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Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2011/12

C.M. Bice, B. P. Zampatti, P.R. Jennings and P. Wilson

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Executive Summary

Estuaries form a dynamic interface between freshwater and marine ecosystems, supporting high levels of biological productivity and diversity. Freshwater inflow and tidal regime determine estuarine salinities, which in turn influence the structure of fish assemblages. Estuaries can support diverse fish assemblages which are characterised by a spatio-temporally variable mix of freshwater, estuarine and marine fish species. Estuaries also represent critical spawning and recruitment habitats, and essential migratory pathways, for diadromous fish. Consequently, changes to flow regimes and physical barriers to movement represent two significant threats to estuarine dependent fishes.

The Coorong estuary lies at the terminus of Australia's largest river system, the Murray-Darling. The river system is highly regulated and on average only ~39% of the natural mean annual discharge now reaches the sea. The estuary is also separated from the lower river by a series of tidal barrages that form an abrupt physical and biological barrier between estuarine and freshwater environments. From 1997–2010, south-eastern Australia experienced severe drought and between 2006 and 2010, a combination of reduced system-wide inflows and over-allocation of water resulted in reduced flow to the Lower Lakes and the cessation of freshwater flow to the Coorong.

Decline in freshwater inflows, disconnection of freshwater and estuarine environments, and increasing estuarine salinity, were accompanied by significant changes in fish assemblage structure. Species richness, diversity and abundance decreased, and fish assemblages became increasingly dominated by marine species in place of freshwater, diadromous and estuarine species. Furthermore, abundance and recruitment of catadromous congolli (*Pseudaphritis urvillii*) and common galaxias (*galaxias maculatus*) were significantly reduced, and migration and spawning seasons contracted.

Extensive rainfall in the Murray-Darling Basin in winter–spring 2010, led to the resumption of freshwater flow to the Coorong and a prolonged period (September 2010–April 2011) of high freshwater discharge. Salinities downstream of the barrages decreased and fish assemblages differed significantly from the period 2007–early 2010, due to increased abundance of freshwater species and estuarine lagoon goby, and decreased abundances of marine and some estuarine species. Abundance of congolli and common galaxias increased significantly but anadromous lampreys were not collected. Whilst positive responses were exhibited by some fish species in 2010/11, the fish assemblage of the Coorong was in a state of flux after the first influx of freshwater in over three years. It may take longer than 6 months to detect the response of some

species to hydrologic variability and connectivity, hence longer-term monitoring is required to determine the trajectory of recovery of this dynamic system following disturbance.

Freshwater inflows and high levels of hydrological connectivity continued throughout 2011/12. The objective of this study was to further investigate the influence of significant freshwater inflows and connectivity between the Lower Lakes and Coorong on fish assemblage structure and migration, and diadromous fish recruitment. Using the barrage fishways as a sampling tool we specifically aimed to:

1. Determine the species composition, and spatial and temporal variability of fish assemblages immediately downstream of the barrages and/or attempting to move between the Coorong and Lower Lakes via the barrage fishways.
2. Investigate the ecological response (i.e. spawning and recruitment) of diadromous fish to freshwater inflows.
3. Utilise this data to inform Target F-1 of the Lower Lakes Coorong and Murray Mouth Icon Site Management Plan (Maunsell 2009); *'maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong'*.

The fish assemblage sampled in 2011/12 was diverse (34 species) and whilst similar to 2010/11 in regards to species composition, there were significant changes in the abundance of some species. Freshwater species remained abundant, albeit less so than 2010/11, and there were increases in the abundance of several estuarine (i.e. lagoon goby (*Tasmanogobius lastii*) and river garfish (*Hyperhamphus regularis*), catadromous (i.e. congolli and common galaxias) and marine migrant species which are often associated with brackish conditions (i.e. mulloway (*Argyrosomus japonicas*) and sandy sprat (*Hyperlophus vittatus*)). Indeed sandy sprat overwhelmingly dominated, constituting ~89% of the total catch numerically. Furthermore, both pouched (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) were collected migrating upstream at the Murray Barrages after last being collected in November 2006.

The abundance of catadromous congolli and common galaxias were among the greatest detected throughout the entire project (2005–2012) and the majority of individuals (>80%) sampled were young-of-year (YOY). Newly recruited congolli and common galaxias were derived from protracted spawning seasons from June–October 2011 and June–December 2011, respectively. High levels of hydrological connectivity between freshwater and estuarine/marine environments, and brackish salinities, likely facilitated protracted spawning seasons and provided conditions conducive to larval/juvenile survival and subsequently enhanced recruitment. The recurrence of pouched and short-headed lamprey in 2011/12 is likely related to the presence of freshwater derived olfactory cues (particularly a conspecific pheromone) in the marine environment and subsequent attraction of adults to the Murray Barrages.

The results of this investigation present further changes to fish assemblages of the Coorong with prolonged freshwater inflow and hydrological connectivity. In general, the assemblage trended towards the diverse but variable fish assemblages that characterise dynamic estuarine environments. Populations of diadromous fish continued to recover following significant declines in recruitment and abundance from 2007–2010 and data collected in 2011/12 indicates that target F-1 (*'maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong'*) of the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan was achieved. Several estuarine and estuarine-dependent marine migrant species increased in abundance in 2011/12 potentially indicating elevated productivity within the Coorong through 2010–2012 and highlighting the need for multiple years of monitoring to detect the responses of some species (e.g. mulloway) to variable hydrology. Importantly, continued freshwater flow and connectivity between the Lower Lakes and the Coorong will be essential for the maintenance of populations of diadromous, estuarine and estuarine-dependent marine species and maintaining dynamism in estuarine fish communities.

1 Introduction

Estuaries form a dynamic interface and important conduit between freshwater and marine ecosystems, supporting high levels of biological productivity and diversity (Day *et al.* 1989; Goecker *et al.* 2009). Freshwater flows to estuaries transport nutrients and sediments and maintain a unique mixing zone between freshwater and marine environments (Whitfield 1999). Nevertheless, throughout the world anthropogenic modification of rivers has diminished freshwater flows to estuaries and threatens the existence of estuarine habitats (Gillanders and Kingsford 2002; Flemer and Champ 2006). In addition, structures that regulate flow may alter the longitudinal connectivity between estuarine and freshwater environments (Lucas and Baras 2001).

Fish are a key indicator of the impacts of altered freshwater inflows to estuaries and of barriers to connectivity (Gillanders and Kingsford 2002; Kocovsky *et al.* 2009). Estuaries support highly diverse and complex fish assemblages with a broad range of life history strategies (Whitfield 1999). Freshwater inflow and tidal regime determine estuarine salinities, influencing the structure of fish assemblages, which in turn are often characterised by a spatio-temporally variable mix of freshwater, estuarine and marine fish species (Kupschus and Tremain 2001; Barletta *et al.* 2005). Estuaries also represent critical spawning and recruitment habitats, and essential migratory pathways, for diadromous fish (McDowall 1988; Beck *et al.* 2001). Consequently, changes to flow regimes and physical barriers to movement represent two significant threats to estuarine dependent fishes, particularly diadromous species (Lassalle and Rochard 2009).

The Coorong estuary in south-eastern Australia lies at the terminus of Australia's largest river system, the Murray-Darling. The river system is highly regulated and on average only ~39% (4723 GL) of the natural mean annual discharge (12,233 GL) now reaches the sea (CSIRO 2008). Furthermore the river now ceases to flow through the river mouth (Murray Mouth) 40% of the time compared to 1% under natural unregulated conditions (CSIRO 2008). The estuary is separated from the lower river by a series of tidal barrages that form an abrupt physical and biological barrier, and have substantially reduced the area of the historical estuary.

From 1997–2010, south-eastern Australia experienced severe drought resulting in reduced inflows to the Murray-Darling Basin (MDB) (Potter *et al.* 2011). Over a four year period (2006–10), a combination of reduced system-wide inflows and over-allocation of water resulted in reduced flow to the Lower Lakes (<600 GL.y^{-1} in 2007 and 2008), causing a reduction in water level of >1.5 m and the cessation of freshwater flow to the Coorong estuary. Disconnection of the Coorong from the freshwater Lower Lakes resulted in increases in estuarine salinities and a concomitant decrease in fish species richness (Zampatti *et al.* 2010). When brackish conditions prevailed, fish assemblages were characterised by a diversity of freshwater, diadromous, estuarine and marine species. As salinities increased, however, freshwater, diadromous and estuarine species were lost and marine species became more common (Zampatti *et al.* 2010). Furthermore, catadromous congolli and common galaxias exhibited high inter-annual variations in recruitment, with significant declines in the abundance of young-of-the-year (YOY) migrants and contraction of migration and spawning periods associated with cessation of freshwater flow to the Coorong and loss of longitudinal connectivity (Zampatti *et al.* 2011). Anadromous short-headed and pouched lamprey, present in 2006/07, were absent through 2007–2010.

Increased inflows in the MDB in 2010/11 resulted in the return of typical water levels to the Lower Lakes and subsequently, the delivery of large volumes of freshwater to the Coorong from September 2010. Increased freshwater inflows resulted in the reinstatement of connectivity between the Lower Lakes and Coorong, and significantly reduced salinities, with concomitant changes to fish assemblage structure and recruitment. The fish assemblage in 2010/11 was dominated by freshwater (e.g. Australian smelt (*Retropinna semoni*)) and small-bodied estuarine species, whilst marine species and some estuarine species decreased in abundance (Zampatti *et al.* 2012). Recruitment of catadromous congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*) was enhanced resulting in increased abundance relative to 2007–2010. Nonetheless, short-headed lamprey and pouched lamprey were not collected.

Freshwater flows continued to be delivered to the Coorong throughout 2011/12. Whilst in 2010/11, the fish assemblage of the Coorong had begun to show signs of recovery following 2007–2010, particularly in regards to the recruitment of catadromous species, the system was undoubtedly in a state of change following the first influx of freshwater in over three years. Several species may require longer time periods (>6 months) before responses to hydrologic variability and connectivity may be detected and ongoing monitoring is essential to determine the trajectory of recovery of this dynamic system following disturbance.

The objective of this study was to further investigate the influence of significant freshwater inflows and reinstatement of connectivity between the Lower Lakes and Coorong on fish assemblage structure and migration, and diadromous fish recruitment. Using the barrage fishways as a sampling tool we specifically aimed to:

1. Determine the species composition, and spatial and temporal variability of fish assemblages immediately downstream of the barrages and/or attempting to move between the Coorong and Lower Lakes via the barrage fishways.

2. Investigate the ecological response (i.e. spawning and recruitment) of diadromous fish to freshwater inflows.
3. Utilise this data to inform Target F-1 of the Lower Lakes Coorong and Murray Mouth Icon Site Management Plan (Maunsell 2009); *'maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong'*.

2 Methods

2.1 Study Site

This study was conducted at the interface between the Coorong estuary and Lower Lakes of the River Murray, in southern Australia (Figure 2-1). The MDB drains an area of ~1,073,000 km^2 and the combined length of the two major rivers, the Murray and the Darling, is ~5,500 km. The River Murray discharges into a shallow (mean depth 2.9 m) expansive lake system, comprised of Lakes Alexandrina and Albert before flowing into the Coorong and finally the Southern Ocean via the Murray Mouth (Figure 2-1). Under natural conditions mean annual discharge is ~12,233 GL but there are strong inter-annual variations in discharge (Puckridge *et al.* 1998). Under regulated conditions, an average of ~4,723 $GL.y^{-1}$ reaches the sea, although from 1997–2010 this has been substantially less and zero on three occasions (Figure 2-2). Discharge in 2010/11 and 2011/12 was ~13,000 GL and >6000 GL, respectively.

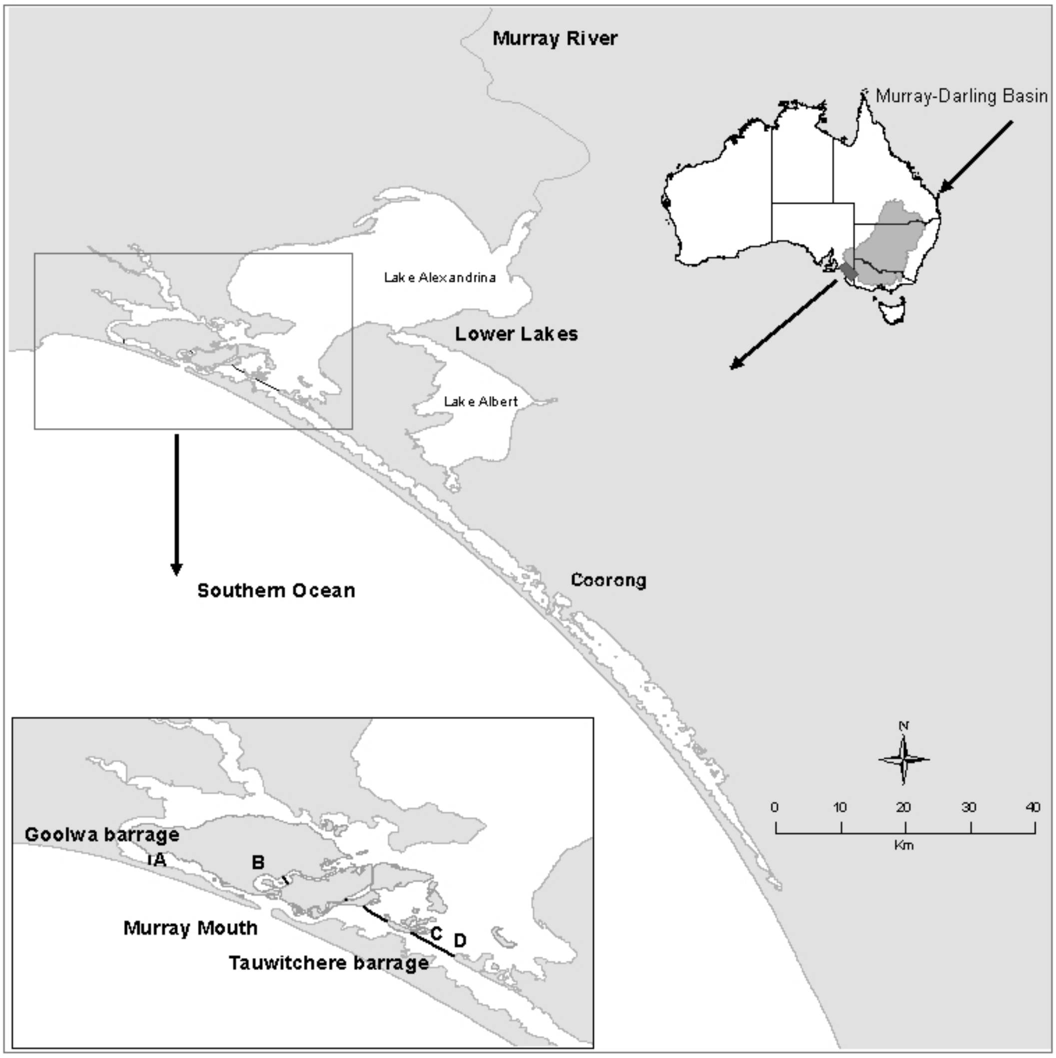

Figure 2-1 A map of the Coorong and Lower Lakes (Lakes Alexandrina and Albert) at the terminus of the Murray River, southern Australia showing the study area in the Coorong estuary, highlighting the Murray Mouth, Goolwa and Tauwitchere barrages and the fish sampling locations (A – Goolwa vertical-slot and adjacent the barrage, B – Hunters Creek vertical slot, C – Tauwitchere large vertical-slot and D – Tauwitchere small vertical-slot and rock ramp).

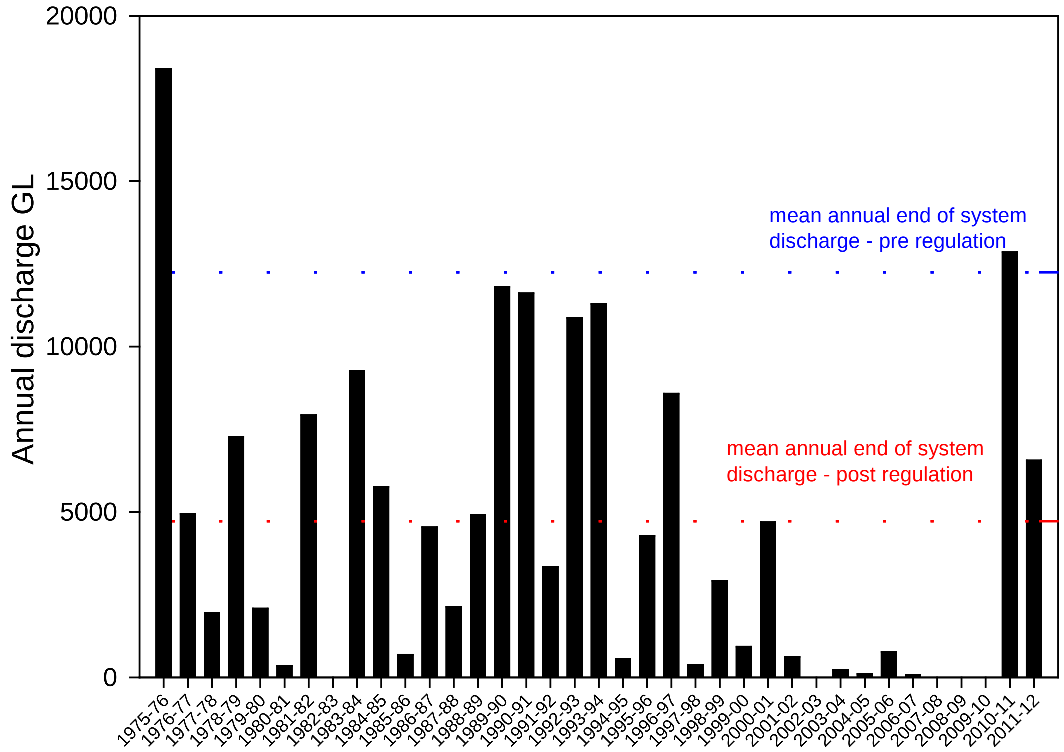

Figure 2-2 Annual freshwater discharge (GL) through the Murray barrages into the Coorong estuary from 1975–May 2012.

The Coorong is a narrow (2-3 km wide) estuarine lagoon running southeast from the river mouth and parallel to the coast, for ~140 km (Figure 2-1). The Coorong consists of a northern and southern lagoon bisected by a constricted region that limits water exchange (Geddes and Butler 1984). The region was designated a Wetland of International Importance under the Ramsar Convention in 1985, based upon its unique ecological character and importance to migratory wading birds (DEH 2000).

In the 1940s, five tidal barrages with a total length of 7.6 km were constructed to prevent saltwater intrusion into the Lower Lakes and maintain stable freshwater storage for water extraction. The construction of the barrages dramatically reduced the extent of the Murray estuary, creating an impounded freshwater environment upstream and an abrupt ecological barrier between marine and freshwater habitats. Pool level upstream of the barrages is typically regulated for most of the year at an average of 0.75 m AHD (Australian Height Datum).

Water level fluctuations below the Murray Barrages are dynamic and complex. The behaviour of tides is influenced directly by sedimentation and in particular water exchange through the Murray Mouth. Since the construction of the barrages tidal exchange has been reduced by an estimated 87-96%, significantly impacting on the hydrodynamic and littoral transport systems within the estuary (Harvey 1996).

Following the construction of the barrages the increased frequency of periods of zero freshwater inflow to the estuary and reduced tidal incursion has contributed to a reduction in estuary depth and hypersaline (>40 g.L^{-1}) salinities (Geddes 1987; Walker 2002). Typically, salinity ranges from marine (30–35 g.L^{-1}) near the Murray Mouth to hypersaline (>100 g.L^{-1}) at the lower end of the Southern Lagoon (Geddes and Butler 1984). During periods of high freshwater discharge, salinities in the northern lagoon can range from fresh to brackish (i.e. 5–30 g.L^{-1}) (Geddes 1987).

2.2 Fish sampling

Samples of fish were collected at the entrance of vertical-slot fishways at Tauwitchere Barrage (35°35'09.35"S, 139°00'30.58"E), Goolwa Barrage (35°31'34.44"S, 138°48'31.12"E) and Hunters Creek (35°32'07.08"S, 138°53'07.48"E), and adjacent to the rock ramp fishway at the southern end of Tauwitchere Barrage (35°35'24.16"S, 139°00'56.83"E) and the Hindmarsh Island abutment of the Goolwa Barrage (35°31'24.16"S, 138°48'33.79"E) (Figure 2-1).

The entrances of the vertical-slot fishways were sampled using aluminium-framed cage traps, designed to fit into the first cell of each fishway (Tauwitchere large vertical-slot: 2.3 m long x 4.0 m wide x ~2.0 m depth and 0.3 m slot widths, Tauwitchere small vertical-slot: 1.2 m long x 1.6 m wide x ~1.0 m depth and 0.2 m slot widths, Goolwa large vertical-slot: 2.6 m long x 3.6 m wide x ~3.6 m depth, 0.3 m slot widths (each baffle was modified in 2010 to three 200 mm wide x 500 mm deep orifices and one surface slot 200 mm wide and of variable depth, Appendix 1), Hunters Creek : 1.6 m long x 1.6 m wide x ~0.6 m depth and 0.1 m slot widths) (Figure 2-3a). Traps for the large vertical slot fishways at Tauwitchere and Goolwa were covered with 6 mm knotless mesh and featured a double cone–shaped entrance configuration (each 0.39 m high x 0.15 m wide) to maximise entry and minimise escapement. Traps for the small vertical-slot fishways at Tauwitchere and Hunters Creek were covered with 3 mm knotless mesh with single cone–shaped entrances (each 0.75 m high x 0.11 m wide).

Large double-winged fyke nets (6.0 m long x 2.0 m wide x 1.5 m high with 8.0 m long wings) covered with 6 mm knotless mesh were used to sample the area immediately adjacent to the Tauwitchere rock ramp fishway (Coorong side) and adjacent to the Hindmarsh Island abutment of the Goolwa Barrage (Coorong side). At the Tauwitchere rockramp the net was positioned so that one wing crossed in front of the outflow from the fishway thus channelling fish in the vicinity of the fishway into the net (Figure 2-3b). At Goolwa, the net was set adjacent to the barrage to capture fish utilising this area.

a) b)

Figure 2-3. a) Cage trap used to sample the Tauwitchere and Goolwa vertical-slot fishways and b) large fyke net used to sample the Tauwitchere rockramp fishway. A net of the same dimensions was also used to sample adjacent to the Hindmarsh Island abutment immediately downstream of the Goolwa Barrage.

Nine weeks of sampling were conducted between 26 July 2011 and 16 February 2012. Each site was sampled overnight 1-3 times per sampling trip/week. Cage traps at the large vertical slot fishways were deployed and retrieved using a mobile crane (Figure 2-3a). All trapped fish were removed and placed in large aerated holding tanks. Each individual was then identified to species and counted. For the catadromous species, congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*), a random sub-sample of 50 individuals were measured to the nearest mm (total length, TL) to represent the size structure of the population. Furthermore, sub-samples of congolli and common galaxias were collected every year, when present, for ageing via otolith microstructure analysis.

Any pouched or short-headed lamprey collected, were implanted with a PIT (Passive Integrated Transponder) tag (Texas Instruments RI-TRP-REHP half-duplex eco-line glass transponders 23.1 mm x 3.85 mm, 0.6 g in air). The majority of weirs on the River Murray in South Australia have vertical-slot fishways that have been fitted with PIT tag reader infrastructure that would record the passage of tagged lamprey should they travel through a fishway (Barrett and Mallen-Cooper 2006).

2.3 Otolith preparation and interpretation of microstructure

Where possible, 50 juvenile congolli and common galaxias were selected randomly from Tauwitchere (large and small vertical-slot, and rock ramp site combined) and Goolwa Barrage (vertical-slot and Hindmarsh Island abutment site combined) to represent the year for otolith analysis. Fish were measured for length (total length (TL), mm) and sagittae were extracted under a dissecting microscope.

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 then 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. Two readers examined each otolith on separate occasions and each reader performed two counts of the increments. Counts from each reader were compared and if they differed by more than 5% the otolith was rejected, but if count variation was within 5%, the mean of all counts was accepted as the best estimate of daily increment number.

Daily increment formation in post larval common galaxias otoliths has been validated previously by McDowall *et al.* (1994). Similar to McDowall *et al.* (1994), pre-hatch increments in common galaxias sections in this study were laid down at such fine resolution they are difficult to interpret consistently using standard light microscopy techniques. Alternatively, an easily identifiable hatch mark identified by McDowall *et al.* (1994) was evident on all sectioned otoliths, 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.

Daily increment formation in post larval congolli otoliths has been validated previously by Cheshire (2005). Daily increments for congolli were easily interpreted and counts were 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.

2.4 Data analysis

Spatio-temporal variation in fish assemblages

Temporal variation in the composition of fish assemblages sampled at each location was assessed between years. The statistical software package PRIMER v. 6.1.12 and PERMANOVA+ (Clarke and Gorley 2006) was used to perform statistical comparisons on fourth-root transformed relative abundance (number of fish.hour^{-1}.trip^{-1}) and species composition data (after Clarke and Warwick 2001). Non-Metric Multi-Dimensional Scaling (MDS) generated from Bray-Curtis similarity matrices were used to graphically represent assemblages from different years in two dimensions. PERMANOVA (permutational ANOVA and MANOVA) based on the same similarity matrices, was used to detect differences in assemblages between years. To allow for multiple comparisons between years at each site, a false discovery rate (FDR) procedure presented by Benjamini and Yekutieli (2001), hereafter the B–Y method FDR correction, was adopted ($\alpha = \sum_{i=1}^{n}(1/i)$; e.g. for $n_{comparisons}$ = 15, B-Y method α = 0.05/ (1/1 + 1/2 + 1/3…….+1/15) = 0.015) (Benjamini and Yekutieli 2001; Narum 2006). When significant differences occurred, a similarity of percentages (SIMPER) analysis was undertaken to identify species contributing to these differences. 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 years at each site using the package PCOrd v 5.12 (McCune and Mefford 2005). Non-abundant species may 'characterise' an assemblage without largely contributing to the difference between years detected with PERMANOVA. Such species may be important indicators of environmental change. A perfect indicator remains exclusive to a particular group or site and exhibits strong site fidelity during sampling (Dufrêne and Legendre 1997). Statistical significance was determined for each species indicator value using the Monte Carlo (randomisation) technique (α = 0.05).

Spatial variation in fish assemblages between sampling locations in 2011/12 was also investigated using MDS, PERMANOVA and ISA. MDS plots generated from Bray-Curtis similarity matrices was used to graphically represent assemblages from different locations in two dimensions and PERMANOVA was used to detect differences in assemblages between locations. To allow for multiple comparisons between sites within 2011/12, a B–Y method FDR correction for significance was adopted. ISA was then used to determine what species characterised assemblages at the different sampling locations in 2011/12.

Differences between years in the standardised abundance (fish.hour^{-1}.trap event^{-1}) of common galaxias and congolli sampled at the Tauwitchere rock ramp, Tauwitchere vertical-slot, Goolwa vertical-slot and adjacent the Hindmarsh Island abutment of Goolwa Barrage were analysed using uni-variate single-factor PERMANOVA (Anderson *et al.* 2008). This routine tests the response of a variable (e.g. fish abundance) to a single factor (e.g. year) in a traditional ANOVA (analysis of variance) experimental design using a resemblance measure (i.e. Euclidean distance) and permutation methods (Anderson *et al.* 2008). Unlike ANOVA, however, PERMANOVA does not assume samples come from normally distributed populations or that variances are equal.

3 Results

3.1 Hydrology and salinity

From mid July 2005 to March 2006 and May to August 2006, low-volume freshwater flows of 1000–12,000 $ML.d^{-1}$ were consistently released into the Coorong (Figure 3-1a). Water was released through barrage 'gates' and fishways on Tauwitchere and Goolwa Barrages. At the commencement of sampling in September 2006, all barrage gates were shut and freshwater was released solely through the barrage fishways (Tauwitchere: 20-40 $ML.d^{-1}$, Goolwa: ~20 $ML.d^{-1}$; Figure 3-1a) until March 2007, when all fishways were closed due to receding water levels in the Lower Lakes. Persistent drought conditions in the MDB resulted in no freshwater being released to the Coorong from March 2007–September 2010 (Figure 3-1a). Significant inflows to the Lower Lakes in late 2010 resulted in the release of large volumes of freshwater to the Coorong throughout the 2010/11 sampling season. Water was released through the barrage fishways and 'gates' on Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere Barrage's, with cumulative flow across the barrages peaking at ~80,000 $ML.d^{-1}$ and consistently >40,000 $ML.d^{-1}$ over the sampling period (Figure 3-1a). Medium-volume freshwater flows continued throughout the 2011/12 sampling season, ranging from 800–34,600 $ML.d^{-1}$, with a mean daily flow (±S.E.M.) of 10,823 ± 657 $ML.d^{-1}$ (Figure 3-1a).

During the period of low-volume freshwater releases (July 2005–March 2007) salinity below Tauwitchere and Goolwa Barrages fluctuated from 1–34 $g.L^{-1}$ and 1–27 $g.L^{-1}$ respectively but regularly ranged from 15–25 $g.L^{-1}$ at both locations (Figure 3-1b). Following the cessation of freshwater releases in March 2007, mean daily salinities at Tauwitchere increased and fluctuated between 30 and 60 $g.L^{-1}$ until September 2010 (Figure 3-1b). Salinities at Goolwa Barrage, between March 2007 and September 2010, also increased ranging from 28–37 $g.L^{-1}$. Following significant increases in freshwater releases to the Coorong in September 2010 (Figure 3-1a), salinities over the 2010/11 sampling period ranged from 0.3–25 $g.L^{-1}$ at Goolwa Barrage and 0.2–27 $g.L^{-1}$ at Tauwitchere Barrage; however, salinities were predominantly <1 $g.L^{-1}$ at both locations (Figure 3-1b). During 2011/12 sampling, salinity at Goolwa ranged from 0.3–32 $g.L^{-1}$ and 3–30 $g.L^{-1}$ at Tauwitchere (Figure 3-1b). Unlike 2010/11, salinity was more variable and appeared to follow a fortnightly lunar cycle, with higher tides resulting in seawater incursion and greater salinities (Figure 3-1b).

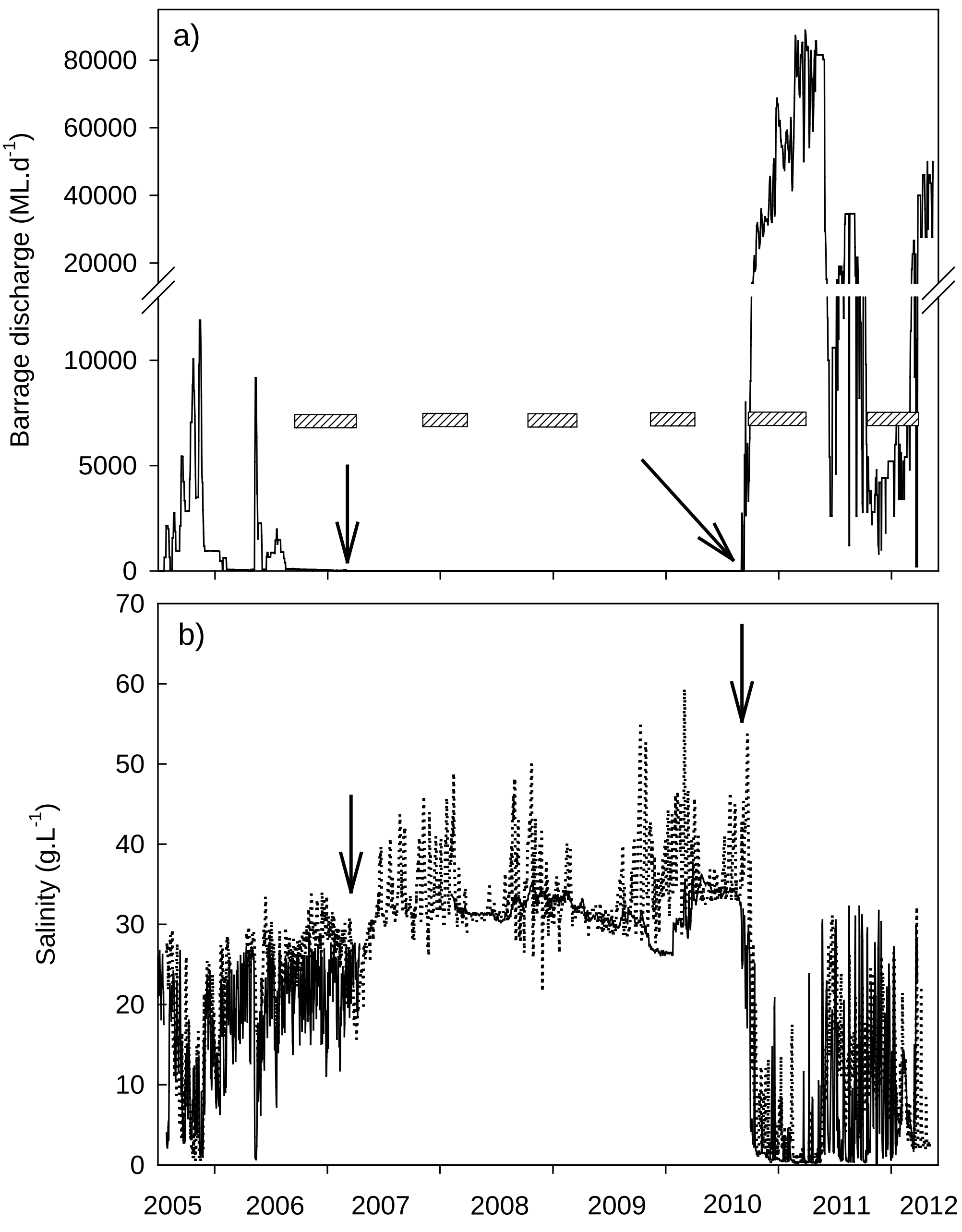

Figure 3-1. a) Mean daily flow (ML.d^{-1}) to the Coorong through the Murray Barrages (all barrages combined) from July 2005 – May 2012 and b) Mean daily salinity (g.L^{-1}) of the Coorong below Tauwitchere (dotted line) and Goolwa (solid line) barrage from July 2005 – March 2010. Sampling periods are represented by hatched bars. Black arrows indicate closure/opening of the barrages and fishways, and cessation/reinstatement of freshwater inflow.

3.2 Catch summary

A total of 3,563,129 fish from 34 species (21 families) were sampled in 2011/12 (Table 3-1). The marine sandy sprat overwhelmingly dominated, comprising ~89% of the total catch and was particularly abundant at the Tauwitchere rock ramp. The freshwater Australian smelt and bony herring, and estuarine lagoon goby, were also abundant comprising 4.7%, 1.7% and 2.5% of the total catch, respectively. The remaining 29 species collectively represented ~2% of the total catch.

Table 3-1. Summary of species and total number of fish sampled from the entrances of the Tauwitchere large vertical-slot, Tauwitchere small vertical-slot, Goolwa vertical-slot and Hunters Creek vertical-slot, and from the Tauwitchere rock-ramp and adjacent Hindmarsh Island abutment of Goolwa Barrage in 2011/12. Species are categorised using estuarine use functional groups from Elliott *et al.* (2007).

**denotes introduced species*

			Tauwitchere large vertical-slot	**Tauwitchere small vertical-slot**	**Tauwitchere downstream**	**Goolwa vertical-slot**	**Goolwa downstream**	**Hunters Creek**	**Total**
Common name	**Scientific Name**	**Functional group**							
	Sampling events No. of species		20 20	26 17	8 25	21 19	8 29	26 15	
Australian smelt	*Retropinna semoni*	Freshwater migrant	52630	22811	77142	12868	2377	47	**167,875**
Murray hardyhead	*Craterocephalus fluviatilis*	Freshwater straggler	0	0	0	0	2	0	**2**
Bony herring	*Nematalosa erebi*	Freshwater straggler	2006	4	46942	688	12902	371	**62,913**
Flat-headed gudgeon	*Philypnodon grandiceps*	Freshwater migrant	336	67	2223	158	1317	261	**4362**
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Freshwater straggler	0	1	0	0	1	0	**2**
Carp gudgeon	*Hypseleotris* spp	Freshwater straggler	0	1	1	2	1	2	**7**
Golden perch	*Macquaria ambigua*	Freshwater migrant	27	45	126	33	85	34	**350**
Common carp	*Cyprinus carpio**	Freshwater straggler	220	440	105	146	77	2132	**3120**
Goldfish	*Carrasius auratus**	Freshwater straggler	4	20	5	6	11	86	**132**
Redfin perch	*Perca fluviatilis**	Freshwater straggler	524	70	8003	207	601	4382	**13,787**
Pouched lamprey	*Geotria australis*	Anadromous	1	4	0	3	1	0	**9**
Short-headed lamprey	*Mordacia mordax*	Anadromous	0	0	0	0	1	0	**1**
Common galaxias	*Galaxias maculatus*	Semi-catadromous	378	2769	474	7974	157	1911	**13,663**
Congolli	*Pseudaphritis urvillii*	Semi-catadromous	896	981	9619	693	1045	2891	**16,125**
Small-mouthed hardyhead	*Atherinosoma microstoma*	Estuarine	317	45	3919	14	56	152	**4503**

Table 3-1 continued.

			Tauwitchere large vertical-slot	Tauwitchere small vertical-slot	Tauwitchere downstream	Goolwa vertical-slot	Goolwa downstream	Hunters Creek	Total
Common name	**Scientific Name**	**Functional group**							
Southern long-finned goby	*Favonigobius lateralis*	Estuarine	0	0	1	0	0	0	**1**
Tamar River goby	*Afurcagobius tamarensis*	Estuarine	115	4	1225	434	10844	69	**12,691**
Blue-spot goby	*Pseudogobius olorum*	Estuarine	0	0	21	7	1	1	**30**
Lagoon goby	*Tasmanogobius lasti*	Estuarine	2257	110	77086	248	10147	74	**89,922**
Bridled goby	*Arenogobius bifrenatus*	Estuarine	2	0	93	0	15	0	**110**
Greenback flounder	*Rhombosolea tapirina*	Estuarine	3	0	14	0	65	0	**82**
Long-snouted flounder	*Ammotretis rostratus*	Estuarine	0	0	2	0	12	0	**14**
Southern garfish	*Hyperhamphus melanchir*	Marine migrant	0	0	8	0	0	0	**8**
River garfish	*Hyperhamphus regularis*	Estuarine	12	0	1641	1	11	0	**1665**
Yellow-eyed mullet	*Aldrichetta forsteri*	Marine migrant	1	0	9	10	2	0	**22**
Flat-tailed mullet	*Liza argentea*	Marine migrant	0	0	0	0	2	0	**2**
Mulloway	*Argyrosomus japonicas*	Marine migrant	0	0	0	0	102	0	**102**
Soldier fish	*Gymnapistes marmoratus*	Marine migrant	0	0	8	0	17	0	**25**
Smooth toadfish	*Tetractenos glaber*	Marine migrant	9	0	8	1	6	0	**24**
Australian salmon	*Arripis trutta*	Marine migrant	5	0	656	0	1780	0	**2441**
Australian herring	*Arripis georgianus*	Marine migrant	0	1	0	0	0	0	**1**
Sandy sprat	*Hyperlophus vittatus*	Marine migrant	2461	281	2618214	4555	543441	2	**3,169,134**
Australian anchovy	*Engraulis australis*	Marine migrant	0	0	0	0	2	0	**2**
Pug nose pipefish	*Pugnaso curtirostris*	Marine migrant	**0**	**0**	**0**	**1**	**1**	**0**	**2**
		Total	**62,385**	**27,653**	**2,847,545**	**28,049**	**585,082**	**12,415**	**3,563,129**

3.3 Temporal variation in fish assemblages

MDS ordination plots show distinct groupings of fish assemblages by year at each sampling location (Figure 3-2). These groupings are supported by PERMANOVA, which detected significant differences in fish assemblages between years at the Tauwitchere rock ramp (*Pseudo*-$F_{5,\ 44}$ = 17.786, p <0.001), Tauwitchere vertical-slot (*Pseudo*-$F_{5,\ 38}$ = 14.301, p <0.001), Goolwa vertical-slot (*Pseudo*-$F_{4,\ 36}$ = 7.546, p <0.001), adjacent the Hindmarsh Island abutment of Goolwa Barrage (*Pseudo*-$F_{3,\ 24}$ = 9.715, p <0.001), Tauwitchere small vertical-slot ($t_{1,\ 44}$ = 17.786, p <0.001) and Hunters Creek vertical-slot (*Pseudo*-$F_{5,\ 44}$ = 17.786, p <0.001).

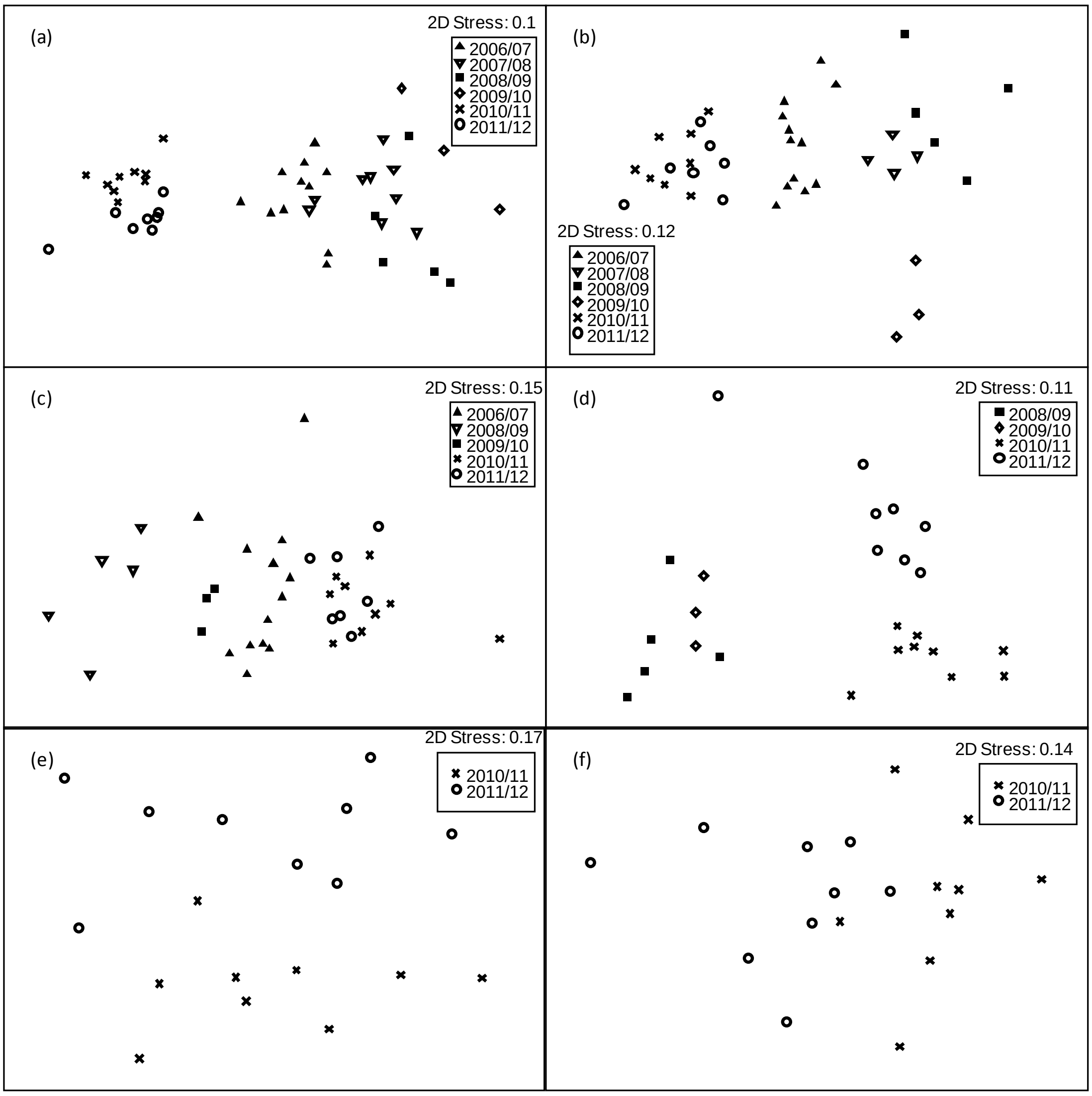

Figure 3-2. MDS ordination plots of fish assemblages sampled at a) Tauwitchere rock ramp, b) Tauwitchere vertical-slot, c) Goolwa vertical-slot, d) adjacent the Hindmarsh Island abutment of Goolwa Barrage, e) Tauwitchere small vertical-slot and f) Hunters Creek vertical-slot, between 2006 and 2012.

Tauwitchere sites

Pair-wise comparisons revealed significant differences in fish assemblages at the Tauwitchere rock ramp between all years, except for 2008/09 and 2009/10 (B-Y method corrected $\alpha = 0.015$) (Table 3-2). Fish assemblages sampled at the Tauwitchere vertical-slot in 2006/07 differed significantly from assemblages sampled in all subsequent years. No significant difference was detected between assemblages sampled in 2007/08, 2008/09 and 2009/10 (Table 3-2). Assemblages sampled in 2010/11 and 2011/12 were not significantly different but both years were significantly different from all preceding years.

When fish assemblages were determined to not be significantly different between years, these years were grouped for SIMPER and indicator species analysis (ISA). SIMPER analysis, adopting a cumulative 40% contribution cut-off for all comparisons, showed that differences in fish assemblages between 2006/07 and 2007/08, and the grouped years 2008/09 and 2009/10, was due to decreased abundance of the freshwater Australian smelt (*Retropinna semoni*), catadromous common galaxias (*Galaxias maculatus*), estuarine small-mouthed hardyhead (*Atherinosoma microstoma*) and lagoon goby (*Tasmanogobius lastii*), and marine migrant sandy sprat (*Hyperlophus vitattus*), and increased abundance of the marine migrant yellow-eyed mullet (*Aldrichetta forsterii*). Fish assemblages in 2010/11 were different from all preceding years due to greater abundances of freshwater species, namely Australian smelt, flat-headed gudgeon (*Philypnodon grandiceps*), bony herring (*Nematalosa erebi*) and redfin perch (*Perca fluviatilis*), and the estuarine lagoon goby. Assemblages in 2010/11 also differed from 2011/12 due to greater abundances of freshwater Australian smelt and redfin perch in 2010/11 but much greater abundances of the estuarine lagoon goby and marine migrant sandy sprat in 2011/12. These two species were also the primary drivers of fish assemblage variation between 2011/12 and the years 2006–2010.

At the Tauwitchere vertical-slot variation in assemblage structure between 2006/07 and the subsequent three years (2007/08, 2008/09 and 2009/10) was due to reduced abundance of the catadromous congolli (*Pseudaphritis urvillii*) and common galaxias, and freshwater flat-headed gudgeon. The years 2010/11 and 2011/12 were not significantly different but differences between this group and preceding years was driven by increased abundance of the freshwater Australian smelt, bony herring and estuarine lagoon goby. The difference in fish assemblage structure between 2010/11 and 2011/12 at the Tauwitchere small vertical-slot was primarily due to greater abundance of flat-headed gudgeon and redfin perch in 2010/11 and slightly greater abundance of Australian smelt in 2011/12.

Table 3-2. PERMANOVA pair-wise comparisons between fish assemblages sampled in 2006/07, 2007/08, 2008/09, 2009/10, 2010/11 and 2011/12 at the Tauwitchere rock ramp (TRR) and Tauwitchere vertical-slot (TVS). PERMANOVA was performed on Bray-Curtis similarity matrices. After B-Y method FDR correction α = 0.015 for the Tauwitchere rock ramp and vertical-slot, α = 0.017.

Location	Pair-wise comparison		*t*	*p* value
	Year	**Year**		
TRR	2006/07	2007/08	2.281	<0.001*
TRR	2006/07	2008/09	2.775	<0.002*
TRR	2006/07	2009/10	3.064	0.003*
TRR	2006/07	2010/11	5.202	<0.001*
TRR	2006/07	2011/12	4.980	<0.001*
TRR	2007/08	2008/09	1.772	0.007*
TRR	2007/08	2009/10	2.144	0.004*
TRR	2007/08	2010/11	6.044	<0.001*
TRR	2007/08	2011/12	5.808	<0.001*
TRR	2008/09	2009/10	2.086	0.02 ns
TRR	2008/09	2010/11	5.496	0.002*
TRR	2008/09	2011/12	5.461	0.002*
TRR	2009/10	2010/11	5.303	0.004*
TRR	2009/10	2011/12	5.277	0.007*
TRR	2010/11	2011/12	2.445	<0.001*
TVS	2006/07	2007/08	2.784	<0.001*
TVS	2006/07	2008/09	3.447	<0.001*
TVS	2006/07	2009/10	3.637	0.002*
TVS	2006/07	2010/11	4.527	<0.001
TVS	2006/07	2011/12	3.506	<0.001*
TVS	2007/08	2008/09	1.597	0.023 ns
TVS	2007/08	2009/10	2.622	0.036 ns
TVS	2007/08	2010/11	5.45	0.002*
TVS	2007/08	2011/12	4.567	0.007*
TVS	2008/09	2009/10	2.439	0.023 ns
TVS	2008/09	2010/11	4.963	0.002*
TVS	2008/09	2011/12	4.439	0.003*
TVS	2009/10	2010/11	4.914	0.004*
TVS	2009/10	2011/12	4.232	0.010*
TVS	2010/11	2011/12	1.447	0.065 ns

* indicates a significant *t* value whilst 'ns' indicates a non-significant *t* value.

Whilst SIMPER reveals species that contribute substantially to differences in fish assemblages between years detected by PERMANOVA, the technique typically highlights the influence of highly abundant species. Whilst non-abundant species may not contribute greatly to the differences detected between assemblages, their presence or absence from given years may provide supportive information and indicate environmental change. Therefore ISA (Dufrêne and Legendre 1997) was carried out to determine species that 'characterised' assemblages in different years or 'groups' of years (as determined by pair-wise comparisons; Table 3-2) at each site.

At the Tauwitchere rock ramp, fish assemblages in 2006/07 were characterised by the presence of short-headed lamprey (*Mordacia mordax*), but in 2007/08, and 2008/09 and 2009/10 collectively, assemblages were increasingly characterised by marine migrant species, including blue sprat (*Spartelloides robustus*), Australian anchovy (*Engraulis australis*), flat-tailed mullet (*Liza argentea*), yellowfin whiting (*Sillago schomburgkii*), prickly toadfish (*Contusus brevicaudus*) and mulloway (*Argyrosomus japonicas*) together with the estuarine black bream (*Acanthopagrus butcherii*) (Table 3-3). The assemblage sampled in 2010/11 was characterised by a suite of nine freshwater species (i.e. golden perch, carp gudgeon complex (*Hypseleotris* spp.), bony herring, Australian smelt, flat-headed gudgeon, dwarf flat-headed gudgeon (*Philypnodon macrostomus*), redfin perch, common carp and goldfish) and one estuarine species (i.e. southern longfin goby (*Favonigobius lateralis*)) (Table 3-3). The assemblage in 2011/12 was characterised by the catadromous common galaxias, two estuarine species (i.e. Tamar River goby (*Afurcagobius tamarensis*) and river garfish (*Hyperhamphus melanchir*)) and two marine migrant species (i.e. Australian salmon (*Arripis truttaceus*) and sandy sprat) (Table 3-3).

At the Tauwitchere vertical-slot, assemblages were characterised by the catadromous congolli and common galaxias, anadromous short-headed lamprey (*Mordacia mordax*) and estuarine flat-tailed mullet (Table 3-4). Pair-wise comparisons revealed that assemblages in 2007/08, 2008/09 and 2009/10 were not significantly different (Table 3-2) and there were no indicator species characterising the assemblage from this grouping. Assemblages were not significantly different between 2010/11 and 2011/12, and these years were collectively characterised by a range of freshwater species (i.e. bony herring, Australian smelt, golden perch, redfin perch, common carp and goldfish) and two estuarine species (i.e. river garfish and lagoon goby) (Table 3-4). At the Tauwitchere small vertical-slot in 2010/11, assemblages were characterised by the freshwater flat-headed gudgeon and redfin perch and in 2011/12, by the catadromous common galaxias (Table 3-4).

Table 3-3. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere rock ramp from 2006–2012. Data from 2008/09 and 2009/10 are grouped as indicated by PERMANOVA pair-wise comparisons.

Species	Year	Indicator Value	*p* value
Tauwitchere rockramp			
Short-headed lamprey	2006/07	45.5	0.002
Blue sprat	2007/08	44.4	0.003
Australian anchovy	2007/08	53.8	0.027
Flat-tailed mullet	2007/08	42.3	0.012
Black bream	2008/09 & 2009/10	32.9	0.021
Mulloway	2008/09 & 2009/10	36.0	0.035
Prickly toadfish	2008/09 & 2009/10	31.5	0.024
Yellowfin whiting	2008/09 & 2009/10	34.8	0.025
Golden perch	2010/11	64.1	0.003
Carp gudgeon complex	2010/11	88.3	<0.001
Bony herring	2010/11	52.6	0.008
Australian smelt	2010/11	61.2	0.001
Flat-headed gudgeon	2010/11	97.3	<0.001
Dwarf flat-headed gudgeon	2010/11	31.5	0.020
Redfin perch	2010/11	83.1	<0.001
Common carp	2010/11	98.7	<0.001
Goldfish	2010/11	52.2	0.003
Southern longfin goby	2010/11	88.3	<0.001
Tamar River goby	2011/12	70.1	<0.001
Australian salmon	2011/12	59.4	0.034
Common galaxias	2011/12	53.6	0.031
River garfish	2011/12	71.9	0.001
Sandy sprat	2011/12	96.7	<0.001

Table 3-4. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere large vertical-slot from 2006–2012 and at the Tauwitchere small vertical-slot from 2010–2012. Based upon PERMANOVA pair-wise comparisons data from 2007–2010 at the Tauwitchere large vertical-slot were grouped together, as were data from 2010/11 and 2011/12.

Species	Year	Indicator Value	*p* value
Tauwitchere large vertical-slot			
Common galaxias	2006/07	96.2	<0.001
Congolli	2006/07	76.4	0.025
Short-headed lamprey	2006/07	33.3	0.014
Flat-tailed mullet	2006/07	32.5	0.032
Bony herring	2010/11 & 2011/12	100	<0.001
Australian smelt	2010/11 & 2011/12	99.8	<0.001
Golden perch	2010/11 & 2011/12	53.3	0.001
Redfin perch	2010/11 & 2011/12	99.9	<0.001
Common carp	2010/11 & 2011/12	92.4	<0.001
Goldfish	2010/11 & 2011/12	26.7	0.029
River garfish	2010/11 & 2011/12	26.7	0.027
Lagoon goby	2010/11 & 2011/12	96.6	<0.001
Tauwitchere small vertical-slot			
Flat-headed gudgeon	2010/11	97.8	<0.001
Redfin perch	2010/11	99.9	0.001
Common galaxias	2011/12	83.5	0.044

Goolwa sites

Pair-wise comparisons revealed significant differences in fish assemblages at the Goolwa vertical-slot between 2006/07 and all subsequent years (B-Y method corrected $\alpha = 0.017$) (Table 3-5). Assemblages sampled in 2008/09 and 2009/10 were not significantly different. Fish assemblages sampled in 2010/11 and 2011/12 were also not significantly different from one another but both years were significantly different from all preceding years. Fish assemblages adjacent the Hindmarsh Island abutment of Goolwa Barrage did not differ significantly between 2008/09 and 2009/10, but assemblages sampled in 2010/11 and 2011/12 were significantly different from all other years.

Table 3-5. PERMANOVA pair-wise comparisons between fish assemblages sampled in 2006/07, 2008/09, 2009/10, 2010/11 and 2011/12 Goolwa vertical-slot (GVS) and adjacent the Hindmarsh Island abutment of Goolwa Barrage (GDS). PERMANOVA was performed on Bray-Curtis similarity matrices. After B-Y method FDR correction $\alpha = 0.017$ for Goolwa vertical-slot analyses and $\alpha = 0.02$ for adjacent the Hindmarsh Island abutment of Goolwa Barrage.

Location	Pair-wise comparison		*t*	*p* value
	Year	Year		
GVS	2006/07	2008/09	2.805	<0.001*
GVS	2006/07	2009/10	1.72	0.015*
GVS	2006/07	2010/11	2.977	<0.001*
GVS	2006/07	2011/12	2.147	<0.001
GVS	2008/09	2009/10	1.865	0.032 ns
GVS	2008/09	2010/11	3.974	<0.001*
GVS	2008/09	2011/12	3.781	0.002*
GVS	2009/10	2010/11	2.64	0.004*
GVS	2009/10	2011/12	2.961	0.007*
GVS	2010/11	2011/12	1.506	0.026 ns
GDS	2008/09	2009/10	1.295	0.161 ns
GDS	2008/09	2010/11	4.222	<0.001*
GDS	2008/09	2011/12	3.370	<0.001*
GDS	2009/10	2010/11	3.334	0.007*
GDS	2009/10	2011/12	2.519	0.006*
GDS	2010/11	2011/12	2.731	<0.001*

Patterns of temporal variation in fish assemblages at the Goolwa vertical-slot were similar to the Tauwitchere large vertical-slot. The difference in the assemblages between 2006/07 and the grouped years 2008/09 and 2009/10 was driven by decreases in the abundance of catadromous congolli and common galaxias, freshwater Australian smelt and marine migrant sandy sprat. Differences in assemblages between the grouped years, 2010/11 and 2011/12, and preceding years was due to increases in freshwater species abundance, namely Australian smelt, bony herring and redfin perch, a decrease in the abundance of the marine migrant flat-tailed mullet (*Liza argentea*) and slightly diminished abundance of the catadromous congolli and common galaxias relative to 2006/07. At the site adjacent the Hindmarsh Island abutment of Goolwa Barrage, differences in assemblages between the grouped years 2008/09 and 2009/10, and both 2010/11 and 2011/12 were driven by increased abundance of four freshwater species (i.e. flat-headed gudgeon, bony herring, Australian smelt and redfin perch), estuarine lagoon goby and the marine migrant sandy sprat, as well as a reduction in the marine migrant yellow-eyed mullet. Assemblages sampled in 2010/11 and 2011/12 differed primarily due to greater abundance of sandy sprat in 2011/12 and greater abundance of the freshwater flat-headed gudgeon and redfin perch, and estuarine small-mouthed hardyhead (*Atherinosoma microstoma*) and bridled goby (*Arenogobius bifrenatus*) in 2010/11.

Indicator species analysis (ISA) of assemblage data from the Goolwa vertical-slot indicated that assemblages in 2006/07 were characterised by the catadromous congolli, anadromous short-headed lamprey and marine migrant mulloway (*Agyrosomus japonicas*). The years 2008/09 and 2009/10 were grouped and characterised by estuarine black bream and three marine migrant species, namely flat-tailed mullet, sea sweep (*Scorpis aequipinnis*) and soldier fish (*Gymnapistes marmoratus*) (Table 3-6). The grouped assemblages in 2010/11 and 2011/12 were characterised by a suite of freshwater species (i.e. bony herring, Australian smelt, flat-headed gudgeon, golden perch, redfin perch, common carp and goldfish) and the estuarine lagoon goby (Table 3-6).

The grouped assemblage sampled adjacent the Hindmarsh Island abutment of Goolwa Barrage in 2008/09 and 2009/10 was characterised by estuarine black bream and three marine migrant species; yellow-eyed mullet, Australian herring (*Arripis georgianus*) and smooth toadfish (*Tetractenos glaber*) (Table 3-6). The assemblage sampled in 2010/11 was characterised by five freshwater species, namely carp gudgeon (*Hypseleotris* spp.), Australian smelt, flat-headed gudgeon, common carp and redfin perch and three estuarine species; bridled goby, blue-spot goby (*Pseudogobius olorum*) and small-mouthed hardyhead (Table 3-6). The assemblage sampled in 2011/12 was characterised by the catadromous common galaxias and two marine migrants; mulloway and Australian salmon (*Arripis trutta*) (Table 3-6)

Table 3-6. Indicator species analysis of fish assemblages in the Coorong at the Goolwa vertical slot from 2006–2012 and adjacent the Hindmarsh Island abutment of Goolwa Barrage from 2008–2012. Data from the Goolwa vertical slot from 2008/09 and 2009/10 were grouped together based upon PERMANOVA pair-wise comparisons, as were data from 2010/11 and 2011/12. Data from adjacent the Hindmarsh Island abutment of Goolwa Barrage from 2008/09 and 2009/10 were also grouped.

Species	Year	Indicator Value	*p* value
Goolwa vertical-slot			
Short-headed lamprey	2006/07	46.2	0.002
Congolli	2006/07	91.9	0.002
Mulloway	2006/07	23.1	0.045
Black bream	2008/09 & 2009/10	66.6	<0.001
Flat-tailed mullet	2008/09 & 2009/10	58.7	0.010
Sea sweep	2008/09 & 2009/10	37.5	0.008
Soldier fish	2008/09 & 2009/10	59.2	<0.001
Bony herring	2010/11 & 2011/12	59.2	0.027
Australian smelt	2010/11 & 2011/12	94.4	<0.001
Flat-headed gudgeon	2010/11 & 2011/12	82.1	<0.001
Golden perch	2010/11 & 2011/12	70.3	0.003
Redfin perch	2010/11 & 2011/12	75.9	0.003
Common carp	2010/11 & 2011/12	55.1	0.008
Goldfish	2010/11 & 2011/12	31.2	0.019
Lagoon goby	2010/11 & 2011/12	99.9	<0.001
Adjacent the Hindmarsh Island abutment of Goolwa Barrage			
Black bream	2008/09 & 2009/10	77.6	0.003
Yellow-eyed mullet	2008/09 & 2009/10	99.6	<0.001
Australian herring	2008/09 & 2009/10	61.7	0.002
Carp gudgeon	2010/11	77.2	<0.001
Flat-headed gudgeon	2010/11	96.7	<0.001
Redfin perch	2010/11	86.1	<0.001
Common carp	2010/11	59.7	0.049
Small-mouthed hardyhead	2010/11	84.1	0.013
Bridled goby	2010/11	98.1	<0.001
Common galaxias	2011/12	53.5	0.044
Mulloway	2011/12	74.8	<0.001
Australian salmon	2011/12	97.2	<0.001

Hunters Creek

At the Hunters Creek vertical-slot, differences in assemblages between 2010/11 and 2011/12 were primarily attributed to greater abundance of the freshwater bony herring, flat-headed gudgeon and redfin perch in 2010/11. ISA determined that the assemblage in 2010/11 was characterised by the freshwater carp gudgeon and flat-headed gudgeon, and estuarine blue-spot goby (Table 3-7). In 2011/12 the assemblage was characterised by the freshwater Australian smelt and golden perch (Table 3-7).

Table 3-7. Indicator species analysis of fish assemblages at the entrance of the Hunters Creek vertical-slot from 2010–2012.

Species	Year	Indicator Value	*p* value
Carp gudgeon	2010/11	52.5	0.048
Flat-headed gudgeon	2010/11	96.2	<0.001
Blue-spot goby	2010/11	53.9	0.031
Australian smelt	2011/12	68.3	0.009
Golden perch	2011/12	66.7	0.009

3.4 Spatial variation in fish assemblages in 2011/12

MDS ordination of fish assemblage data from 2011/12 exhibited distinct groupings of fish assemblages by capture location (Figure 3-3), supported by PERMANOVA, which detected significant differences in fish assemblages between capture locations (*Pseudo-F*$_{5,\,47}$ = 10.465, *p* < 0.001). Pair-wise comparisons indicated that assemblages differed significantly between all capture locations (B-Y method corrected α = 0.015), with the exception of the Goolwa vertical-slot and Tauwitchere large vertical-slot (Table 3-8).

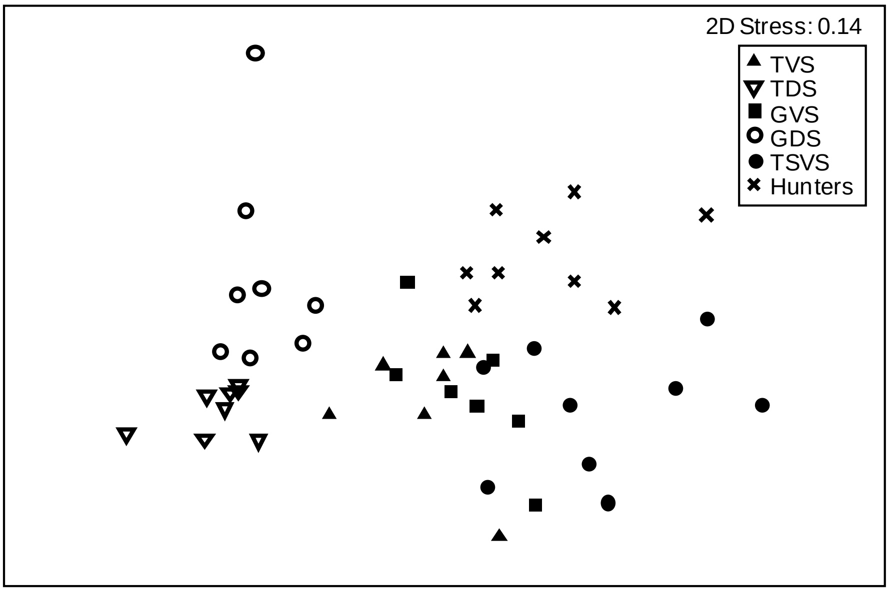

Figure 3-3. MDS ordination plot of fish assemblages sampled at the Tauwitchere large vertical-slot (TVS), Tauwitchere rock ramp (TRR), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS), Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (GDS) and Hunters Creek vertical-slot (Hunters) in 2011/12.

Table 3-8. PERMANOVA pair-wise comparisons of fish assemblages from the Tauwitchere rock ramp (TRR), Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS), Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (GDS) and Hunters Creek vertical-slot (Hunters) in 2011/12. PERMANOVA was performed on bray-curtis similarity matrices. B-Y method corrected α = 0.015.

Pair-wise comparison		*t*	***p* value**
Location	**Location**		
TRR	TVS	4.012	<0.001*
TRR	GVS	4.745	<0.001*
TRR	GDS	2.525	<0.001*
TRR	Hunters	5.289	<0.001*
TRR	TSVS	4.650	<0.001*
TVS	GVS	1.427	0.047ns
TVS	GDS	2.818	<0.001*
TVS	Hunters	2.736	<0.001*
TVS	TSVS	2.090	<0.001*
GVS	GDS	3.032	<0.001*
GVS	Hunters	2.579	0.002*
GVS	TSVS	1.729	<0.001
GDS	Hunters	2.579	0.002*
GDS	TSVS	3.676	<0.001*
Hunters	TSVS	2.013	<0.001*

Indicator species analysis was used to determine species that characterised assemblages at different sampling locations in 2011/12. Of 34 species sampled, 19 were deemed to be significant indicators of the fish assemblage at a particular location (Table 3-9). The estuarine Tamar river goby, greenback flounder (*Rhombosolea tapirina*) and long-snouted flounder (*Ammosetris rostratus*), and marine migrant mulloway (*Agyrosomus japonicas*) and Australian salmon (*Arripis trutta*) characterised the assemblage at the Hindmarsh Island abutment site immediately downstream of the Goolwa Barrage, whilst a range of freshwater (i.e. golden perch, bony herring, flat-headed gudgeon, Australian smelt and redfin perch), catadromous (i.e. congolli), estuarine (river garfish, bridled goby, blue-spot goby (*Pseudogobius olorum*), lagoon goby and small-mouthed hardyhead) and marine migrant species (i.e. yellow-eyed mullet and sandy sprat) characterised the assemblage at the Tauwitchere rock ramp site. There were no significant indicators from the Tauwitchere large vertical-slot, Tauwitchere small vertical-slot or Goolwa vertical-slot. The catch at the Hunters Creek vertical-slot was characterised by goldfish.

Table 3-9. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere rockramp (TRR), Tauwitchere vertical-slot (TVS), Tauwitchere small-bodied vertical-slot (TSVS), Goolwa vertical-slot (GVS), Hindmarsh Island abutment site immediately downstream of the Goolwa Barrage (GDS) and Hunters Creek vertical-slot (Hunters) in 2011/12.

Species	**Location**	**Indicator value**	***p* value**
Tamar river goby	GDS	83.5	0.011
Long-snouted flounder	GDS	43.0	0.005
Mulloway	GDS	75.0	<0.001
Australian salmon	GDS	77.4	<0.001
Greenback flounder	GDS	81.3	<0.001
Yellow-eyed mullet	TRR	34.5	0.023
Bridled goby	TRR	73.0	<0.001
River garfish	TRR	86.6	<0.001
Sandy sprat	TRR	83.3	0.012
Small-mouthed hardyhead	TRR	94.2	<0.001
Blue-spot goby	TRR	63.9	<0.001
Lagoon goby	TRR	90.1	<0.001
Congolli	TRR	63.9	<0.001
Golden perch	TRR	48.4	0.015
Bony herring	TRR	74.7	0.007
Redfin perch	TRR	80.6	<0.001
Flat-headed gudgeon	TRR	61.4	0.014
Australian smelt	TRR	70.6	<0.001
Goldfish	Hunters	44.1	0.017

Given the much greater numbers of fish sampled at the Tauwitchere rock ramp site and the Hindmarsh Island abutment site immediately downstream of the Goolwa Barrage, and the likelihood of masking differences between the vertical-slot fishways, a second ISA was run using only data from the vertical-slot fishways. This analysis revealed that amongst the vertical-slot fishways, the assemblage at the Tauwitchere large vertical-slot was characterised by the freshwater Australian smelt and bony herring together with four estuarine species; small-mouthed hardyhead, river garfish, lagoon goby and greenback flounder. The Goolwa vertical-slot assemblage was characterised by the marine migrant yellow-eyed mullet and the

Hunters Creek vertical-slot assemblage by freshwater goldfish and redfin perch (Table 3-10). There were no significant indicator species of the assemblage at the Tauwitchere small vertical-slot.

Table 3-10. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS) and Hunters Creek vertical-slot (Hunters) in 2011/12.

Species	**Location**	**Indicator value**	***p* value**
Australian smelt	TVS	65.6	0.016
Bony herring	TVS	68.3	0.009
Small-mouthed hardyhead	TVS	58.4	0.025
River garfish	TVS	41.4	0.033
Lagoon goby	TVS	91.3	0.001
Greenback flounder	TVS	42.9	0.016
Yellow-eyed mullet	GVS	39.5	0.023
Goldfish	Hunters	66.8	0.007
Redfin perch	Hunters	81.0	0.016

3.5 Temporal variation in abundance and recruitment of diadromous species

Lamprey

Upstream adult migrants of anadromous short-headed lamprey (*Mordacia mordax*) were collected from the Tauwitchere rock ramp (*n* = 13), Tauwitchere large vertical slot (*n* = 5) and Goolwa vertical slot (*n* = 22) between mid September and mid November 2006 (Figure 3-4a). One adult pouched lamprey (*Geotria australis*) was also collected at the Tauwitchere rock ramp in September 2006 (Figure 3-4b). No lamprey were sampled in 2007/08, 2008/09, 2009/10 or 2010/11, but in 2011/12, adults of both pouched and short-headed lamprey were again collected migrating upstream. Pouched lamprey were sampled in late July at the Tauwitchere large vertical slot (*n* = 1), Goolwa vertical-slot (*n* = 3) and Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (*n* = 1) and in late July and mid November at the Tauwitchere small vertical slot (*n* = 4) (Figure 3-4b). One short-headed lamprey was also collected from the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage in November 2011 (Figure 3-4a). Of nine pouched lamprey collected, six were implanted with PIT tags. One individual (total length = 586 mm) tagged at the Goolwa vertical-slot on the 26th July 2011 ascended the Lock 1 fishway on the 8th October 2011.

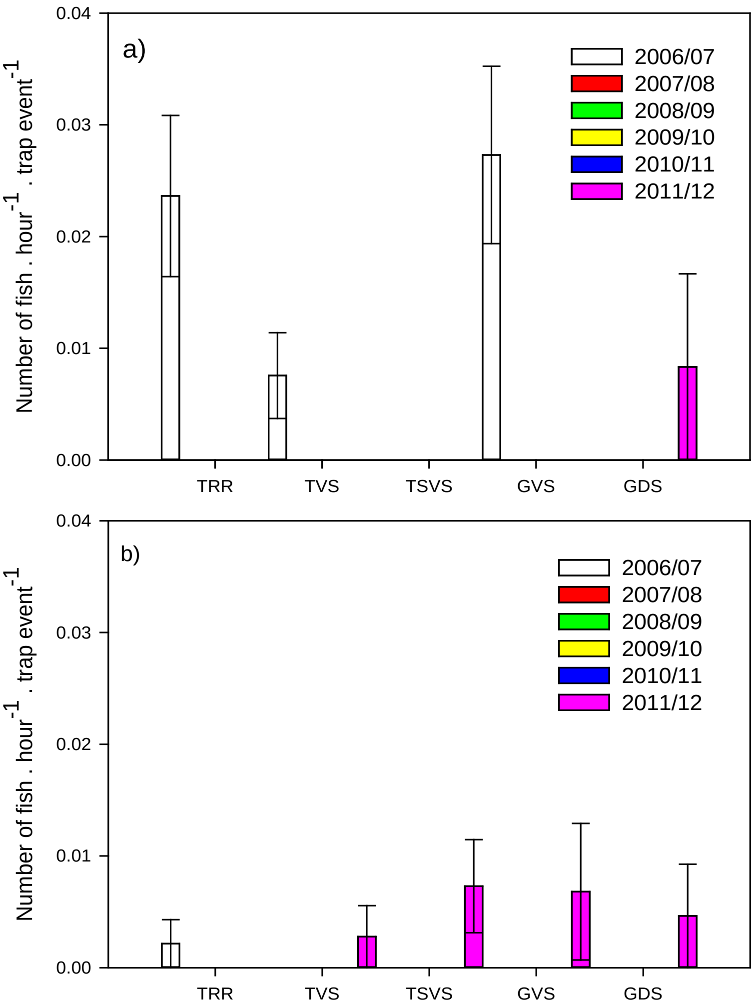

Figure 3-4. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of a) short-headed lamprey and b) pouched lamprey at the Tauwitchere rock ramp (TRR), Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS) and the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (GDS) from 2006 – 2012. Goolwa vertical-slot was not sampled in 2007/08 and the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage was not sampled in 2006/07 and 2007/08. The Tauwitchere small vertical-slot was only sampled in 2010/11 and 2011/12.

Congolli and common galaxias

The abundance of the catadromous congolli and common galaxias differed significantly between years at the Tauwitchere rock ramp (uni-variate single-factor PERMANOVA: congolli, *Pseudo-F*$_{5,\ 85}$ = 34.36, p <0.001; common galaxias, *Pseudo-F*$_{5,\ 85}$ = 21.93, p <0.001), Tauwitchere vertical-slot (congolli, *Pseudo-F*$_{5,\ 96}$ = 12.11, p <0.001; common galaxias, *Pseudo-F*$_{5,\ 96}$ = 46.17, p <0.001) and the Goolwa vertical-slot (congolli, *Pseudo-F*$_{4,\ 96}$ = 10.46, p <0.001; common galaxias, *Pseudo-F* $_{4,\ 96}$ = 4.04, p = 0.005) (Figure 3-5). The abundance of the common galaxias differed significantly between years at the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (*Pseudo-F* $_{3,\ 33}$ = 7.05, p = 0.006) but the abundance of congolli was not significantly different between years (congolli, *Pseudo-F* $_{3,\ 33}$ = 2.27, p = 0.10) (Figure 3-5).

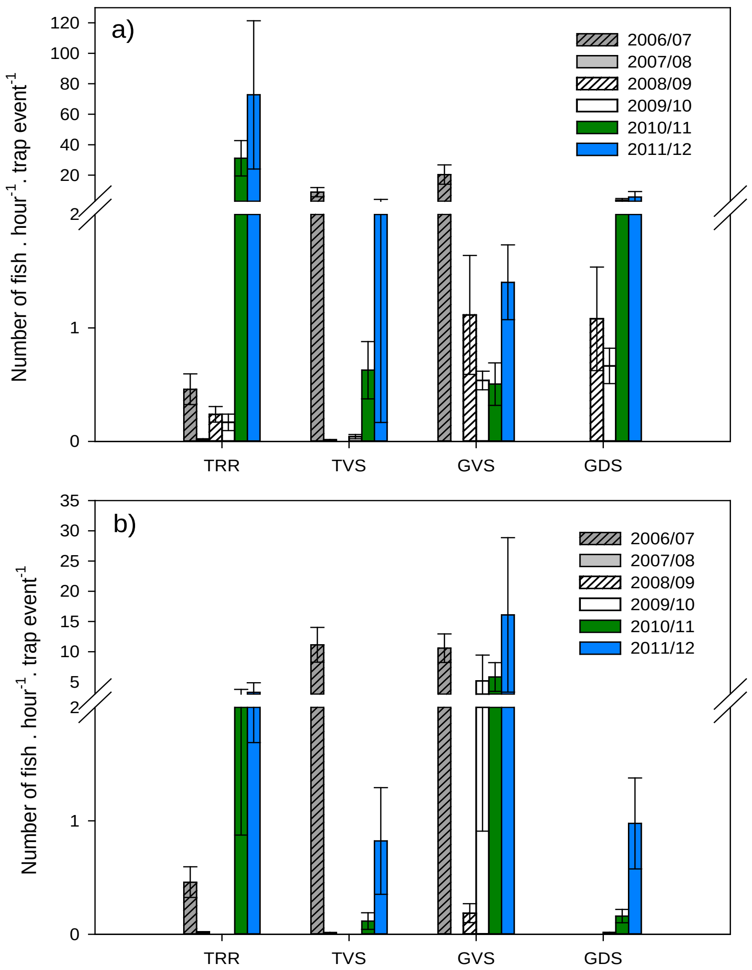

Figure 3-5. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of a) congolli and b) common galaxias at the Tauwitchere rockramp (TRR), Tauwitchere vertical-slot (TVS), Goolwa vertical-slot (GVS) and the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage (GDS) from 2006–2012. Goolwa vertical-slot was not sampled in 2007/08 and the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage was not sampled in 2006/07 and 2007/08.

The abundance of congolli in 2011/12 was among the highest recorded at all sites over the entire study (since 2006) (Figure 3-5a). Patterns of variability in abundance were generally consistent across sites with decreased abundances during 2007–2010 followed by increased abundance in 2010/11, particularly at the Tauwitchere rock ramp and at the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage; albeit without statistical significance. Abundances remained similar at these two sites in 2011/12 but increased further at both the Tauwitchere large vertical slot and Goolwa vertical-slot, returning to levels similar to those recorded in 2006/07.

In 2011/12, common galaxias was sampled in greatest abundance relative to all previous years at all sites except for the Tauwitchere large vertical-slot (Figure 3-5b). As with congolli, common galaxias was typically sampled in low abundance during 2007–2010, with the exception of the Goolwa vertical-slot where this species was sampled in relatively high abundance in 2009/10. Following the reconnection of the Lower Lakes and Coorong in 2010/11 there were generally increases in the abundances of this species relative to the preceding year, with further increases in abundance occurring at the Tauwitchere large vertical-slot, Goolwa vertical-slot and at the Hindmarsh island abutment site immediately downstream of the Goolwa Barrage in 2011/12.

Below Tauwitchere Barrage (Tauwitchere rock ramp, large vertical-slot and small vertical-slot data combined) in September and October 2011, congolli exhibited broad length distributions (i.e. 20–221 mm TL and 27–247 mm TL, respectively) (Figure 3-6a). A newly recruited 0+ cohort ranging 27–34 mm TL was present in October, comprising ~25% of the sampled population. The abundance of congolli below Tauwitchere Barrage peaked in November–December, with the 0+ cohort ranging 26–42 mm TL and increasing in abundance to represent >85% of the population in November. Further growth of this cohort was evident in December, ranging 32–65 mm TL. General abundance began to decrease in January but the 0+ cohort still comprised >80% of the population.

A similar pattern was evident below Goolwa Barrage (vertical-slot and site adjacent Hindmarsh Island abutment site immediately downstream of Goolwa Barrage data combined) with a broad length distribution in September 2011 (52–188 mm TL) and relatively even contribution of fish of different sizes to the total population (Figure 3-6b). By October a 0+ cohort, ranging 23–44 mm TL, was present and comprised >60% of the population. Progression of this cohort was evident through the following months, comprising >50% and >80% of the population in November and December respectively. Similar to Tauwitchere, abundance began to decline in January, as did the proportion of the population representing the 0+ cohort, which declined to ~25%.

At Hunters Creek a 0+ cohort was evident and dominant as of September 2011 (Figure 3-6c). As per the previous two locations, abundance peaked in November (n = 2710) when the 0+ cohort comprised >98% of the sampled population. This cohort remained dominant through December and January but general abundances began to decline.

Similar to congolli, common galaxias exhibited a broad range of lengths at Tauwitchere in September 2011 (35–132 mm TL) with two distinct cohorts; a 0+ group ranging 35–52 mm TL and a group of larger adult fish ranging 68–132 mm TL (Figure 3-7a). Abundance peaked in October (n = 1324) when the 0+ cohort ranged 34–52 mm TL and comprised >85% of the population. Abundance declined marginally through November, December and January, and length-frequency distributions became broader, indicating the growth of the 0+ cohort and appearance of new small (<40 mm TL) 0+ individuals. By January 2011, a distinction between 0+ and older fish was not apparent, although >90% of the sampled population were <80 mm TL, the majority of which were likely 0+.

At Goolwa in September 2011, the length-frequency distribution was quite different to Tauwitchere, with the population dominated by an adult cohort >80 mm TL and only two potential 0+ individuals (Figure 3-7b). Abundance increased dramatically in October (*n* = 7141) with the population ranging 34–124 mm TL and the 0+ cohort (34–61 mm TL) comprising ~90% of the population. As at Tauwitchere, abundance declined gradually through November, December and January, and length-frequency distributions became broader. Nonetheless, the 0+ cohort dominated (>60%) the population in both November and December, and still represented >50% of the population in January 2012.

Comparable with the length-frequency distribution patterns for congolli, length distribution of common galaxias at Hunters Creek in September 2011 differed from both Tauwitchere and Goolwa, in that the 0+ cohort (40–59 mm TL) was already dominant and there were very few adult fish (Figure 3-7c). This cohort remained dominant throughout sampling with individuals <60 mm TL representing ~93%, 87%, 94%, 72% and 65% of the sampled population from September 2011 to January 2012. Abundance peaked in November (*n* = 1054), later than at Tauwitchere and Goolwa, and gradually decreased through December and January.

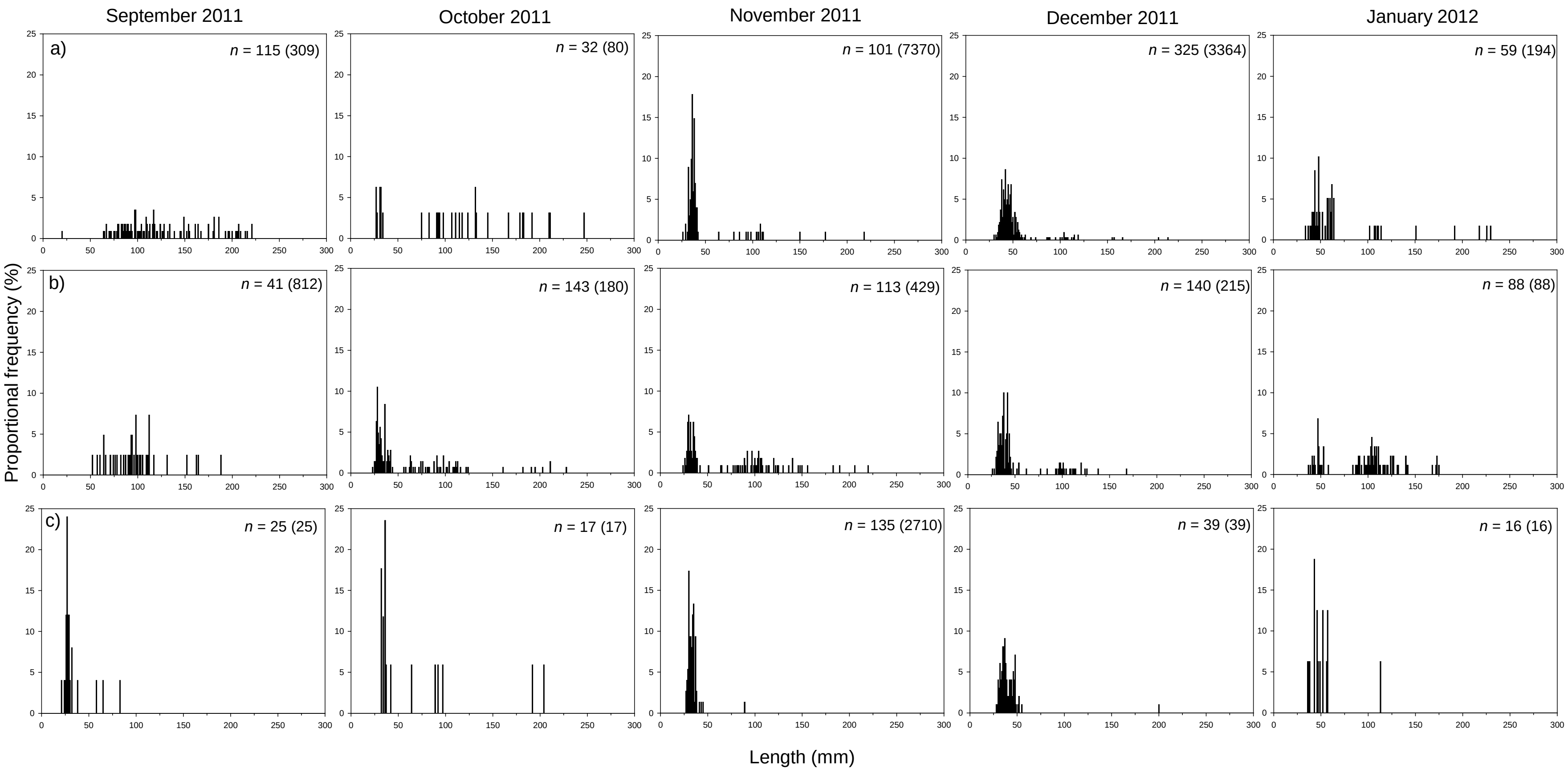

Figure 3-6. Monthly length-frequency distributions (total length, mm) of congolli sampled below a) Tauwitchere Barrage (rock ramp, large vertical-slot and small vertical-slot combined) b) Goolwa Barrage (vertical-slot and site adjacent Hindmarsh Island abutment site immediately downstream of Goolwa Barrage combined) and c) at the entrance of the Hunters Creek vertical-slot from September 2011–January 2012. *n* is the number of fish measured and the total number of fish collected in each month at each site is presented in brackets.

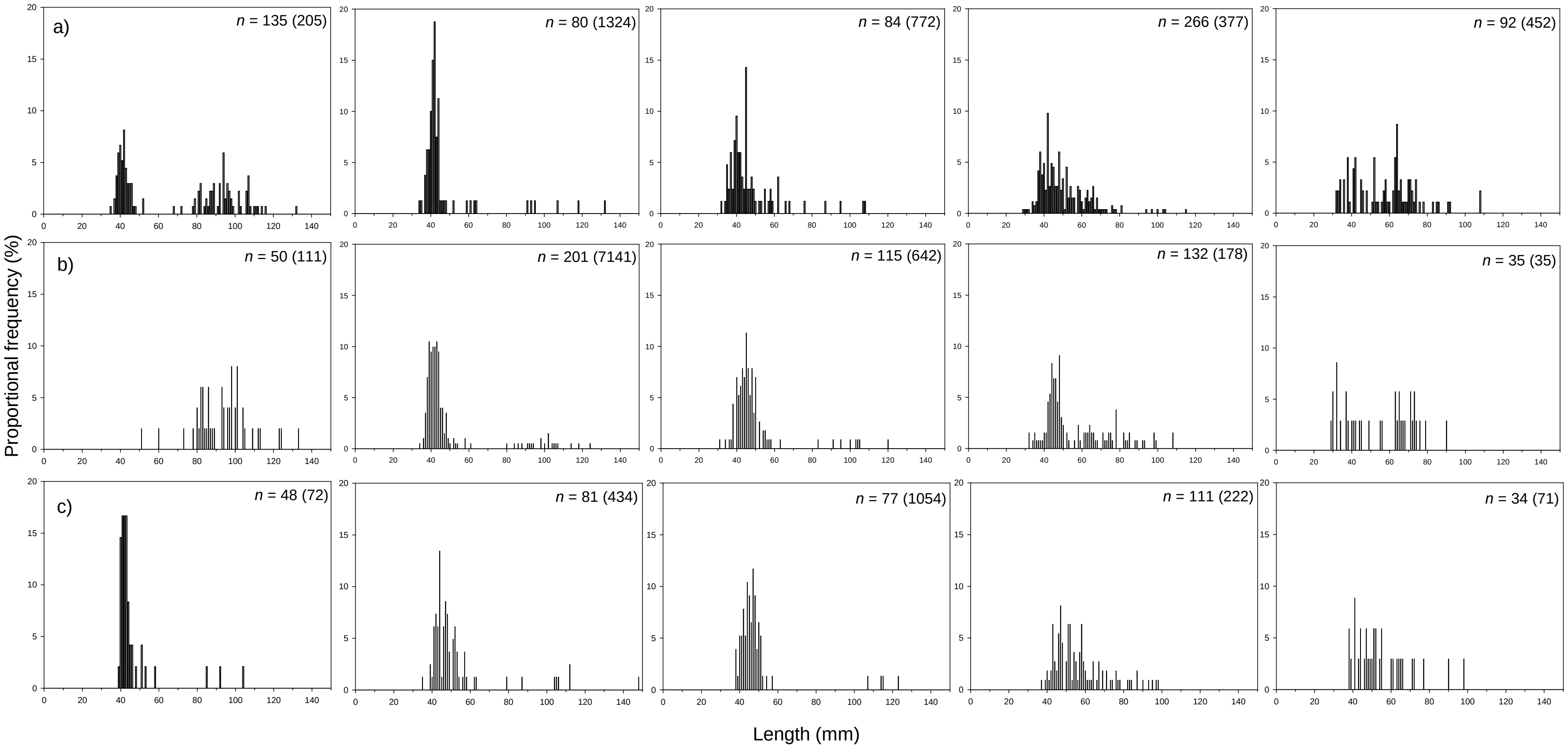

Figure 3-7. Monthly length-frequency distributions (total length, mm) of common galaxias sampled below a) Tauwitchere Barrage (rock ramp, large vertical-slot and small vertica- slot combined) b) Goolwa Barrage (vertical-slot and site adjacent Hindmarsh Island abutment site immediately downstream of Goolwa Barrage combined) and c) at the entrance of the Hunters Creek vertical-slot from September 2011 – January 2012. *n* is the number of fish measured and the total number of fish collected in each month at each site is presented in brackets.

3.6 Spawning and hatch dates

3.6.1 Congolli

In 2006/07, spawning date distributions for congolli at both Tauwitchere (rock ramp and vertical-slot combined) and Goolwa Barrage indicated an extended reproductive season with distinct periods of higher spawning success (Figure 3-8a). At Tauwitchere, successful recruits were derived from spawning that occurred over a ~88 day period from 4 July to 29 September 2006. Peak periods in spawning success were observed during late August and early September. At Goolwa successful recruits resulted from spawning that occurred for a duration of ~112 days. Spawning occurred earlier than observed at Tauwitchere, commencing on 25 June 2006 and continuing through to 14 October 2006. Peak periods in spawning success were observed from mid–late July.

At Tauwitchere in 2007/08, 2008/09 and 2009/10, successful recruits were derived from spawning that occurred over contracted periods relative to 2006/07, spanning ~44 days (19 July–31 August 2007), ~36 days (19 July–23 August 2008) and ~13 days (11 July–23 July 2009), respectively (Figure 3-8b-d). In 2010/11, however, spawning again occurred over a protracted duration, similar to 2006/07, of ~75 days from 10 July–21 September 2010 (Figure 3-8e). Successful recruits sampled in 2011/12 were derived from a protracted spawning season of ~89 days, over the same period as 2006/07 recruits, from 3 July–29 September, with peak spawning activity between mid-July and mid-August (Figure 3-8f).

Sites at Goolwa were not sampled in 2007/08, but in 2008/09 and 2009/10 successful recruits originated from contracted spawning seasons, relative to 2006/07, of ~66 days (2 July–5 September 2008) and ~64 days (13 July–14 September 2009) (Figure 3-8c and d). In 2010/11, spawning again occurred over a protracted period of ~104 days from 21 July–1 November (Figure 3-8e). Similar to both 2006/07 and 2010/11, in 2011/12 recruits were derived from spawning over a protracted season of ~98 days from 28 June–3 October 2011 (Figure 3-8f). The greatest proportion of recruits was derived from spawning in August 2011.

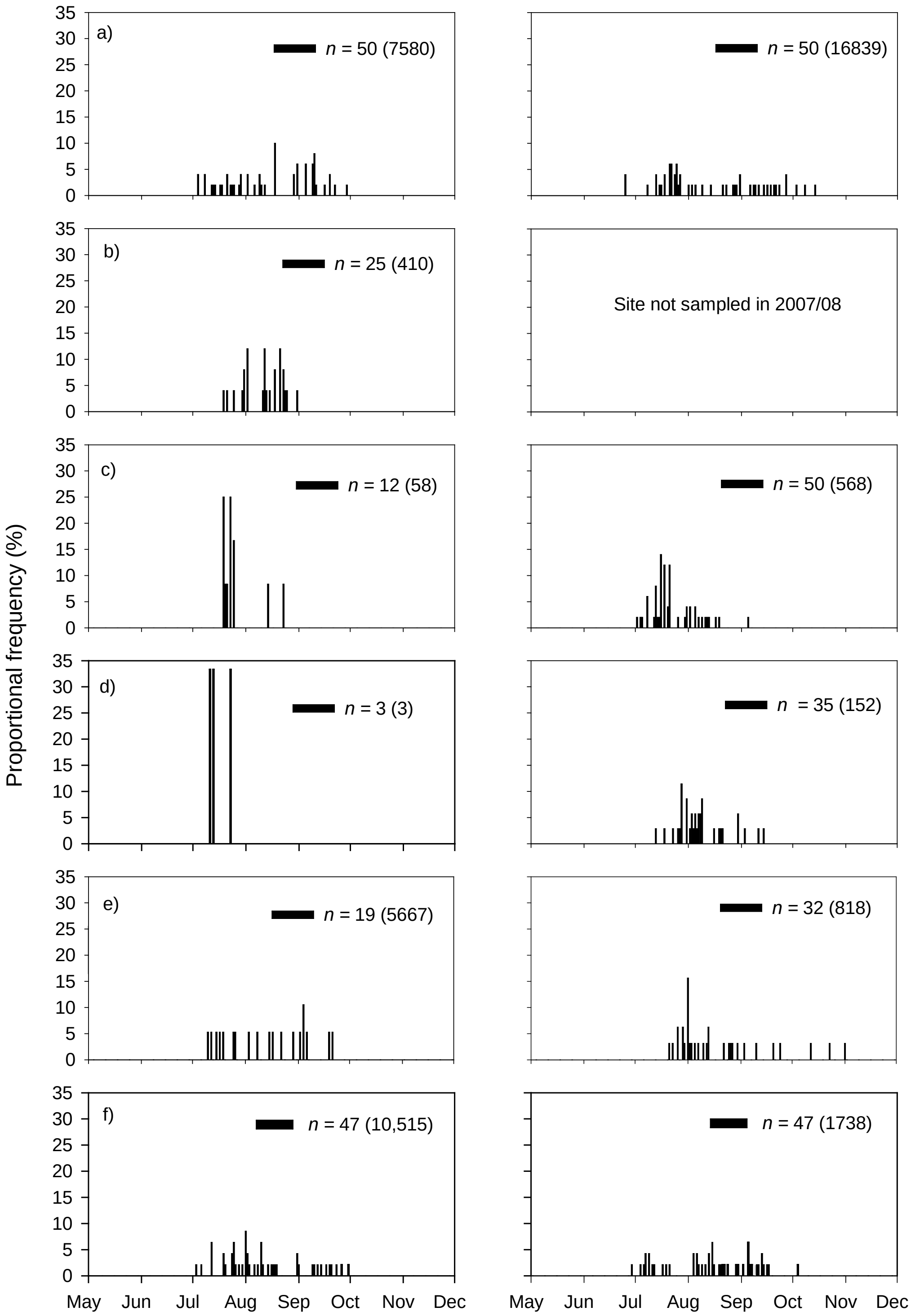

Figure 3-8. Estimated spawning date frequency of post-larval congolli sampled from downstream Tauwitchere (left-hand side; rock ramp and vertical-slot entrance sites combined) and Goolwa Barrages (right-hand side; vertical-slot entrance and Hindmarsh Island abutment of Goolwa Barrage sites combined) in a) 2006/07, b) 2007/08, c) 2008/09, d) 2009/10, e) 2010/11 and f) 2011/12. *n* is the number fish that were aged from each location within each year. The total number of individuals collected from each location is presented in brackets.

3.6.2 Common galaxias

In 2006/07, hatching dates for common galaxias at Tauwitchere and Goolwa were characterised by broad flat distributions, evidence of an extended spawning season with continuous recruitment success (Figure 3-9a). At Tauwitchere successful recruits were derived from spawning that occurred over a period of ~156 days, hatching from 17 June 2006 to 19 November 2006. At Goolwa successful recruits resulted from spawning that occurred for a similar duration of ~165 days, although hatching occurred earlier on 28 May 2006 and continued to 8 November 2006.

In 2007/08 at Tauwitchere, hatching date distribution had contracted relative to 2006/07 (Figure 3-9b), with recruits derived from spawning that occurred over a substantially shorter period of ~46 days (hatch period: 27 May–11 July 2007). In 2008/09 and 2009/10, recruits were absent from Tauwitchere. In 2010/11, recruits were again present and were derived from a contracted hatching season relative to 2006/07, of ~68 days from 21 July–26 September (Figure 3-9e). In 2011/12 at Tauwitchere, the recruits collected were derived from a protracted spawning season, greater than that of 2006/07, hatching over a period of ~186 days from 20 June–22 December 2011 (Figure 3-9f). Spawning occurred throughout this period but the greatest proportion of recruits was derived from spawning in September–October.

Sites at Goolwa were not sampled in 2007/08, but in 2008/09 and 2009/10 successful recruits were derived from spawning that occurred over shorter periods relative to 2006/07 ($D = 0.63$, $p < 0.001$), hatching over ~48 days (10 August–26 September 2008) and ~82 days (2 August–21 October), respectively (Figure 3-9c and d). In 2010/11, hatching occurred over a similarly contracted duration to 2009/10, of ~85 days from 18 July–10 October, with a period of peak hatching in early August (Figure 3-9e). In 2011/12, as per Tauwitchere, recruits were derived from a protracted spawning season greater than in 2006/07, hatching over a period of ~179 days from 28 June–23 December (Figure 3-9f). Spawning occurred throughout this period but the greatest proportion of recruits was derived from spawning in August–September.

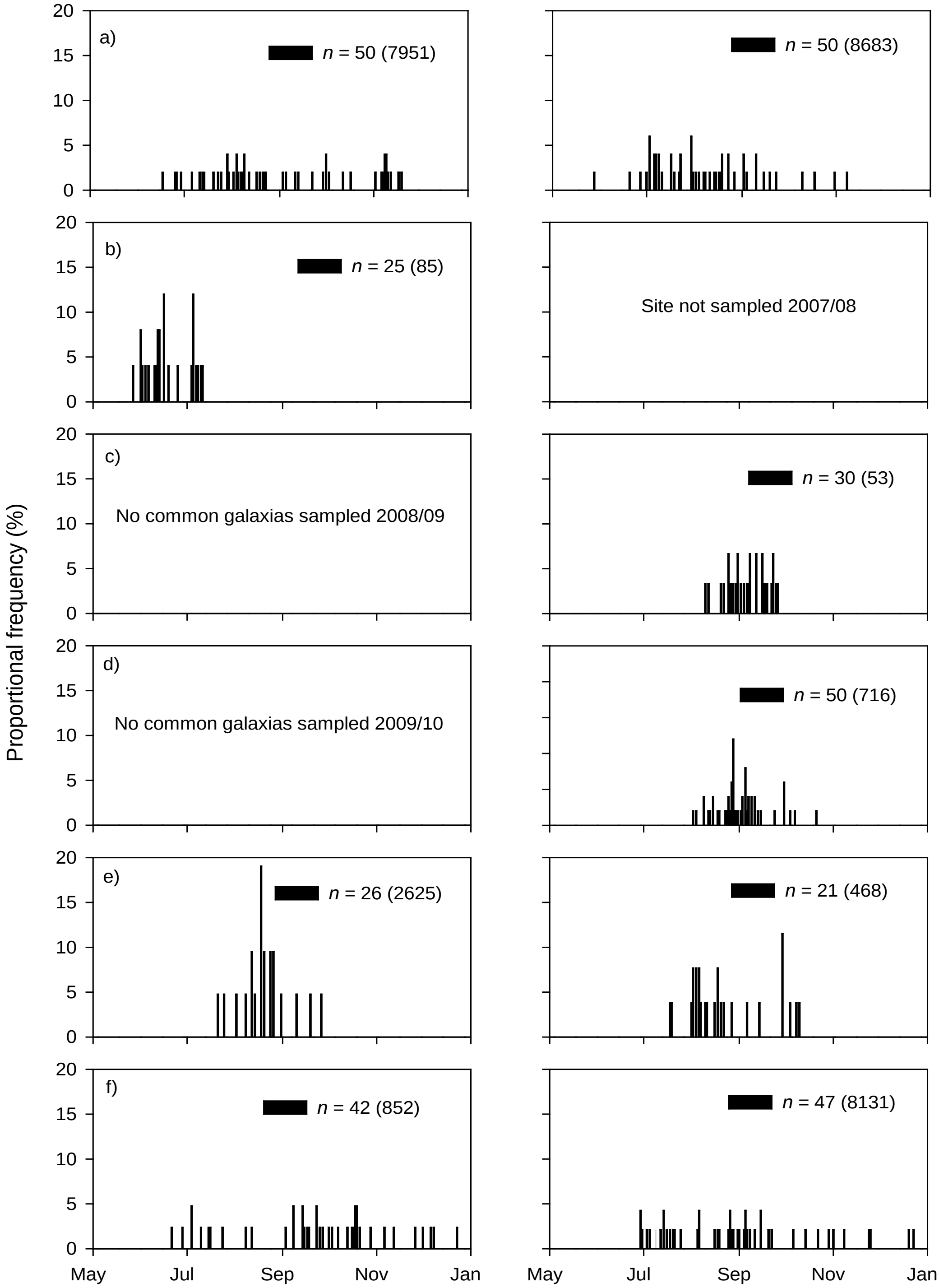

Figure 3-9. Estimated spawning date frequency of post-larval common galaxias sampled from downstream Tauwitchere (left-hand side; rock ramp and vertical-slot entrance sites combined) and Goolwa Barrages (right-hand side; vertical-slot entrance and Hindmarsh Island abutment of Goolwa Barrage sites combined) in a) 2006/07, b) 2007/08, c) 2008/09, d) 2009/10, e) 2010/11 and f) 2011/12. *n* is the number fish that were aged from each location within each year. The total number of individuals collected from each location is presented in brackets.

4 Discussion

4.1 Fish assemblage

Temporal Variation

In 2011/12, 34 fish species, representing 21 different families, were sampled at six sites immediately downstream of the Murray Barrages in the Coorong estuary. Species richness was greater than that recorded in all previous years sampling from 2006–2011 (Zampatti *et al.* 2011 and 2012). The marine migrant sandy sprat dominated the catch, with the freshwater Australian smelt and bony herring, and estuarine lagoon goby the next most numerous species. Catadromous congolli and common galaxias were also abundant with the vast majority (>80% of the total catch) of individuals of both species representing upstream migrating juveniles (0+ year class).

The fish assemblage sampled in 2011/12 consisted of a diverse range of life history strategies including obligate freshwater, diadromous, estuarine and marine species, with each represented by one or more species that was abundant (i.e. >10,000 individuals). It contrasts the fish assemblage observed during an extended period (2007–early 2010) of no freshwater release to the Coorong when marine migrant and some medium to large-bodied estuarine species were most abundant, whilst diadromous and freshwater species were absent or in low abundance (Zampatti *et al.* 2011). It also contrasts the fish assemblage observed in 2010/11, which was also highly diverse but dominated by a group of common freshwater species (i.e. Australian smelt, redfin perch, bony herring and flat-headed gudgeon) which numerically comprised >65% of the total catch (Zampatti *et al.* 2012). Whilst these species remained abundant in 2011/12, a single species, the marine migrant sandy sprat, comprised almost 90% of the total catch.

Sandy sprat are a small-bodied (typically <100 mm TL), pelagic, schooling clupeid, which is common in coastal bays and estuaries across southern Australia (Potter and Hyndes 1999; Gomon *et al.* 2008). Whilst considered a marine migrant species, the results of this study suggest an association with freshwater inflows to the Coorong, with the species caught in greatest abundance during years of freshwater flow (i.e. 2006/07, 2010/11 and 2011/12) and lowest during years of low or zero freshwater inflow (2007–2010) (Zampatti *et al.* 2011 and 2012). Sandy sprat is zooplanktivorous and is likely benefited by influxes of freshwater zooplankton into the Coorong during times of high flow and increased productivity. Studies in other parts of southern Australia have shown the species to be an important food source for larger piscivorous fishes (e.g. Australian salmon; Hoedt and Dimmlich 1994) and piscivorous birds such as little penguins (Klomp and Wooler 1995) and little terns (Taylor and Roe 2004). Deegan *et al.* (2010) also present some evidence suggesting that sandy sprat is preyed upon by both mulloway and black bream within the Coorong. Given the high abundance of this species, it is likely to be important to trophic dynamics within the Coorong, particularly in the River Murray estuary reach (between Pelican Point and Goolwa Barrage) where, contrary to the North and South Lagoons, it supplants small-mouthed hardyhead as the most abundant small-bodied fish (Ye *et al.* 2012).

We used ISA (Dufrêne and Legendre 1997) to determine those species that characterised fish assemblages at each site over time. At both the Tauwitchere large vertical-slot and Goolwa vertical-slot assemblages were determined to be not significantly different between 2010/11 and 2011/12, and thus no indicator species differentiated the assemblages between these years. Nonetheless, ISA of data from the other sites suggested that the assemblage in 2011/12 differed from that of 2010/11 in being characterised by the catadromous common galaxias, estuarine Tamar River goby and river garfish, and three marine migrant species, sandy sprat, mulloway and Australian salmon.

Marine migrant species, particularly juvenile mulloway, can be common in estuaries (Gray and McDonnall 1993; Griffiths 1996). Mulloway were sampled in highest abundance in the Coorong in 2011/12, with all fish collected ranging from 90–241 mm TL, which are likely 0+ and 1+ year old (Silberschneider *et al.* 2009). Indeed Ye *et al.* (2012) found 0+ and 1+ mulloway to be the dominant year classes within the Coorong in 2011/12 and these fish appear to have been spawned and recruited to the Coorong estuary during high freshwater flows in 2010/11. Ferguson *et al.* (2008) have previously associated strong year classes of mulloway within the Coorong with years of high freshwater inflow. These results highlight the need for longer-term (i.e. >1 year) monitoring to detect the responses of long-lived fish to hydrologic variability.

The influence of salinity on spatio-temporal variation in estuarine fish assemblage structure has been documented widely (Lonergan and Bunn *et al.*, 1999; Barletta *et al.*, 2005; Baptista *et al.*, 2010). Indeed the results of this study, during 2006–2012, confirm the importance of spatio-temporal variation in salinity in influencing fish assemblage patterns in the Coorong. At a range of spatial and temporal scales, low salinities caused by high freshwater flows (e.g. 2010/11) often result in low species diversity and high abundances of a few freshwater and estuarine dependent species (Lamberth *et al.,* 2008). Brackish salinities (e.g. 2006/07 and 2011/12) result in high species diversity, with a range of freshwater, estuarine and marine migrant and vagrant species present (Baptista *et al.*, 2010), and high salinities (i.e. marine; 2007–2010) caused by diminished freshwater inflows result in decreased species diversity characterised by the loss of freshwater species and increases in marine species (Martinho *et al.* 2007).

<u>Spatial Variation</u>

In 2011/12, fish assemblages differed significantly between all capture locations, with the exception of the Goolwa vertical-slot and Tauwitchere large vertical-slot. Species richness varied from 15 species at the entrance of the Hunters Creek vertical-slot to 29 species at the site adjacent the Hindmarsh Island abutment of Goolwa Barrage. In general, freshwater species and small-bodied estuarine species (e.g. gobies) characterised the assemblage at Tauwitchere, whilst medium-bodied estuarine species (e.g. greenback flounder) and marine migrant species (e.g. Australian salmon and mulloway) characterised the assemblage at Goolwa.

Large and diverse catches at the two sites immediately downstream of Goolwa and Tauwitchere barrages masked differences in the fish assemblages between the fishway entrances, therefore we analysed fishway sites independent of downstream sites. In general the Tauwitchere large vertical-slot was characterised by freshwater species and several estuarine species which were also abundant at the Tauwitchere rock ramp. The Hunters Creek vertical-slot was characterised by the non-native freshwater species goldfish and redfin perch, and common carp were also abundant. The catadromous congolli and common galaxias were sampled in medium–high abundance at all fishways and thus did not characterise the assemblage at any single fishway. Spatial differences in fish assemblages at fishways, and sites immediately downstream of the barrages, may reflect spatio-temporal variation in salinity at these sites, connectivity between the open waters of Lake Alexandrina (e.g. Tauwitchere) or more confined channels (e.g. Goolwa and Hunters Creek), differences in habitat below each barrage and proximity to the Murray Mouth. For instance, close proximity to the Murray Mouth may result in greater abundances of Australian salmon and mulloway at Goolwa, whilst high abundances of common carp and goldfish may reflect the presence of preferred wetland habitat upstream of the Hunters Creek fishway.

4.2 Abundance and recruitment of diadromous fish

Following an absence of about five years from 2007–2011, adult pouched and short-headed lamprey were again collected migrating upstream at the Murray Barrages. Whilst sampled in lower abundances than 2006/07, a total of nine pouched lamprey and one short-headed lamprey were collected at the Tauwitchere and Goolwa Barrages in July and November. Contrary to 2011/12, in 2006/07 short-headed lamprey was more abundant than pouched lamprey. One pouched lamprey, PIT tagged at Goolwa Barrage, was detected ascending the Lock 1 vertical-slot fishway in October 2011, which represents a movement of ~275 km from the Murray Mouth. Anecdotal evidence suggests that large-scale mass migrations of these species in the lower River Murray were common in the past (Lintermans *et al.* 2007).

There is little information on the biology of lamprey species in the MDB but in the northern hemisphere migratory adult sea lamprey (*Petromyzon marinus*) have been shown to select spawning rivers based on olfactory cues in river outflows (Vrieze *et al.* 2010) and most likely a specific larval pheromone (Bjerselius *et al.* 2000). The high levels of hydrologic connectivity between the Coorong and Lower Lakes, and large volume of freshwater flows during the winter-spring migratory season for lamprey, likely provided the olfactory cues to stimulate upstream migration and the subsequent recurrence of lamprey at the Murray Barrages. The absence of these species from the catch in 2010/11, despite high-volume freshwater flows, may be related to the September onset of flow, occurring following the peak migration season.

The abundances of both congolli and common galaxias were among the highest recorded for the entire project (since 2006) (Zampatti *et al.* 2010, 2011). Relative to 2006/07, the abundance of both species in 2011/12 was particularly high at the Tauwitchere rock ramp and the Hindmarsh Island abutment site downstream of Goolwa Barrage, but lower at the vertical-slots on both Tauwitchere and Goolwa Barrages. This result is likely related to the ability of fish to locate fishway entrances under variable hydrology. In 2006/07, freshwater was discharged to the Coorong solely via fishways and thus attraction to the fishway entrances was enhanced relative to 2011/12 when the large volumes of freshwater were also released from barrage gates, potentially rendering fishway entrances difficult for fish to locate. As such, simultaneous sampling of both fishways and fish accumulations below barriers is more informative of fish movement patterns than sampling fishways alone.

Similar to both 2006/07 and 2010/11, the majority of congolli and common galaxias collected in 2011/12 were YOY. Successful recruitment of catadromous species was most likely a result of high levels of hydrological connectivity between freshwater and marine environments throughout 2011/12 and increased spawning and/or survival of larvae and juveniles under brackish salinities (Whitfield 1994; Gillanders and Kingsford, 2002). Back calculated spawning and hatching dates for YOY congolli and common galaxias, respectively, were established by interpreting otolith microstructure (i.e. daily increment formation). Both species exhibited protracted spawning/hatching periods in 2011. Congolli spawned over a similar duration to 2006/07 and 2010/11 (i.e. 3–4 months from mid-July to late October) and considerably longer than that observed from 2007–2009. Common galaxias hatched over a period of approximately 6 months from June to December, similar to 2006/07, and greater than 2010 and 2007– 2009. Protracted spawning seasons enable the early life stages of fish to be exposed to a broader range of environmental conditions, hence maximising the prospects of survival and recruitment (Secor 2007).

Spawning was essentially continuous over the spawning period for both species, although spawning intensity appeared greatest for congolli in late July/early August 2011. Hatch intensity for common galaxias at Tauwitchere was greatest between September and November 2010 and greatest at Goolwa between July and September 2010. There is some inter-annual variation in peak spawning/hatching activity for congolli and common galaxias but the key spawning/hatching periods appeared to be July–October and July–November, respectively (Zampatti *et al.* 2011). To enable the spawning and recruitment of catadromous congolli and common galaxias the provision of freshwater flow to the Coorong and adequate downstream and upstream fish passage through the tidal barrages is essential during these periods. Provision of freshwater flow and connectivity over the winter-spring period will also cater for the life history processes of anadromous lamprey.

5 Conclusions

Freshwater flows and connectivity between freshwater and marine environments play a crucial role in structuring the composition of estuarine fish assemblages and facilitating the recruitment of catadromous congolli and common galaxias, and anadromous lamprey in the MDB. Over a four year period (2006/07–2009/10), excessive regulation of freshwater inflow to the Coorong estuary led to increases in salinity, a loss of fish species diversity and reduced abundances of diadromous and some estuarine species. Freshwater inflows to the Coorong resumed in late 2010, with the greatest volume of water released since 1976. Salinities downstream of the barrages decreased and ranged between freshwater and brackish, with concomitant changes to fish assemblages. Freshwater species dominated together with estuarine lagoon goby, whilst other estuarine species and marine species decreased in abundance. Abundances of catadromous congolli and common galaxias also increased significantly but anadromous lampreys were not collected. Freshwater inflows and high levels of hydrological connectivity continued throughout 2011/12. Assemblages in 2011/12 were diverse (34 species), with high abundance of freshwater, small-bodied estuarine and catadromous species, and particularly the marine migrant sandy sprat. The abundance of catadromous congolli and common galaxias was among the greatest sampled over the entire project. Furthermore, pouched and short-headed lamprey were again captured migrating upstream at the Murray Barrages. Freshwater flow through the barrages generates brackish salinities in the Coorong and connectivity between the Southern Ocean, Coorong and Lower Lakes, in turn promoting high species diversity in the Coorong and high abundances of YOY catadromous species.

In 2011/12, fish assemblages differed significantly between sites, with the exception of the Goolwa vertical-slot and Tauwitchere large vertical-slot fishways. In general, fish assemblages at Tauwitchere sites were characterised by freshwater and small-bodied estuarine species, whilst Goolwa sites were characterised by medium-bodied estuarine species and marine migrants.

Catadromous species were common across all locations, whilst some freshwater species, notably non-native common carp and redfin perch, characterised the assemblage at Hunters Creek. Fish assemblages in the Coorong, however, were spatially variable at temporal scales ranging from hours to years. Consequently, we recommend that decisions regarding the release location of water from the barrages should be based on the complete long-term (i.e. multi-year) dataset from this project.

Abundance of catadromous congolli and common galaxias were greater in 2011/12 than 2010/11. Similar to the other two years of freshwater inflow and hydrological connectivity (i.e. 2006/07 and 2010/11), the majority of congolli and common galaxias collected were YOY. In 2010/11, limited connectivity was facilitated from July–September 2010 with operation of the Goolwa boat lock, prior to flows arriving in September. In 2011/12, high levels of connectivity and freshwater inflows throughout the entire period facilitated protracted spawning seasons and likely provided conditions conducive to larval/juvenile survival and subsequently recruitment, which resulted in further increases in abundance of these species in 2011/12. This data indicates that management target F-1 (*'maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong'*) of the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan (Maunsell 2009) was achieved in 2011/12.

Continued medium to high end-of-system flows in the MDB in 2011/12 resulted in further changes to fish assemblages in the Coorong estuary. Immediately downstream of the Murray Barrages, fish assemblages trended towards the diverse but variable fish assemblages that characterise dynamic estuarine environments. Freshwater species were still abundant, but less than 2010/11, catadromous species exhibited further increases in abundance and there were significant increases in the abundance of several estuarine and marine migrant species that are associated with freshwater inflows and brackish conditions. These changes likely reflect slightly decreased freshwater discharge relative to 2010/11 and subsequently, slightly higher salinities, and also time lags involved in detecting the ecological response of some species to freshwater inflows. For instance, increased abundance of juvenile mulloway in 2011/12 was likely due to enhanced spawning and recruitment during high flows in 2010/11. Furthermore, the high abundance of sandy sprat may reflect high levels of productivity within the Coorong during 2010–2012 in association with freshwater inflows. Importantly, continued freshwater flow and connectivity between the Lower Lakes and the Coorong appears essential for the maintenance of populations of diadromous, estuarine and estuarine-dependent marine species and maintaining dynamism in estuarine fish communities.

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