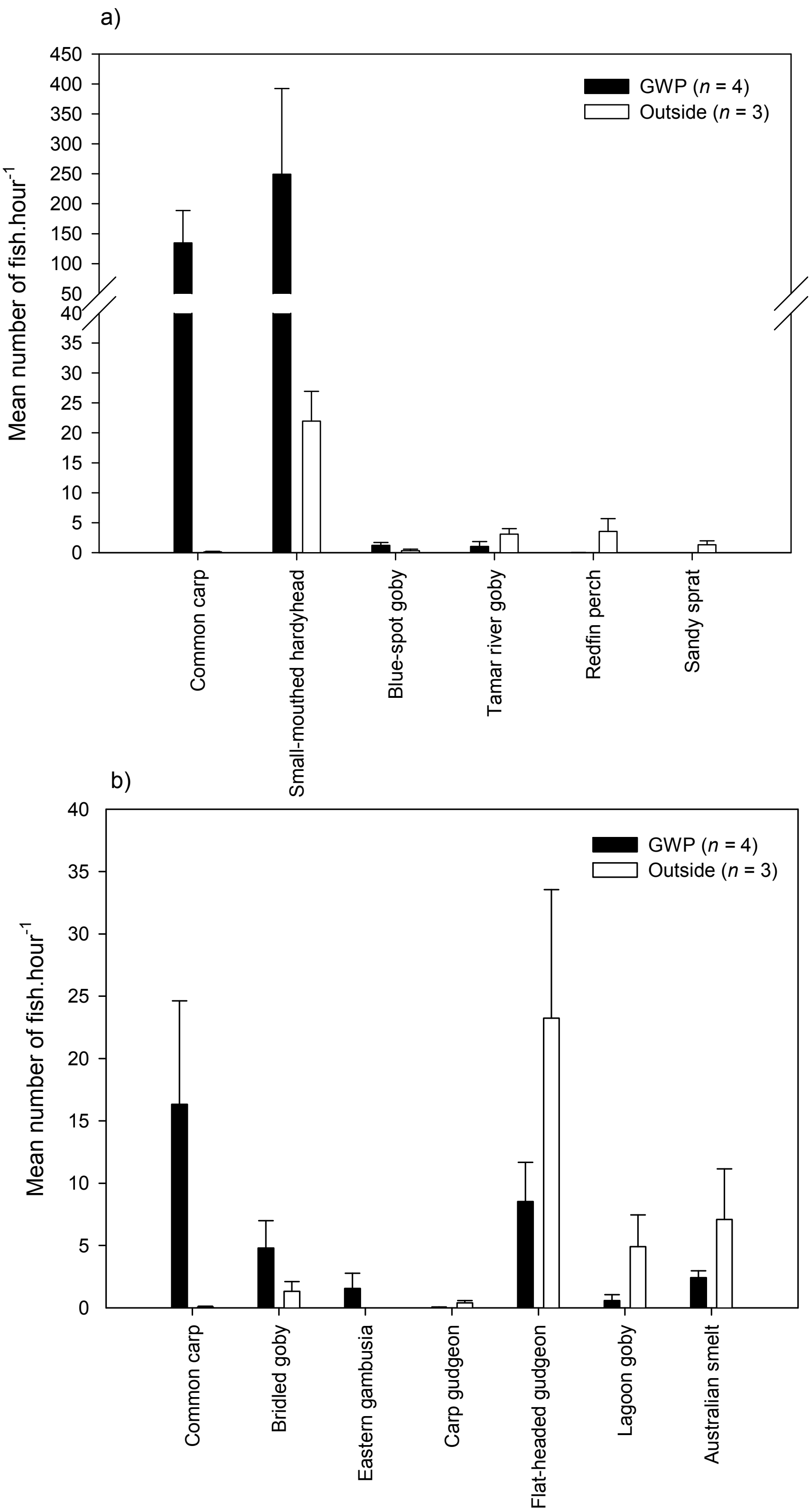

Figure 5. Relative abundances (mean number of fish.hour^{-1}) of species determined to significantly contribute to differences between fish assemblages (by SIMPER) and/or are significant indicators (ISA) of the fish assemblage at a given location (i.e. GWP or outside GWP) in (a) December 2009 and (b)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

3.4. Spatial variation in recruitment patterns

3.4.1. Length-frequency analysis

Spatial differences in the recruitment of the seven most abundant species (i.e. small-mouthed hardyhead, flat-headed gudgeon, lagoon goby, Australian smelt, common galaxias, bony herring and common carp) 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 August 2009 ($D = 0.22$, $p = 0.04$), December 2009 ($D = 0.45$, $p < 0.001$) and April 2010 ($D = 0.82$, $p < 0.001$) (Figure 6a). Length distribution at both locations was similar in August 2009 but there were a number of individuals < 40 mm FL 'within' the GWP but not at sites 'outside'. In December 2010, length distributions from both locations were bi-modal, with adult cohorts at 50-74 mm FL and likely young-of-year (YOY) cohorts at 20-39 mm FL. However, the YOY cohort represented >60% of the population 'within' the GWP compared to ~23% 'outside' the GWP. Progression of the YOY cohort was evident at both locations in April 2010 but the population 'within' the GWP was dominated by fish 25-39 mm FL (>75%) compared with 40-54 mm FL (>70%) 'outside' of the GWP.

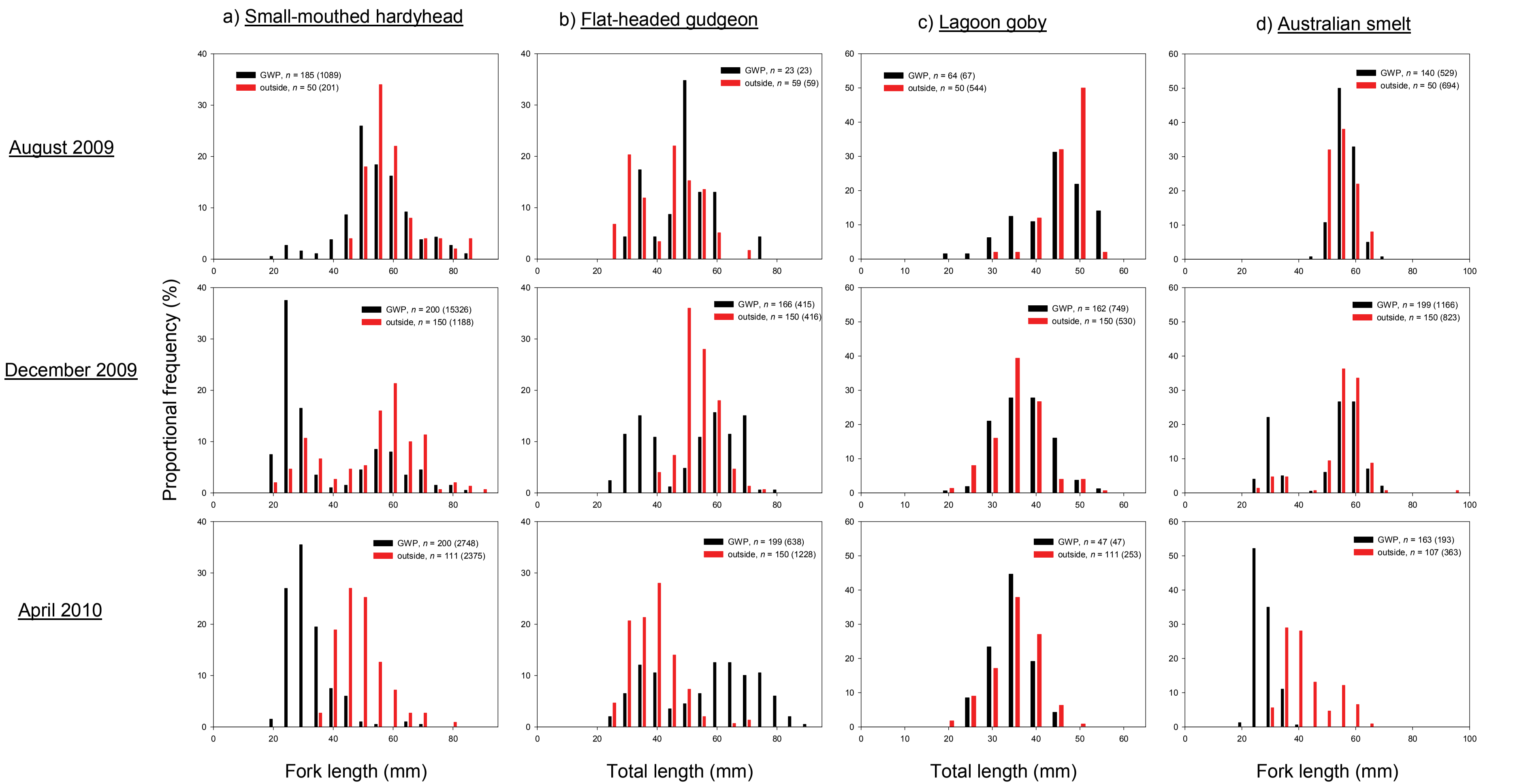

Figure 6. Length-frequency distributions of (a) small-mouthed hardyhead, (b) flat-headed gudgeon, (c) lagoon goby and (d) Australian smelt sampled from sites 'within' and 'outside' the GWP in August 2009, December 2009 and April 2010. Sample sizes indicate the number of fish measured for length and the total number of fish sampled (in brackets).

Flat-headed gudgeon

Length-frequency distributions of flat-headed gudgeon differed significantly between locations in August 2009 (D = 0.35, p = 0.03), December 2009 (D = 0.36, p < 0.001) and April 2010 (D = 0.58, p < 0.001) (Figure 6b). Length distributions appear similar in August 2009 but in December 2009, fish 'outside' the GWP exhibited a uni-modal distribution with peak abundance at 50-64 mm TL, whilst fish from 'within' the GWP exhibited a bi-modal distribution with a similar adult cohort >55 mm TL and a likely YOY cohort at 25-39 mm TL, potentially indicating earlier spawning at this location. In April 2010 flat-headed gudgeon 'within' the GWP still exhibited a bi-modal length distribution with an adult cohort peaking at 60-79 mm TL and the YOY cohort centred around 30-44 mm TL (~30% of catch). Flat-headed gudgeon from sites 'outside' the GWP exhibited a uni-modal distribution and were dominated by YOY individuals 25-44 mm TL (>70%).

Lagoon goby

The length-frequency distribution of lagoon goby differed significantly between locations in December 2009 (D = 0.17, p = 0.03) but not in August 2009 (D = 0.25, p = 0.06) or April 2010 (D = 0.23, p = 0.06). Length-frequency distributions at both locations were uni-modal during all sampling events, with populations at both locations dominated by adults >40 mm TL in August 2009 with an increasing proportion of YOY (<40 mm TL) in December 2009 and April 2010 (Figure 6c).

Australian smelt

The length-frequency distribution of Australian smelt differed significantly between locations in August 2009 (D = 0.32, p = 0.001), December 2009 (D = 0.2, p < 0.001) and April 2010 (D = 0.83, p < 0.001) (Figure 6d). Length distributions appeared similar in August 2009 with populations at both locations exhibiting uni-modal distributions dominated by adult fish (50-64 mm FL). In December 2009, populations from both locations were still dominated by this adult cohort but YOY cohorts (25-39 mm FL) were present, comprising >30% of the population 'within' the GWP and ~10% 'outside' of the GWP. In April 2010, fish >50 mm FL had decreased in abundance 'outside' of the GWP and were absent 'within' the GWP. Individuals 'within' the GWP were substantially smaller than those from 'outside' the GWP, ranging 23-40 mm FL compared to 33-65 mm TL.

Common galaxias

The length frequency distribution of Common galaxias differed significantly between locations in December 2009 (D = 0.19, p = 0.02) but not in August 2009 (D = 0.29, p = 0.91) or April 2010 (D = 0.16, p = 0.57) (Figure 7a). In August 2009, populations from both locations were dominated by adult fish >60 mm FL. In December 2009, YOY cohorts 35-54 mm FL were present and dominated populations at both locations. The progression of YOY cohorts was evident at both locations in April 2010 with individuals 60-69 mm FL most abundant.

Bony herring

Bony herring were not sampled in sufficient numbers in August 2009 to allow length-frequency analysis. Nonetheless, length-frequency distributions differed significantly in December 2009 (D = 0.3, p < 0.001) and April 2010 (D = 0.34, p < 0.001) (Figure 7b). At both locations during December 2009 and April 2010 bony herring exhibited bi-modal length distributions which largely indicates the use of both gill net and fyke net data, with gill nets effective at sampling larger individuals and fyke nets effective at sampling smaller individuals. A YOY cohort was present at both locations in December 2010 but was dominated by smaller fish 'within' the GWP (20-39 mm FL) compared to 'outside' the GWP (60-79 mm FL). In April 2010, the YOY cohorts comprised similar proportions of the populations but exhibited a broader size range 'outside' of the GWP (26-163 mm TL) compared to sites 'within' the GWP (30-115 mm FL).

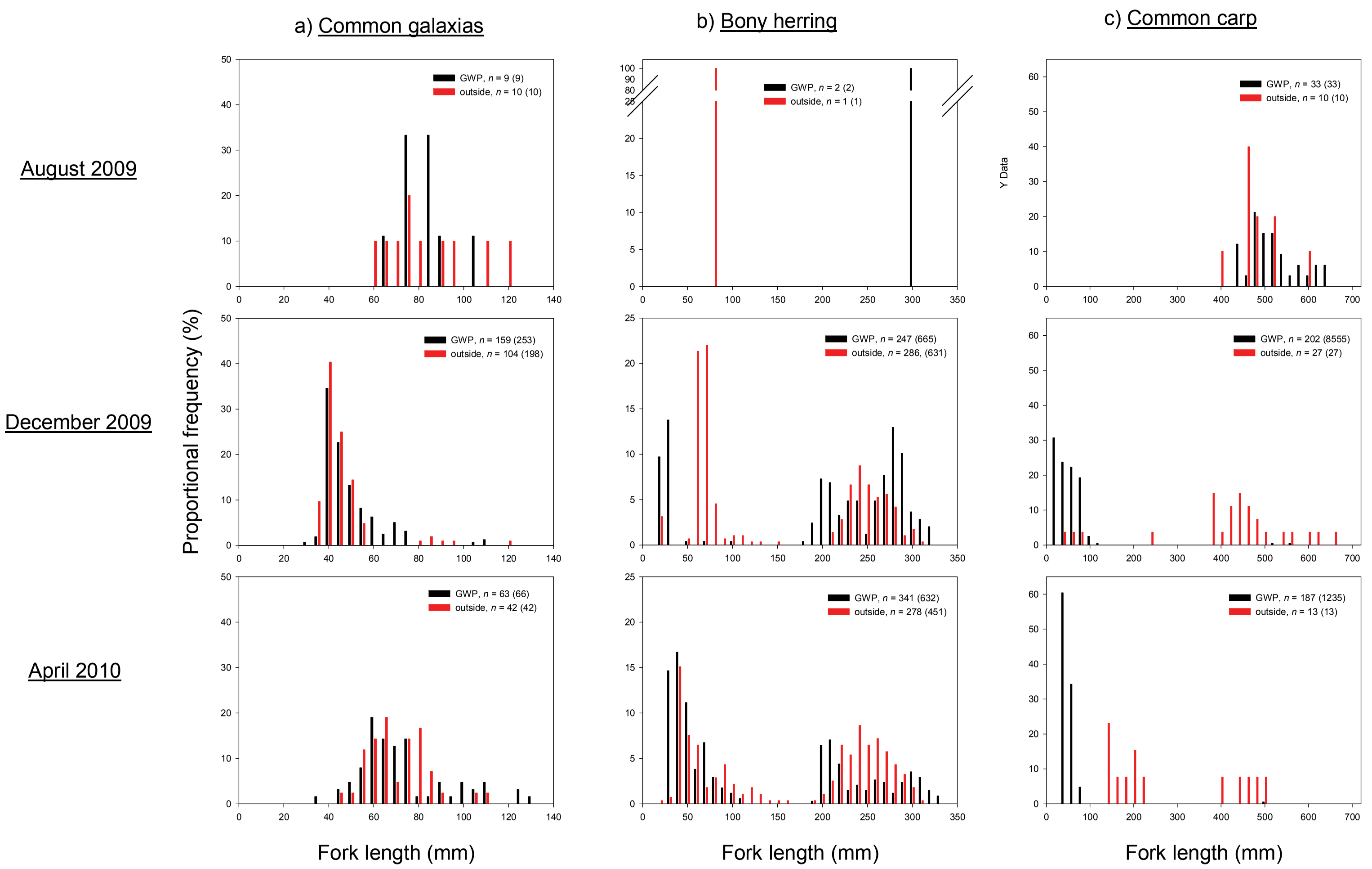

Figure 7. Length-frequency distributions of (a) common galaxias, (b) bony herring and (c) Common carp sampled from sites within the GWP and outside the GWP in August 2009, December 2009 and April 2010. Sample sizes indicate the number of fish measured for length and the total number of fish sampled (in brackets).

Common carp

The length-frequency distribution of common carp did not differ between locations in August 2009 ($D = 0.42$, $p = 0.1$) but differed significantly between locations in December 2009 ($D = 0.87$, $p < 0.001$) and April 2010 ($D = 0.99$, $p < 0.001$). In August 2009, populations in both locations were dominated by adult fish 400-600 mm FL (Figure 7c). In December 2009, the population outside of the GWP remained dominated by adult fish. A YOY cohort was present comprising ~10% of the population but this consisted of just three individuals. Within the GWP >99% of the population (total catch, $n = 8555$ individuals) was comprised by a YOY cohort 28-114 mm FL (Figure 8). Again in April 2010 >99% of the population ($n = 1235$ individuals) 'within' the GWP was comprised of the YOY cohort (42-97 mm FL). Outside of the GWP in April 2010, adult fish (>400 mm FL) comprised ~37% of the population, whilst a cohort 140-239 mm FL comprised the remaining ~63%, but this constituted just eight individuals.

Figure 8. Large numbers of YOY common carp sampled within the GWP in December 2009.

3.4.2. Otolith microstructure analysis

Common galaxias

Common galaxias otoliths exhibited clear increments (Figure 9) surrounding a concentric hatch check. Of 101 sagittae analysed, five (~5%) were discarded due to inconsistency in counts.

Individuals analysed from 'within' the GWP were spawned and 'hatched' over a period of ~144 days from 01/08/2009 – 22/12/2009, whilst individuals from 'outside' of the GWP were spawned over a shorter period, hatching over ~105 days from 31/08/2009 – 13/12/2009 (Figure 10). Hatch date-distributions differed significantly between locations (Kolmogorov-Smirnov 'goodness of fit', D = 0.36, p = 0.004) with spawning occurring ~1 month earlier 'within' the GWP (Figure 10a & b).

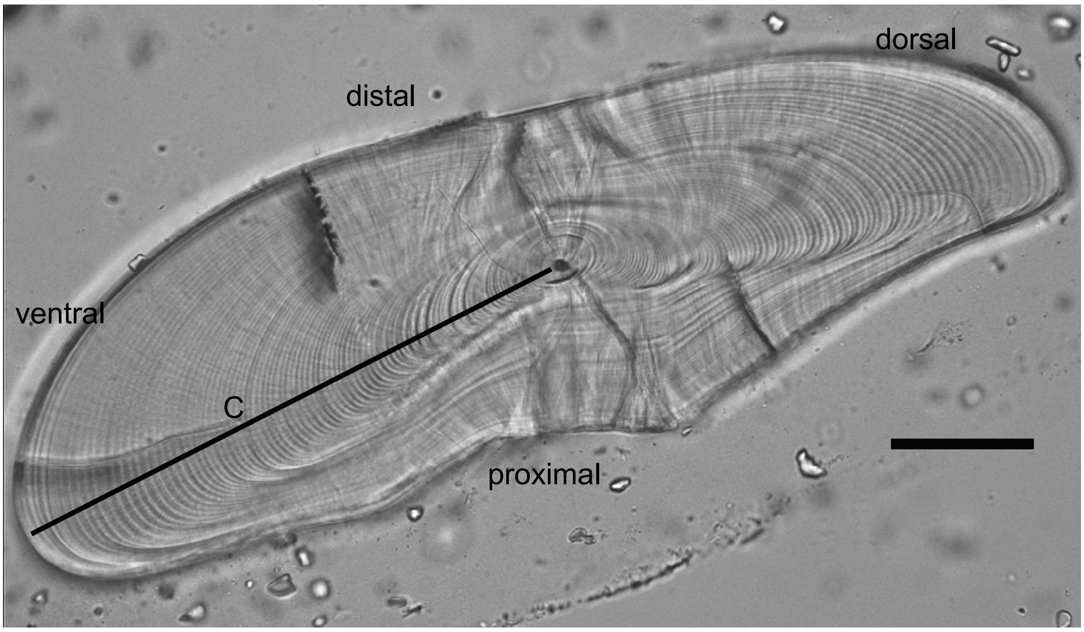

Figure 9. Transverse section of a common galaxias sagittae depicting daily increments. C represents the counting axis for estimates of daily age. Scale bar: 100 μm.

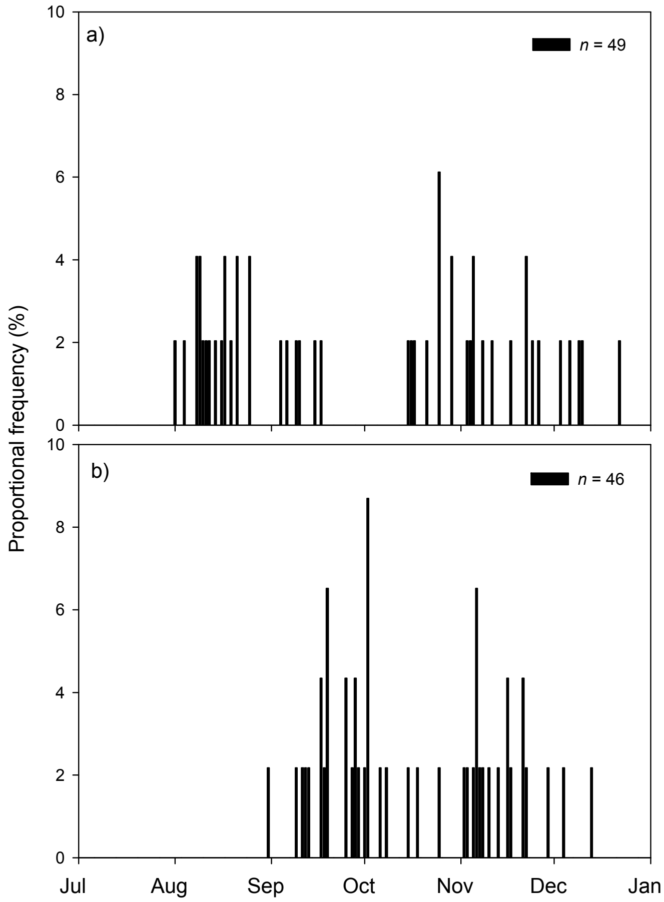

Figure 10. Hatch date-frequency distributions of common galaxias captured (a) 'within' the GWP and (b) 'outside' the GWP (fish collected in both December 2009 and April 2010 are pooled for both locations).

The length of common galaxias increased with age in a linear fashion both 'within' ($Length_t = 19.91 + 0.229age$, $R^2 = 0.88$) and 'outside' the GWP ($Length_t = 5.8 + 0.313age$, $R^2 = 0.88$) (Figure 11). By comparing the slopes of length-at-age relationships, using ANCOVA, individuals from 'outside' the GWP exhibited a significantly greater growth rate over the project period than individuals from 'within' the GWP ($F_{(1, 93)} = 11.97$, $p = 0.001$) (Figure 11).

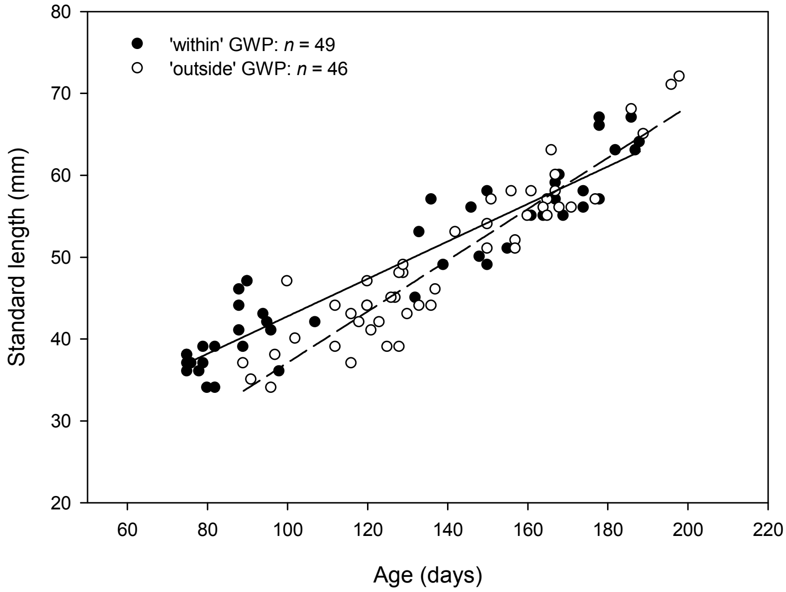

Figure 11. Length-at-age of common galaxias collected from 'within' the GWP (solid circles) and 'outside' the GWP (hollow circles) for otolith microstructure analysis in 2009/10 (data from December 2009 and April 2010 are pooled). Linear regression models have been applied for both locations ('within' GWP - solid line; 'outside' GWP – dashed line).

Australian smelt

Over 50% of Australian smelt collected for otolith analysis from 'within' the GWP and all individuals collected from 'outside' the GWP in December 2009 were determined to have been spawned in the previous spawning season, in spring/summer 2008/09, and were thus excluded from analysis. The majority of these individuals were estimated to be ≥250 days of age, although confidence in counts for these individuals was low due to a region of 'poor clarity' on the outer third of the otoliths, which increased the difficulty of increment counts. Nonetheless, there was a high confidence in increment counts for fish ≤100 days of age in December 2009 and ≤200 days of age in April 2010 (Figure 12) and thus spawn date-frequency distributions were determined for fish collected from 'within' and 'outside' the GWP that were spawned in 2009/10. Of 37 sagittae analysed from 'within' the GWP, 2 (~5%) were discarded due to inconsistency in increment counts, whilst 5 of 25 sagittae (~20%) were discarded from 'outside' of the GWP.

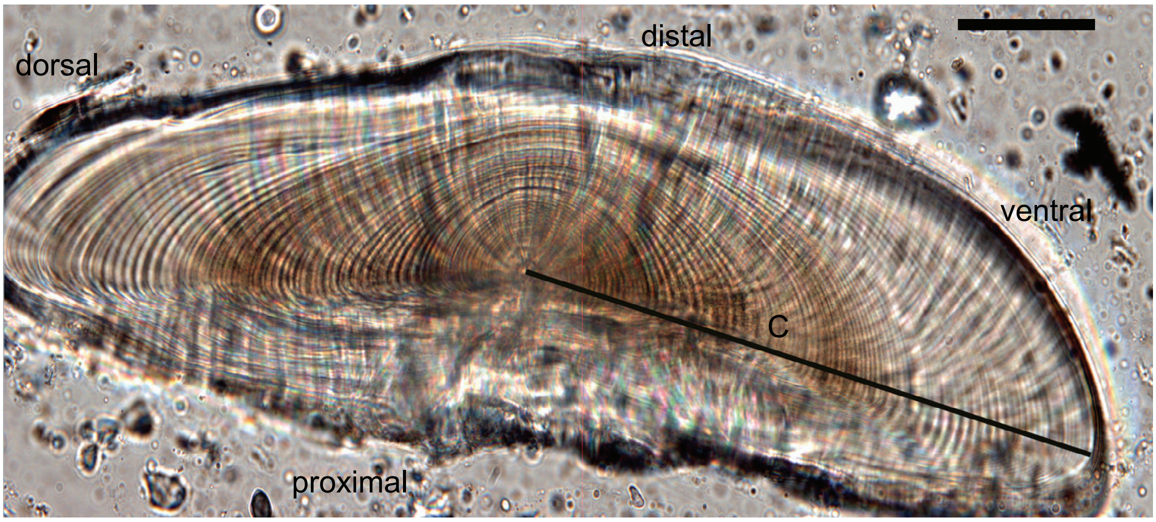

Figure 12. Transverse section of an Australian smelt sagittae depicting daily increments. C represents the counting axis for estimates of daily age. Scale bar: 100 µm.

Individuals analysed from 'within' the GWP were spawned over a period of ~109 days from 18/09/2009 – 04/01/2010, whilst individuals from 'outside' of the GWP were spawned over a slightly shorter period of ~83 days from 25/09/2009 – 16/12/2009 (Figure 13). Nonetheless, spawn date-frequency distributions did not differ significantly between locations (Kolmogorov-Smirnov 'goodness of fit', D = 0.35, p = 0.09).

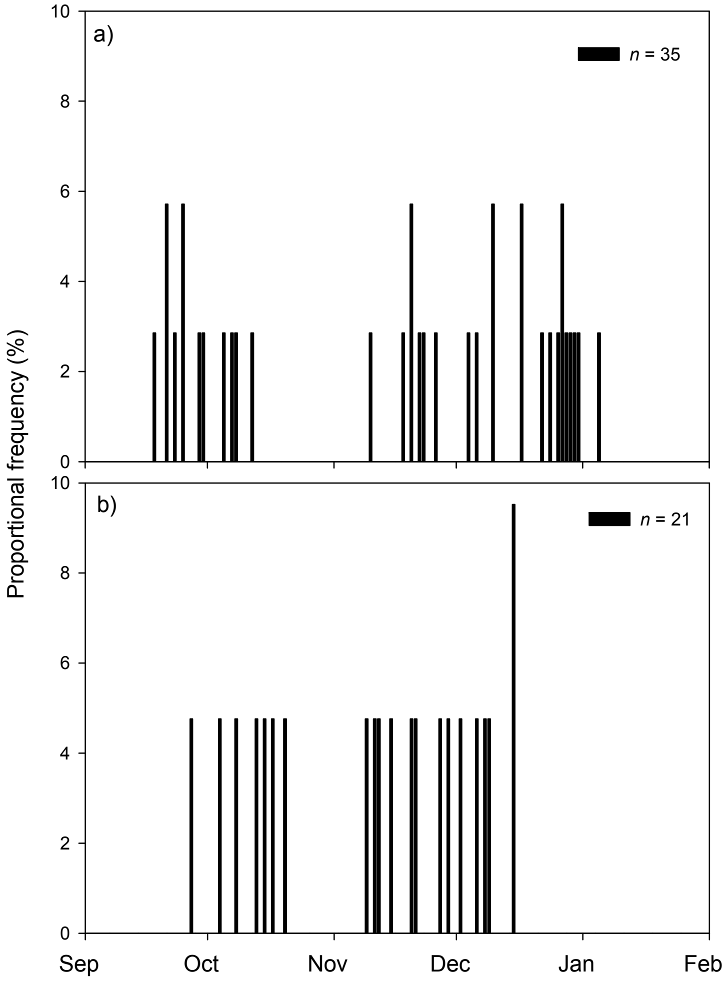

Figure 13. Spawn date-frequency distributions of Australian smelt captured (a) ‘within’ the GWP and (b) ‘outside’ the GWP (fish collected in both December 2009 and April 2010 are pooled for both locations).

Australian smelt from ‘outside’ of the GWP exhibited a poor relationship between length and age ($Length_t = 12.58 + 0.155age$, R^2 = 0.6), whilst individuals from ‘within’ the GWP exhibited no relationship between length and age (R^2 = 0.004) (Figure 14). Thus, ANCOVA could not be used to compare regressions between locations. Nonetheless, there was little distinguishable increase in length with age for individuals collected from ‘within’ the GWP, whilst individuals from ‘outside’ the GWP appeared to exhibit a greater growth rate with increasing length with age (Figure 14).

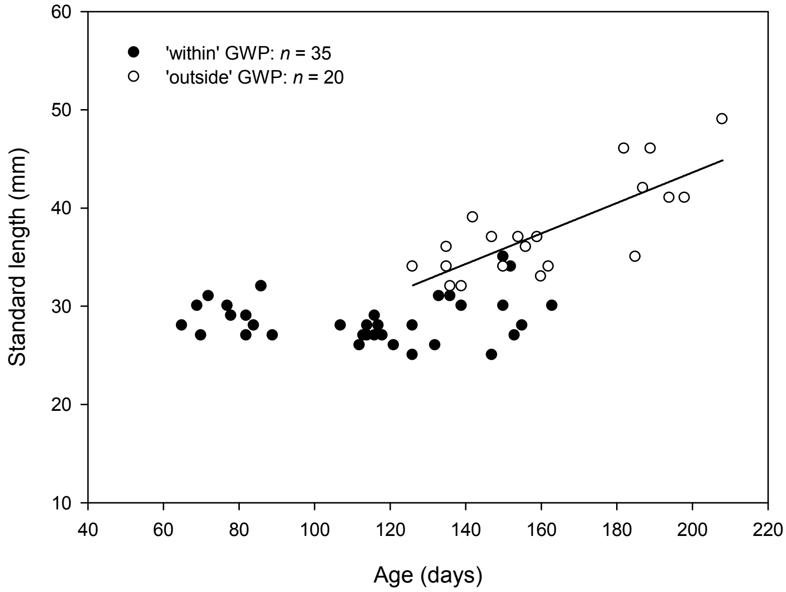

Figure 14. Length-at-age of Australian smelt collected from 'within' the GWP (solid circles) and 'outside' the GWP (hollow circles) for otolith microstructure analysis in 2009/10 (data from December 2009 and April 2010 are pooled). A linear regression model was applied for individuals from 'outside' of the GWP.

3.5. Fish condition

Very few fish exhibited evidence of parasites, lesions, disease or deformity, thus low sample sizes did not allow statistical analysis between locations. 'Within' the GWP in August 2009 a single Australian smelt and common carp exhibited deformities, whilst a single congolli presented with a wound. 'Within' the GWP in December 2009, a single juvenile common carp displayed a deformity. Several other juvenile common carp were observed exhibiting extreme deformities but were not part of the measured sub-sample and thus were not included in an analysis of fish condition. Additionally in December 2009, 'outside' of the GWP a single small-mouthed hardyhead exhibited a deformity whilst a single common galaxias presented with a wound. In April 2010, 'outside' of the GWP, three bony herring and a single common carp displayed deformities.

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* (GWLMP) was initiated. The plan aimed primarily to maintain higher water levels and limit further exposure 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). The aim of the current project was to investigate the response of fish species to the raising of water levels in the Goolwa Weirpool (GWP) as part of the GWLMP.

4.1. General catch

A diverse range of species with various life-history strategies were captured over the study period. Obligate freshwater, catadromous, estuarine and marine migrant species were collected both 'within' and 'outside' the GWP. Species richness (*n* = 23) was greater than that observed in other recent monitoring in the Lower Lakes including Wedderburn and Hammer (2003) (*n* = 21), Bice *et al* (2008) (*n* = 20), and Wedderburn and Barnes (2009) (*n* = 20). This was primarily due to the presence of 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 these species.

Importantly, unlike Wedderburn and Hammer (2003) and Bice *et al* (2008), no Yarra pygmy perch (nationally listed as *vulnerable* under the *EPBC Act* (1999)), southern pygmy perch (protected under the *Fisheries Act* (2007) and considered endangered in South Australia (Hammer *et al.* 2009)) or dwarf flat-headed gudgeon were detected. Dwarf flat-headed gudgeon are often patchily distributed and sampled in low abundances but remain widespread in the Lower MDB (Lintermans 2007; Hammer *et al.* 2009). Nonetheless, the absence of Yarra pygmy perch from monitoring in this and other projects (Bice *et al.* 2009; Wedderburn and Barnes 2009; Bice *et al.* 2010; Wedderburn and Hillyard In Prep), indicates the potential loss of the sole wild population of this species in the MDB. Southern pygmy perch were, however, sampled at Black Swamp, at the confluence of the Finniss River and Tookayerta Creek, by Bice *et al.* (2010), indicating the species is persisting in the region in low abundances.

4.2. Spatial and temporal variation in fish assemblages

Fish assemblages 'within' and 'outside' the GWP differed significantly between sampling events but temporal variation in assemblages was not consistent between locations. Fish assemblages 'within' and 'outside' the GWP were similar in August 2009 but following the managed rise in water level 'within' the GWP fish assemblages differed significantly between locations in December 2009 and April 2010.

Differences between locations were primarily due to significantly greater abundances of non-native common carp and some small-bodied estuarine species (i.e. small-mouthed hardyhead, blue-spot goby and bridled goby) 'within' the GWP and greater abundances of several freshwater (i.e. carp gudgeon, flat-headed gudgeon, Australian smelt and redfin) and small-bodied estuarine species (i.e. sandy sprat and lagoon goby) 'outside' of the GWP. Thus, different species exhibited varied responses to changing conditions within the GWP.

The abundance of common carp 'within' the GWP was ~1000 times and ~250 times greater than abundances 'outside' in December 2009 and April 2010 respectively. Analysis of length-frequency distributions indicated that the increase in abundance 'within' the GWP was due to a substantial spawning and recruitment event following water level rise. This response was not detected at sites 'outside' of the GWP.

Common carp typically spawn in well-vegetated habitats in still or slow-flowing waters (Crivelli 1981; Koehn *et al.* 2000). Increased water level resulted in a response from aquatic vegetation, with germination and growth of submergent species that were absent from the area prior to the GWLMP (Nicol and Gehrig 2010). Furthermore, re-inundation of the dry lake bed likely resulted in increased primary and secondary productivity, at least in the short-term, leading to abundant food resources and high survival of juvenile common carp. Consequently, it appears that the GWLMP provided optimal conditions for spawning and recruitment of this species.

The euryhaline small-mouthed hardyhead was also significantly more abundant 'within' the GWP in December 2009 (~10-fold) and length-frequency analysis also indicates that increased abundance was likely due to increased spawning and recruitment. Nonetheless, whilst this species may have exhibited a positive response in December 2009, by April 2010 abundances at both locations were similar. The estuarine bridled goby was most abundant 'within' the GWP in April 2010 and likely benefited from rising salinity in the GWP between December 2009 and April 2010.

The abundance of all native freshwater species 'within' the GWP did not increase significantly in association with raised water levels in December 2010. Instead, most native freshwater species exhibited increases in abundance 'outside' the GWP, relative to within the GWP, in April 2010. Whilst important structural habitat in the form of aquatic macrophytes was present 'within' the GWP, high salinities (~20, 000 $\mu S.cm^{-1}$) compared to outside the weir pool (~5000 $\mu S.cm^{-1}$) may have disadvantaged freshwater fish species

One native obligate freshwater species that was collected in greater numbers 'within' the GWP, albeit without statistical significance, was Murray hardyhead. The majority of individuals sampled 'within' the GWP in April 2010 (>90 %, total catch n = 11) were YOY (i.e. < 50 mm FL) likely spawned in spring/summer 2009/10. Murray hardyhead were also sampled by other research projects 'within' the GWP near the Currency Creek site in November 2009 (Bice *et al.* 2010) and near the Hindmarsh Island Bridge in March 2010 (Wedderburn and Hillyard In Prep). This species typically inhabited vegetated habitats in the Lower Lakes prior to water level recession (Wedderburn and Hammer 2003; Bice and Ye 2007; Wedderburn *et al.* 2007) and thus, may have benefited from increases in aquatic vegetation 'within' the GWP. Furthermore, this species is tolerant of high salinities (Wedderburn *et al.* 2008) and is widely believed to prefer moderately saline conditions (i.e. ≤ 35,000 $\mu S.cm^{-1}$). As such, the GWP may represent favourable habitat for Murray hardyhead but further monitoring is required to confirm this.

4.3. Spatial variation in recruitment patterns

Variation in the recruitment patterns of selected species between the GWP and 'outside' the GWP was investigated using length-frequency analysis and ageing (i.e. otolith microstructure analysis for common galaxias and Australian smelt). Whilst the abundance of several of the selected species did not differ between the GWP and 'outside' the GWP, disparate length-frequency distributions, spawn-date frequency distributions and length-at-age relationships suggest differential spawning (e.g. timing), growth and recruitment patterns between locations.

The raising of water levels 'within' the GWP resulted in a significant response of submerged vegetation and reconnection of fringing emergent vegetation (Nicol and Gehrig 2010), thus providing spawning substrates and increasing habitat complexity for fish. Furthermore, the re-inundation of dry lake bed likely resulted in an initial increase in primary and secondary productivity. Such conditions would appear favourable for spawning and recruitment in many freshwater species that preferably reside in vegetated habitats and utilise vegetation as a spawning substrate.

Conditions appeared favourable for spawning and recruitment in common carp, which exhibited a large recruitment event 'within' the GWP following water level rise with YOY fish numerically dominating the population (>99%) in both December 2009 and April 2010. Based on length-frequency distributions, earlier spawning (relative to 'outside' the GWP) and initial strong recruitment were exhibited by small-mouthed hardyhead, flat-headed gudgeon and Australian smelt in December 2009 'within' the GWP; however, in April 2010 growth and recruitment of these species was greater 'outside' the GWP.

This pattern was confirmed for Australian smelt, and to a lesser degree common galaxias, through ageing. Both species had more protracted spawning seasons 'within' the GWP, with spawning beginning earlier and, in the case of Australian smelt, also ceasing later than 'outside' the GWP. Nevertheless, more protracted spawning seasons, relative to 'outside' the GWP did not infer greater recruitment success for both species. Furthermore, growth rates 'within' the GWP were found to be diminished relative to 'outside' the GWP. As such, a pattern of earlier spawning followed by subsequently poor growth rates 'within' the GWP likely also occurred in flat-headed gudgeon and small-mouthed hardyhead.

Diminished growth and recruitment of small-mouthed hardyhead, flat-headed gudgeon, Australian smelt and common galaxias 'within' the GWP relative to 'outside', following initial positive responses in December 2010, was likely due to a combination of factors. Firstly, as water level began to recede after December 2010, primary and secondary productivity likely decreased after an initial 'boom' with peak water levels; subsequently food resources (e.g. zooplankton) may have become limiting. Indeed, Walsh (2010) monitored zooplankton diversity and abundance 'within' the GWP in September 2009 and January 2010 and determined that there was a marked decrease in species diversity and abundances between these sampling dates. Nonetheless, no sites were sampled 'outside' of the GWP and thus no comparison of available food resources could be made between locations. Future concomitant monitoring of zooplankton and fish would provide greater insight into the relationship between zooplankton and fish abundance and recruitment in the region. Secondly, the large abundance of juvenile common carp may have resulted in competitive interactions (i.e. for space and resources) with small-bodied native species, particularly under conditions of limited resource availability. Thirdly, salinity within the GWP remained relatively high throughout the study period and had again risen to ~20, 000 $\mu S.cm^{-1}$ by April 2010. Whilst the salinities 'within' the GWP were within the tolerance limits of most native freshwater species (see review Bice 2010), they are likely outside optimal ranges and thus the growth and recruitment of native species may have also been influenced by elevated salinity.

4.4. Conclusions and management recommendations

The GWLMP 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 represents a significant barrier to fish movement. This project highlights that undertaking engineering interventions 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.

Ongoing monitoring, in 2010/11 and beyond, will provide greater insight into the medium-term impact of the GWLMP on native and non-native fish species. Specifically, this monitoring may determine the success of the juvenile common carp recruitment observed in the current study and subsequent contribution to the sub-adult/adult population. Furthermore, the response of native and non-native species to natural increases in water levels (i.e. increased inflows) in comparison to their response under managed water levels (2009/10) will be investigated in 2010/11.

Future monitoring may also be improved by linking fish sampling with zooplankton sampling to provide insight on the relationship between zooplankton and fish recruitment. Furthermore, assessment of fish condition would be improved with the use of weight-at-length and weight-at-age relationships together with length-at-age relationships.

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