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Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2016/17

C. M. Bice, B. P. Zampatti and J. Fredberg

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EXECUTIVE SUMMARY

The Lower Lakes and Coorong, at the terminus of the Murray–Darling Basin (MDB), are considered a wetland of international importance under the Ramsar Convention and an icon site under *The Living Murray Initiative*. The region supports a diverse fish assemblage of ecological, cultural and commercial importance. An understanding of variability in estuarine fish populations and assemblage structure in relation to freshwater inflow and antecedent conditions is fundamental to the management of the estuarine ecosystems. In the Lower Lakes and Coorong, data on diadromous fish migration and estuarine fish assemblage structure has been collected since 2006 to inform against specific ecological objectives and targets within the Lower Lakes, Coorong and Murray Mouth Icon Site Management Plan.

The objective of this study was to investigate the influence of freshwater inflows and connectivity between the Lower Lakes and Coorong on fish assemblage structure and migration, and diadromous fish recruitment in 2016/17. By sampling fish attempting to move through the barrage fishways and inhabiting sites adjacent the barrages, we aimed to:

1. Determine the species composition and abundance of fish species immediately downstream of the barrages and/or attempting to move between the Coorong and Lower Lakes via the barrage fishways in 2016/17, and assess spatio-temporal variation in assemblage structure in relation to 2006–2016;
2. Assess spatio-temporal variability in the recruitment and relative abundance of catadromous fish (i.e. congolli and common galaxias) attempting to migrate upstream at the Murray Barrages in 2016/17, and in relation to long-term data from 2006–2016;
3. Utilise these data to inform on Ecological Targets associated with the following revised Ecological Objective (F-1) – *'Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong'* (Robinson 2014); and
4. Inform operation of the barrages and development of the lakes and barrages operating strategies.

Hydrology in 2016/17 was characterised by the third high flow event (i.e. >60,000 $ML.d^{-1}$) since the inception of the monitoring program, and largest since 2010/11, peaking at ~80,000 $ML.d^{-1}$. In association, salinity below the barrages was fresh to brackish (predominantly 0.2–10 $g.L^{-1}$). The fish assemblage sampled in 2016/17 was diverse (28 species) and abundant (>1.7 million individuals were sampled), with a two-fold increase from total abundance in 2015/16. The

assemblage was dominated by the marine estuarine-opportunist sandy sprat (*Hyperlophus vittatus*, 4.5%), whilst the freshwater Australian smelt (*Retropinna semoni,* 8.4%) and bony herring (*Nematalosa erebi,* 6.4%), and catadromous congolli (*Pseudaphritis urvillii* 7.1%) were also abundant. Assemblages from 2016/17 shared some similarity with those of previous high flow years (e.g. high abundances of freshwater species, 2010/11) and 2014–2016 (i.e. high abundance of catadromous fishes).

The abundance of the catadromous congolli and common galaxias (*Galaxias maculatus*) remained high in 2016/17, relative to 2006–2012, but had declined from peak abundance in 2014/15. Over 90% of all individuals sampled were newly recruited young-of-the-year. High levels of recruitment of catadromous species in 2016/17 was likely a result of a combination of two mechanisms: 1) high levels of hydrological connectivity between freshwater and marine environments throughout 2016/17 and subsequently, favourable conditions for migration, spawning and survival of larvae/juveniles under brackish salinities; and 2) high spawning output as a result of high abundance of reproductively mature adults. Strong recruitment was observed from 2010/11 to 2013/14, and likely led to high abundance of reproductively mature individuals during the 2016 spawning season, contributing to high spawning output. These results highlight the importance of providing freshwater discharge to the Coorong on an annual basis and the cumulative benefit of consecutive ‘favourable’ years on population dynamics.

A combined total of eight pouched lamprey were sampled from the Murray Barrages from spring/summer (n = 1) and specific winter monitoring (n = 7) in 2016/17. This suggested the peak migration period for this species during winter and the need to incorporate specific winter monitoring to adequately assess population status. No short-headed lamprey were sampled throughout 2016/17, but the peak migration season of this species was not adequately sampled (i.e. August–November).

In 2016/17, catadromous species exhibited seasonal peaks in migration in January, which for congolli is generally consistent with previous years, but was unusual for common galaxias (peak abundance typically occurs in October–December). Based on timing of movement from 2006–2017, freshwater discharge and fishway operation should be facilitated at Tauwitchere and Goolwa Barrages annually from at least June–January. This encompasses three key periods: 1) June–August to allow for downstream spawning migrations of congolli and common galaxias and upstream migrations of pouched lamprey; 2) August–November to allow for upstream migrations

of short-headed lamprey; and 3) October–January to allow for the upstream migrations of juvenile congolli and common galaxias.

The results of this investigation highlight the influence of high volume freshwater inflow and hydrological connectivity on fish assemblages of the Coorong. In general, the assemblage trended towards the diverse but variable fish assemblages that characterise dynamic estuarine environments under freshwater influence. Abundances of catadromous congolli and common galaxias remained high relative to all preceding years, with the exception of 2013–2016. These recent data indicate that the annual recruitment target was met for congolli, but not for common galaxias. Nonetheless, failure to meet the target for common galaxias was a result of peak abundance occurring in January, which is outside of the period for metric calculation. Taking into account the atypical intra-annual variation in abundance for common galaxias it is likely that the Ecological Objective (F-1) *'promoting the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong'* was met for both catadromous species. Alternatively, ecological targets relating to the migration of pouched lamprey and short-headed lamprey were not achieved in 2016/17. Continued freshwater discharge and connectivity between the Lower Lakes and the Coorong is essential for the maintenance of populations of diadromous, estuarine and estuarine-dependent marine species and maintaining diversity in estuarine fish communities.

Keywords: estuarine, fishway, diadromous, *Galaxias*, *Pseudaphritis*, lamprey.

1. INTRODUCTION

1.1. Background

Estuaries form a dynamic interface and 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). The interplay of temporally variable freshwater inflow and tidal cycle determines estuarine salinity regimes, 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 significant threats to estuarine dependent fishes, particularly diadromous species (Lassalle and Rochard 2009).

The Lower Lakes and Coorong estuary in south-eastern Australia lie at the terminus of Australia's longest river system, the Murray–Darling, and the region is an icon site under *The Living Murray Initiative* (TLM). 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 ocean (CSIRO 2008). Furthermore, the river now ceases to flow through the 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 (the 'Millennium Drought') resulting in reduced inflows to the Murray-Darling Basin (MDB) (Van Dijk *et al.* 2013). Over a four year period (2006–2010), a combination of reduced system-wide inflows and consumptive water use resulted in reduced flow to the Lower Lakes (<600 GL.y^{-1} in 2007 and 2008), causing a reduction in water level downstream of Lock 1 of >1.5 m and the cessation of freshwater flow to the Coorong estuary. Disconnection of the Coorong from the Lower Lakes resulted in increased salinities in the Coorong and a concomitant decrease in fish species diversity (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, the abundance of freshwater, diadromous and estuarine species decreased and marine species became more common (Zampatti *et al.* 2010). Furthermore, catadromous congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*) 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 (Zampatti *et al.* 2011). Anadromous short-headed lamprey (*Mordacia mordax*) and pouched lamprey (*Geotria australis*), present in 2006/07, were absent through 2007–2010.

The following six year period (2010–2016), was characterised by contrasting hydrology; increased inflows in the MDB in 2010/11 resulted in large-scale flooding and the return of typical water levels to the Lower Lakes, and subsequently, the delivery of large volumes (12,498 GL) of freshwater to the Coorong, with further moderate volumes of freshwater in 2011/12 (8795 GL), and 2012/13 (5177 GL), but declining discharge through 2013/14 (1647 GL), 2014/15 (984 GL) and 2015/16 (562 GL). Annual (650 GL) and three-year rolling average (2000 GL.yr^{-1}) targets for barrage discharge volumes established under the Icon Site Environmental Water Management Plan, were achieved in all years except 2015/16. Increased discharge, relative to 2007–2010, was accompanied by significant changes in fish assemblage structure in the Murray Estuary. The fish assemblage in 2010/11 was dominated by freshwater (e.g. Australian smelt *Retropinna semoni*) and small-bodied estuarine species (e.g. lagoon goby *Tasmanogobius lasti*), whilst marine species and some estuarine species decreased in abundance (Zampatti *et al.* 2012). Recruitment of catadromous congolli and common galaxias was enhanced, resulting in increased abundance relative to 2007–2010. Nonetheless, short-headed lamprey and pouched lamprey were not collected.

The fish assemblages in 2011/12 and 2013/14 (no sampling was conducted in 2012/13) trended towards diverse but variable assemblages characteristic of dynamic estuarine environments (Bice *et al.* 2012). Freshwater species remained present, but less abundant than in 2010/11, whilst the abundance of catadromous (congolli and common galaxias), and certain estuarine (e.g. lagoon goby) and marine migrant (sandy sprat *Hyperlophus vittatus*) species increased. Additionally, both short-headed lamprey and pouched lamprey were sampled in low numbers in 2011/12. Fish assemblages in 2014/15 and 2015/16, reflected declining freshwater discharge, with assemblage structure transitioning towards that observed in 2006/07, prior to the prolonged period of zero discharge (2007–2010) (Bice *et al.* 2016). Nonetheless, the abundance of catadromous fishes remained high, and substantial numbers of pouched lamprey were detected during specific winter monitoring in 2015 (Bice and Zampatti 2015).

The year 2016/17, represented the seventh consecutive year of freshwater discharge to the Coorong and connectivity between the Coorong and Lower Lakes, post the Millennium drought (Van Dijk *et al.* 2013). This provided the opportunity to assess the continued response of fish assemblage structure, movement and recruitment to freshwater flow and connectivity. Such data are integral to the understanding of hydrologically mediated patterns in fish assemblage structure and movement. Ultimately, these data can be used to assess specific ecological targets as revised by Robinson (2014) and outlined in the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan and will aid future management of the system, including informing the lakes and barrages operating strategies.

1.2. Objectives

The objective of this study was to investigate the influence of 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 abundance of fish immediately downstream of the barrages and/or attempting to move between the Coorong and Lower Lakes via the barrage fishways in 2016/17, and assess spatio-temporal variation in assemblage structure in relation to 2006–2016;
2. Investigate spatio-temporal variability in the recruitment and relative abundance of catadromous fish (i.e. congolli and common galaxias) attempting to migrate upstream at the Murray Barrages in 2016/17, in relation to long-term data from 2006–2016;
3. Utilise these data to inform on Ecological Targets associated with the following revised Ecological Objective (F-1): *'Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong'* (Robinson 2014); and

4. Inform the development of lakes and barrages operating strategies currently under development through the Variable Lakes Project.

2. METHODS

2.1. Study area and fishways

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 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.

Under natural conditions, mean annual discharge was ~12,233 GL, but there was strong inter-annual variation (Puckridge *et al.* 1998). Under regulated conditions, an average of ~4723 $GL.y^{-1}$ reaches the sea, although from 1997–2010 this was substantially less and zero for a period of over three years (March 2007 – September 2010) (Figure 2-2). Discharge increased abruptly in September 2010 and annual discharges in 2010/11, 2011/12 and 2012/13 were approximately 12,500, 8800 and 5200 GL, respectively (Figure 2-2). Annual discharge continued to decrease through 2013/14 (~1600 GL), 2014/15 (~984 GL), 2015/16 (~562 GL) and 2016/17 (~6536 GL) (Figure 2-2).

The Coorong is a narrow (2–3 km wide) estuarine lagoon running southeast from the Murray Mouth and parallel to the coast for ~140 km (Figure 2-1). It 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 (Phillips and Muller 2006).

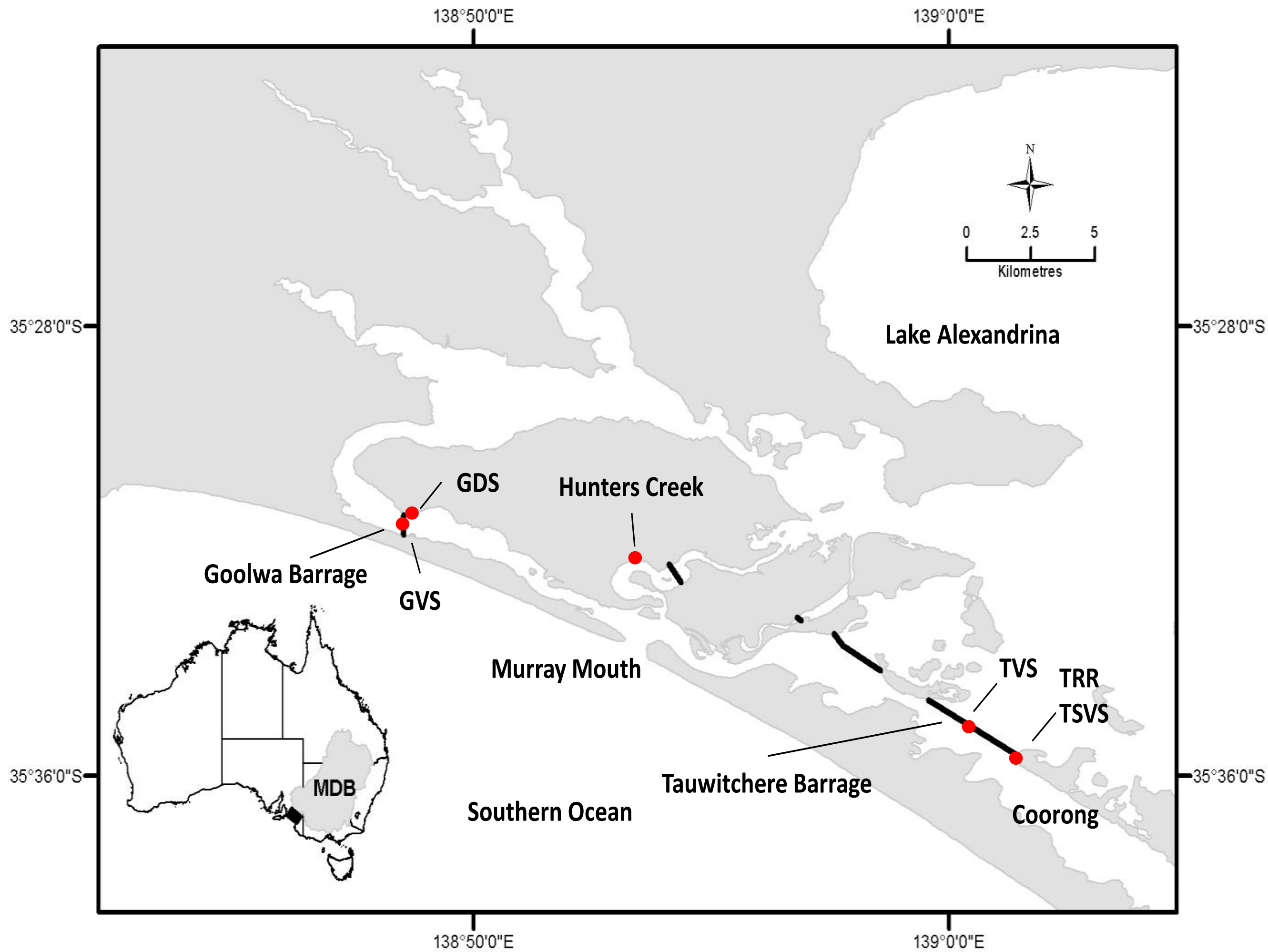

Figure 2-1. A map of the Coorong and Lake Alexandrina at the terminus of the River Murray, southern Australia showing the study area in the Coorong estuary, highlighting the Murray Mouth and Murray Barrages (bold lines). Goolwa and Tauwitchere barrages are identified, as are the fish sampling locations (red dots); Goolwa vertical-slot (GVS), adjacent Goolwa Barrage (GDS), Hunters Creek vertical slot (Hunters Creek), Tauwitchere large vertical-slot (TVS) and Tauwitchere small vertical-slot (TSVS) and rock ramp (TRR).

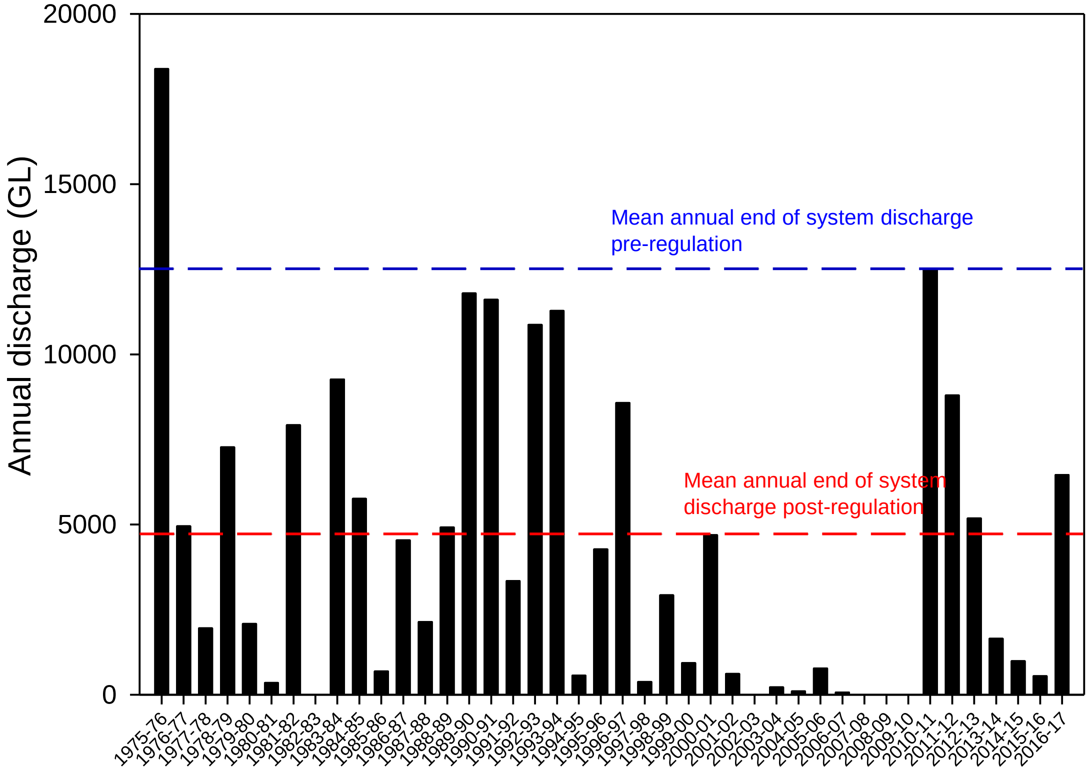

Figure 2-2. Annual freshwater discharge (GL) through the Murray Barrages into the Coorong estuary from 1975–June 2016. Dashed lines represent mean annual end of system discharge pre- (blue) and post-regulation (red).

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 consumptive use (Figure 2-1). The construction of the barrages dramatically reduced the extent of the estuary, creating an impounded freshwater environment upstream and an abrupt ecological barrier between estuarine/marine and freshwater habitats. Pool level upstream of the barrages was typically regulated for most of the year at an average of 0.75 m AHD (Australian Height Datum), but in recent years has been varied to meet ecological objectives.

Following the construction of the barrages the increased frequency of years without freshwater discharge to the estuary and reduced tidal incursion has contributed to a reduction in estuary depth and the prevalence of hypersaline (>40 $g.L^{-1}$) salinities (Geddes 1987, Walker 2002). During times of low freshwater discharge, 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 near the Murray Mouth and in the Northern Lagoon are typically brackish (i.e. 5–30 $g.L^{-1}$) (Geddes 1987).

In 2004, three experimental fishways (2 x large vertical-slots and 1 x rock ramp) were constructed on the Murray Barrages (Barrett and Mallen-Cooper 2006) with the aim of facilitating fish movement between the Coorong and Lower Lakes. The two large vertical slot fishways (slope = 13.6%), located on Goolwa and Tauwitchere Barrages, were designed to pass fish >150 mm total length (TL) and discharge approximately 30–40 $ML.d^{-1}$ (Mallen-Cooper 2001). Assessments of these fishways indicated they were effective in passing large-bodied species, but the passage of small-bodied species and small life stages (<100 mm TL) was largely obstructed (Stuart *et al.* 2005, Jennings *et al.* 2008). The rock ramp fishway (slope = 1:27) constructed on Tauwitchere Barrage aimed to pass fish 40–150 mm in length. Nevertheless, this fishway was found to have a limited operational window with function influenced by downstream tidal level and upstream water levels (Jennings *et al.* 2008).

In 2009, additional small vertical-slot fishways (slope ~3%) were constructed on Tauwitchere barrage and the Hunters Creek causeway. These new fishways were designed with internal hydraulics that were considered favourable for the upstream passage of small-bodied fish (i.e. low headloss, velocity and turbulence) and to operate with low discharge (<5 $ML.d^{-1}$). Both fishways effectively facilitate the passage of small-bodied fish (Zampatti *et al.* 2012).

A series of new fishways have recently been completed or are under construction, as part of the *Coorong, Lower Lakes and Murray Mouth Program* (Bice et al. 2017). These fishways are likely to greatly enhance fish passage at the Murray Barrages, but are not monitored under the current program.

2.2. Fish sampling

Samples of fish were collected from the entrances of four vertical-slot fishways in 2016/17 (Figure 2-1 and Table 2-1). Samples of fish were also collected from a site adjacent to the rock ramp fishway at the southern end of Tauwitchere Barrage and a site adjacent the Hindmarsh Island abutment of the Goolwa Barrage (hereafter 'adjacent Goolwa Barrage') (Figure 2-1 and Table 2-1).

Table 2-1. Details of sites where fish were sampled at the Murray Barrages in 2016/17, including site name, abbreviated name used throughout and the barrage associated with site, as well as latitude and longitude.

Name	Abbreviation	Barrage	Latitude	Longitude
Tauwitchere large vertical-slot	TVS	Tauwitchere	35°35'09.35''S	139°00'30.58''E
Tauwitchere small vertical-slot	TSVS	Tauwitchere	35°35'23.44''S	139°00'56.23''E
Tauwitchere rock ramp	TRR	Tauwitchere	35°35'23.60''S	139°00'56.30''E
Goolwa vertical-slot	GVS	Goolwa	35°31'34.44''S	138°48'31.12''E
Adjacent Goolwa Barrage	GDS	Goolwa	35°31'24.16''S	138°48'33.79''E
Hunters Creek vertical-slot	Hunters	Hunters Creek causeway	35°32'07.08''S	138°53'07.48''E

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); 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 immediate area downstream of Tauwitchere Barrage at the rock ramp fishway and downstream Goolwa Barrage (Figure 2-3b). At both locations, the net was set adjacent to the barrage to capture fish utilising this area.

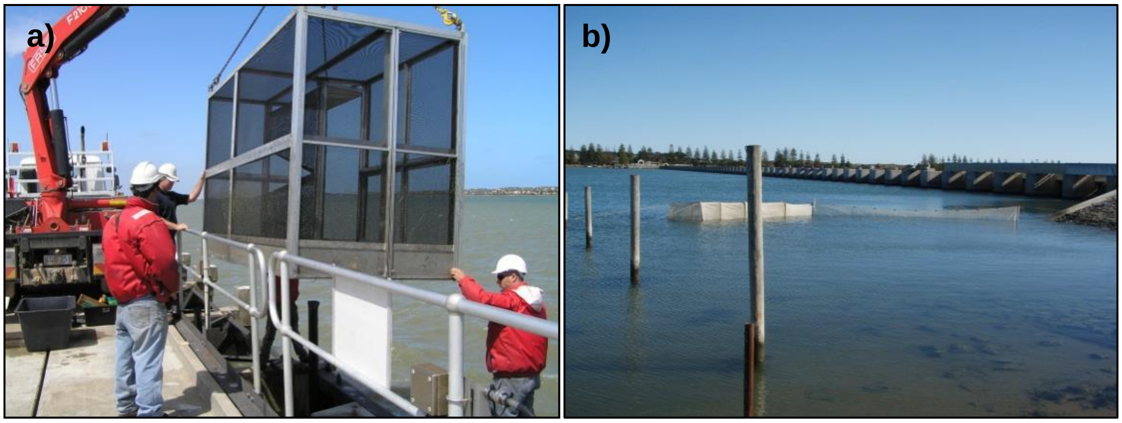

Figure 2-3 a) Cage trap used to sample the Tauwitchere and Goolwa vertical-slot fishways and b) large fyke net used to sample adjacent Goolwa Barrage. A net of the same dimensions was also used to sample adjacent to the Tauwitchere rock ramp.

Four weeks of sampling were conducted monthly between 25 October 2016 and 20 January 2017. The sites adjacent the Tauwitchere rock ramp and Goolwa Barrage were sampled once overnight during each sampling week. All vertical-slot fishway sites were sampled overnight 3 times per sampling week, with the exception of the Goolwa large vertical-slot, which could not be sampled in November 2016 due to limited access on Goolwa Barrage. 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 aerated holding tanks. Each individual was then identified to species and counted. For catadromous congolli and common galaxias, during each trapping event a random sub-sample of up to 50 individuals were measured to the nearest mm (total length, TL) to represent the size structure of the population.

Estimated daily barrage discharge and salinity data were obtained from the Department of Environment, Water and Natural Resources (DEWNR).

2.3. Data analysis

Temporal variability in fish assemblages

Temporal variability in fish assemblages was investigated by assessing changes in total fish abundance (all species combined), species richness and diversity, and fish assemblage structure (i.e. species composition and individual species abundance). Differences in the relative abundance (fish.hour^{-1}.trap event^{-1}) of fish (all species combined) sampled between years at each site were analysed using uni-variate single-factor PERMANOVA (permutational ANOVA and MANOVA), in the software package PRIMER v. 6.1.12 and PERMANOVA+ (Anderson *et al.* 2008). These analyses were performed on fourth-root transformed relative abundance data. This routine tests the response of a variable (e.g. total 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, PERMANOVA does not assume samples come from normally distributed populations or that variances are equal. Changes in species richness and diversity were qualitatively assessed by comparing total species richness (number of species sampled across all sampling sites) and the contribution of species from different estuarine-use categories and guilds (as defined by Potter *et al.* 2015) between years (Table 2-2). Data from the Tauwitchere small-vertical slot and Hunters Creek vertical-slot were excluded from these analyses as they have only been sampled since 2010.

The composition of fish assemblages sampled at each location was assessed between all sampling years (i.e. 2006–2017). Non-Metric Multi-Dimensional Scaling (MDS) generated from Bray-Curtis similarity matrices of fourth-root transformed relative abundance data (number of fish.hour^{-1}.trip^{-1}) were used to graphically represent assemblages from different years in two dimensions. PERMANOVA, 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' 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 2006). 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 (Dufrene and Legendre 1997). Statistical significance was determined for each species indicator value using the Monte Carlo (randomisation) technique (α = 0.05).

Table 2-2. Definitions of fish 'estuarine use' categories and guilds represented by fishes of the Coorong, following the approach of Potter et al. (2015). Examples of representative species from the Coorong are presented for each guild.

Category and guild	Definition	Example
Marine category		
Marine straggler	Truly marine species that spawn at sea and only sporadically enter estuaries, and in low numbers.	King George whiting (*Sillaginodes punctatus*)
Marine estuarine-opportunist	Marine species that spawn at sea, but regularly enter estuaries in substantial numbers, particularly as juveniles, but use, to varying degrees, coastal marine waters as alternative nurseries.	Mulloway (*Argyrosomus japonicus*)
Estuarine category		
Solely estuarine	Species that complete their life cycles only in estuaries.	Small-mouthed hardyhead (*Atherinosoma microstoma*)
Estuarine and marine	Species represented by populations that may complete their life cycles only in estuaries, but also discrete populations that complete their lifecycle in marine environments.	Yellow-eyed mullet (*Aldrichetta forsteri*)
Diadromous category		
Anadromous	Most growth and adult residence occurs in the marine environment prior to migration into, spawning and larval/juvenile development in freshwater environments.	Pouched lamprey (*Geotria australis*)
Catadromous	Most growth and adult residence occurs in the freshwater environments prior to migration into, spawning and larval/juvenile development in marine environments.	Congolli (*Pseudaphritis urvillii*)
Semi-catadromous	As per catadromous species, but spawning run extends as far as downstream estuarine areas rather than the ocean.	Common galaxias (*Galaxias maculatus*)
Freshwater category		
Freshwater straggler	Truly freshwater species that spawn in freshwater environments and only sporadically enter estuaries, and in low numbers.	Golden perch (*Macquaria ambigua ambigua*)
Freshwater estuarine-opportunist	Freshwater species found regularly and in moderate numbers in estuaries, and whose distribution can extend beyond low salinity zones of these system.	Bony herring (*Nematalosa erebi*)

Intra-annual spatial variability in fish assemblages

Spatial variation in fish assemblages between sampling locations in 2016/17 was also investigated using MDS, PERMANOVA and ISA. Due to differences in sampling methods, spatial variation was assessed separately for the vertical-slot fishway sites and the two sites sampled with the large fyke net (i.e. the Tauwitchere rock ramp and adjacent Goolwa Barrage). MDS plots generated from Bray-Curtis similarity matrices were 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 2016/17, 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 2016/17.

Spatio-temporal variability in diadromous species abundance

Inter-annual (2006–2017) differences in the standardised abundance (fish.hour^{-1}.trap event^{-1}) of pouched lamprey and short-headed lamprey were qualitatively assessed. Inter-annual differences in the standardised abundance of common galaxias and congolli (fish.hour^{-1}.trap event^{-1}) sampled at all six sites were analysed using uni-variate single-factor PERMANOVA (Anderson *et al.* 2008). Intra-annual (monthly) differences in the standardised abundance (fish.hour^{-1}.trap event^{-1}) of common galaxias and congolli sampled at all sites in 2016/17 were also analysed using uni-variate single-factor PERMANOVA (Anderson *et al.* 2008).

2.4. Assessment against TLM Ecological Targets

A specific Ecological Objective (F-1), revised by (Robinson 2014) and to be outlined in the revised Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan (In Press) is to – *'Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong'*. The achievement of this objective is determined by the assessment of three ecological targets developed as part of the TLM Condition Monitoring Refinement Project (Robinson 2014). These targets were developed from empirical data collected from 2006 to 2014 and relate specifically to the migration and recruitment of congolli and common galaxias, and the migration of short-headed and pouched lamprey:

1. The annual abundance of upstream migrating YOY congolli is ≥ the lower confidence bound of the recruitment reference value (i.e. lower bound 22.67 YOY.hr^{-1});

2. The annual abundance of upstream migrating YOY common galaxias is ≥ the lower confidence bound of the recruitment reference value (i.e. lower bound 3.12 YOY.hr^{-1}); and
3. Pouched lamprey and short-headed lamprey are sampled from ≥60% of the vertical-slot fishway sites sampled in any given year.

Ecological Target 1

This target is assessed by calculating an annual recruitment index for congolli, derived by calculating overall site abundance of upstream migrating YOY (i.e. fish.hr^{-1}) during the period November to January and comparing that to a predetermined reference value and associated confidence intervals. Annual recruitment index is calculated using equation 1:

Equation 1 $RI = (S_1(mean((r^*A_{Nov}))+(r^*A_{Dec})+(r^*A_{Jan})) + S_2(mean((r^*A_{Nov})+(r^*A_{Dec})+(r^*A_{Jan})).....S_n)$

where S = site, A = abundance (fish hour^{-1}) and r = the proportion of the sampled population comprised of YOY (i.e. <60 mm in length). The annual recruitment index (*RV*) ± half confidence interval = 44.26 ± 21.78 YOY.hr^{-1}.

Ecological Target 2

This target is assessed by calculating an annual recruitment index for common galaxias, derived by calculating overall site abundance of upstream migrating YOY (i.e. fish.hr^{-1}) during the period October to December and comparing that to a predetermined reference value and associated confidence intervals. Annual recruitment index is calculated using equation 1:

Equation 2 $RI = (S_1(mean((r^*A_{Oct}))+(r^*A_{Nov})+(r^*A_{Dec})) + S_2(mean((r^*A_{Oct})+(r^*A_{Nov})+(r^*A_{Dec})).....S_n)$

where S = site, A = abundance (fish hour^{-1}) and r = the proportion of the sampled population comprised of YOY (i.e. <60 mm in length). The annual recruitment index (*RV*) ± half confidence interval = 6.12 ± 3.00 YOY.hr^{-1}.

Ecological Target 3

The achievement of this target is assessed by determining a migration index for both pouched lamprey and short-headed lamprey. The annual migration index is calculated as the ratio of the proportion of sites from which these species were sampled in a given year, against the proportion of sites from which these species were sampled in a predetermined reference year:

Equation 3 $$\boldsymbol{Short - headed\ lamprey\ MI(year)} = \frac{\textbf{Proportion of sites where detected (of GVS,GDS,TVS,TRR and TSVS)}}{\textbf{Proportion of sites where detected in 2006/07}}$$

Equation 4 $$\boldsymbol{Pouched\ lamprey\ MI(year)} = \frac{\textbf{Proportion of sites where detected (of GVS,GDS,TVS,TRR and TSVS)}}{\textbf{Proportion of sites where detected in 2011/12}}$$

This provides a value of *MI* of ≤1.0 and an arbitrary tolerance of 0.4 is adopted, i.e. *MI* ≥ 0.6 is taken to suggest achievement of target. These indices are calculated from all monitoring undertaken at the Murray Barrages in a given year, including spring/summer monitoring under the current project and specific lamprey monitoring during winter, which has occurred in 2011, 2013 and 2015 (Bice and Zampatti 2015). Whilst this influences comparability of data between years it was deemed necessary for these rare species and inter-annual variability in sampling effort needs to be considered during interpretation of results.

3. RESULTS

3.1. Hydrology

Freshwater discharge to the Coorong and salinity were highly variable over the period 2005–2017. Prior to sampling in 2006, low-volume freshwater flows of 1000–12,000 ML.d^{-1} were consistently released into the Coorong through barrage 'gates', but by September 2006 discharge was confined to fishways (Tauwitchere: 20–40 ML.d^{-1}, Goolwa: ~20 ML.d^{-1}) (Figure 3-1a). Low inflows from the River Murray and receding water levels in the Lower Lakes resulted in the closure of fishways in March 2007 (Figure 3-1a) and persistent drought in the MDB resulted in no freshwater being released to the Coorong until September 2010. Significant inflows to the Lower Lakes in late 2010 saw the fishways reopened and the release of large volumes of freshwater to the Coorong throughout the 2010/11 sampling season. Cumulative flow across the barrages peaked at >80,000 ML.d^{-1} with a mean daily discharge (± SE) of 49,955 ± 1396 ML.d^{-1} over the 2010/11 sampling period (Figure 3-1a). Medium-volume freshwater flows continued throughout the 2011/12 sampling season (range 800–34,600 ML.d^{-1}; mean daily discharge = 10,823 ± 657 ML.d^{-1}) and 2012/13 (range 220–69,000 ML.d^{-1}; mean daily discharge = 12,617 ± 948 ML.d^{-1}), although no sampling was conducted in 2012/13 (Figure 3-1a). Low–medium volume flows occurred throughout 2013/14 with flow during the sampling season ranging 20–18,020 ML.d^{-1} and a mean daily discharge of 1617 ± 217 ML.d^{-1}. Discharge continued to decrease through 2014/15 (range 8–2950 ML.d^{-1}; mean = 1547 ± 67 ML.d^{-1}) and 2015/16 (range 1–1503 ML.d^{-1}; mean = 128 ± 28 ML.d^{-1}). In 2016/17, discharge increased substantially relative to all previous years with the exception of 2010/11, with cumulative flow across the barrages peaking at >80,000 ML.d^{-1} and a mean daily discharge (± SE) of 36,851 ± 2277 ML.d^{-1} over the sampling period.

During sampling in 2006/07, salinity below Tauwitchere and Goolwa Barrages fluctuated 20–34 g.L^{-1} (mean = 28.42 ± 0.18 g.L^{-1}) and 11–29 g.L^{-1} (mean = 21.93 ± 0.29 g.L^{-1}), respectively (Figure 3-1b). Following the cessation of freshwater releases in March 2007, salinities at Tauwitchere increased and ranged 30–60 g.L^{-1} until September 2010, with mean salinities during sampling ranging 34–36 g.L^{-1}. Salinities at Goolwa Barrage, between March 2007 and September 2010, also increased, ranging from 26–37 g.L^{-1} with mean salinities during sampling ranging 26–34 g.L^{-1}. Following significant increases in freshwater releases to the Coorong in September 2010, salinities over the 2010/11 sampling period ranged 0.3–25 g.L^{-1} at Goolwa Barrage and 0.2–27 g.L^{-1} at Tauwitchere Barrage; however, mean salinities were significantly reduced at both

Goolwa (1.95 ± 0.31 g.L^{-1}) and Tauwitchere (3.78 ± 0.33 g.L^{-1}) (Figure 3-1b). During 2011/12 sampling, salinity at Goolwa ranged 0.3–32 g.L^{-1} (mean = 10.39 ± 0.77 g.L^{-1}) and 3–26 g.L^{-1} (mean = 12.69 ± 0.42 g.L^{-1}) at Tauwitchere (Figure 3-1b), but was more variable than 2010/11, appearing to follow a fortnightly lunar cycle, with higher tides resulting in seawater incursion and greater salinities. In 2012/13, salinity fluctuated over a similar range to 2011/12, but no sampling was conducted. During sampling in 2013/14, decreasing freshwater flows resulted in increased salinity relative to the three previous years; nevertheless, conditions remained 'brackish' with salinity ranging 0.5–30 g.L^{-1} (mean = 13.53 ± 0.86 g.L^{-1}) at Goolwa and 5–22 g.L^{-1} (mean = 10.39 ± 0.77 g.L^{-1}) at Tauwitchere. Further decreases in freshwater discharge were associated with increases in salinity in 2014/15 (Goolwa: range 7–32 g.L^{-1}; mean = 18.68 ± 0.60 g.L^{-1}. Tauwitchere: range 15–32 g.L^{-1}; mean = 22.73 ± 0.39 g.L^{-1}) and 2015/16 (Goolwa: range 21–31 g.L^{-1}; mean = 27 ± 2.86 g.L^{-1}. Tauwitchere: range 19–34 g.L^{-1}; mean = 27.76 ± 3.16 g.L^{-1}). Substantial increase in discharge in 2016/17 was associated with reduced salinities, similar to 2010/11, ranging 0.2–26 g.L^{-1} at Goolwa Barrage and 0.2–20 g.L^{-1} at Tauwitchere Barrage. Mean salinities were substantially reduced relative to 2014–2016 at both Goolwa (3.45 ± 0.68 g.L^{-1}) and Tauwitchere (4.98 ± 0.46 g.L^{-1})

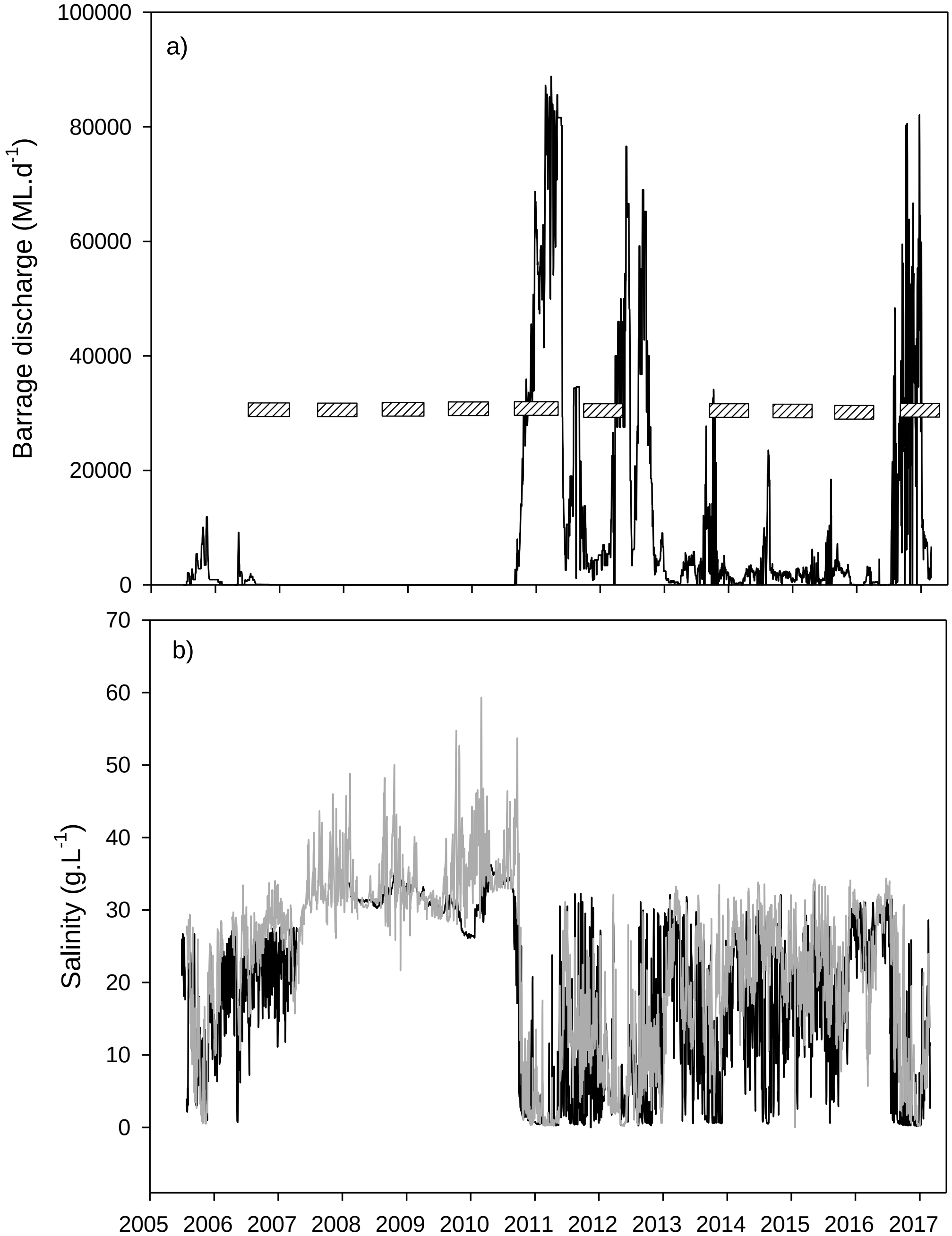

Figure 3-1. a) Mean daily flow (ML.d^{-1}) to the Coorong through the Murray Barrages (all barrages combined) from July 2005–March 2017 and b) Mean daily salinity (g.L^{-1}) of the Coorong below Tauwitchere (grey line) and Goolwa (black line) barrages from July 2005–March 2017. Sampling periods are represented by hatched bars. Barrage discharge data was sourced from DEWNR, whilst salinity data was sourced from water quality monitoring stations immediately below Tauwitchere and Goolwa Barrages (DEWNR 2017).

3.2. Catch summary

A total of 1,784,476 fish from 28 species were sampled in 2016/17 (Table 3-1). The marine estuarine-opportunist sandy sprat overwhelmingly dominated the total catch (74.5%), whilst the freshwater Australian smelt (8.4%) and bony herring (*Nematalosa erebi*) (6.4%), and semi-catadromous congolli (7.1%) were also abundant. The remaining 24 species collectively comprised <4% 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 Goolwa Barrage in 2016/17. Species are categorised using estuarine use guilds from Potter et al. (2015).

Common name	**Scientific Name**	**Guild**	**Tauwitchere large vertical-slot**	**Tauwitchere small vertical-slot**	**Tauwitchere rock ramp**	**Goolwa vertical-slot**	**Adjacent Goolwa Barrage**	**Hunters Creek**	**Total**
		Sampling events	12	12	4	9	4	11	
		No. of species	13	11	22	12	21	18	
Australian smelt	*Retropinna semoni*	Freshwater estuarine opportunist	12,543	52,325	65,382	18,357	668	7	**149,282**
Bony herring	*Nematalosa erebi*	Freshwater estuarine opportunist	445	4,167	59,833	36,957	11,230	692	**113,324**
Flat-headed gudgeon	*Philypnodon grandiceps*	Freshwater estuarine opportunist	95	64	10,078	416	9,251	430	**20,334**
Dwarf flat-headed gudgeon	*Philypnodon macrostomus*	Freshwater straggler	0	0	0	1	39	8	**48**
Carp gudgeon	*Hypseleotris* spp	Freshwater straggler	0	0	0	0	34	21	**55**
Golden perch	*Macquaria ambigua ambigua*	Freshwater straggler	13	2	1,638	26	5	3	**1,687**
Common carp	*Cyprinus carpio**	Freshwater straggler	33	1	19	4	9	62	**128**
Goldfish	*Carassius auratus**	Freshwater straggler	1	0	0	0	0	2	**3**
Redfin perch	*Perca fluviatilis**	Freshwater straggler	197	170	1,840	47	308	10	**2,572**
Eastern gambusia	*Gambusia holbrooki**	Freshwater straggler	0	0	3	0	0	0	**3**
Pouched lamprey	*Geotria australis*	Anadromous	0	0	0	1	0	0	**1**
Common galaxias	*Galaxias maculatus*	Semi-catadromous	242	939	337	3,817	317	1,321	**6,973**
Congolli	*Pseudaphritis urvillii*	Catadromous	1,270	4,836	10,598	100,462	8,535	1,285	**126,986**
Short-finned eel	*Angullia australis*	Catadromous	0	0	0	0	1	0	**1**
Small-mouthed hardyhead	*Atherinosoma microstoma*	Solely estuarine	0	1	478	0	31	21	**531**

denotes introduced species

Table 3-1 continued.

Common name	Scientific Name	Guild	Tauwitchere large vertical-slot	Tauwitchere small vertical-slot	Tauwitchere rock ramp	Goolwa vertical-slot	Adjacent Goolwa Barrage	Hunters Creek	Total
Tamar River goby	*Afurcagobius tamarensis*	Solely estuarine	3	1	870	0	3,984	4	**4,862**
Blue-spot goby	*Pseudogobius olorum*	Solely estuarine	0	0	39	0	5	16	**60**
Lagoon goby	*Tasmanogobius lasti*	Solely estuarine	6	5	20,533	1	7,259	6	**27,810**
River garfish	*Hyperhamphus regularis*	Solely estuarine	0	0	54	0	0	0	**54**
Bridled goby	*Arenogobius bifrenatus*	Estuarine & marine	1	0	166	0	53	26	**246**
Yellow-eyed mullet	*Aldrichetta forsteri*	Estuarine & marine	0	0	3	0	2	1	**6**
Soldier fish	*Gymnapistes marmoratus*	Estuarine & marine	0	0	1	0	0	0	**1**
Greenback flounder	*Rhombosolea tapirina*	Marine estuarine-opportunist	0	0	7	0	19	0	**26**
Long-snouted flounder	*Ammosetris rostratus*	Marine estuarine-opportunist	0	0	1	0	2	0	**3**
Australian herring	*Arripis georgianus*	Marine estuarine-opportunist	0	0	1	0	0	0	**1**
Flat-tailed mullet	*Liza argentea*	Marine estuarine-opportunist	0	0	0	0	1	50	**51**
Sandy sprat	*Hyperlophus vittatus*	Marine estuarine-opportunist	1	0	853,127	21	476,278	0	**1,329,427**
King George whiting	*Sillaginodes punctatus*	Marine straggler	0	0	1	0	0	0	**1**
		Total	**14,850**	**62,511**	**1,025,009**	**160,110**	**518,031**	**3,965**	**1,784,476**

3.3. Temporal variation in fish assemblages

Total fish abundance, species richness and diversity

The mean number of fish (all species combined) sampled per trap event varied substantially from 2006/07 to 2016/17 (Figure 3-2), with significant differences between years detected at the Tauwitchere rock ramp (*Pseudo-F*$_{9, 61}$ = 10.44, p < 0.001), Tauwitchere vertical-slot (*Pseudo-F*$_{9, 52}$ = 8.77, p < 0.001), Goolwa vertical-slot (*Pseudo-F*$_{8, 51}$ = 3.34, p = 0.009) and Hunters Creek vertical-slot (*Pseudo-F*$_{5, 33}$ = 2.60, p = 0.050), but not at the Tauwitchere small vertical-slot (*Pseudo-F*$_{5, 33}$ = 0.66, p = 0.671) or adjacent Goolwa Barrage (*Pseudo-F*$_{7, 41}$ = 2.05, p = 0.088). Patterns of temporal variability in total fish abundance were similar at all locations, with low total abundance during the period of no freshwater discharge and disconnection through 2007–2010 and high total abundance from 2010–2016 (Figure 3-2). Abundance remained high, but variable in 2016/17, with total abundance at the Goolwa vertical-slot and Tauwitchere rock ramp amongst the highest recorded over the entire project.

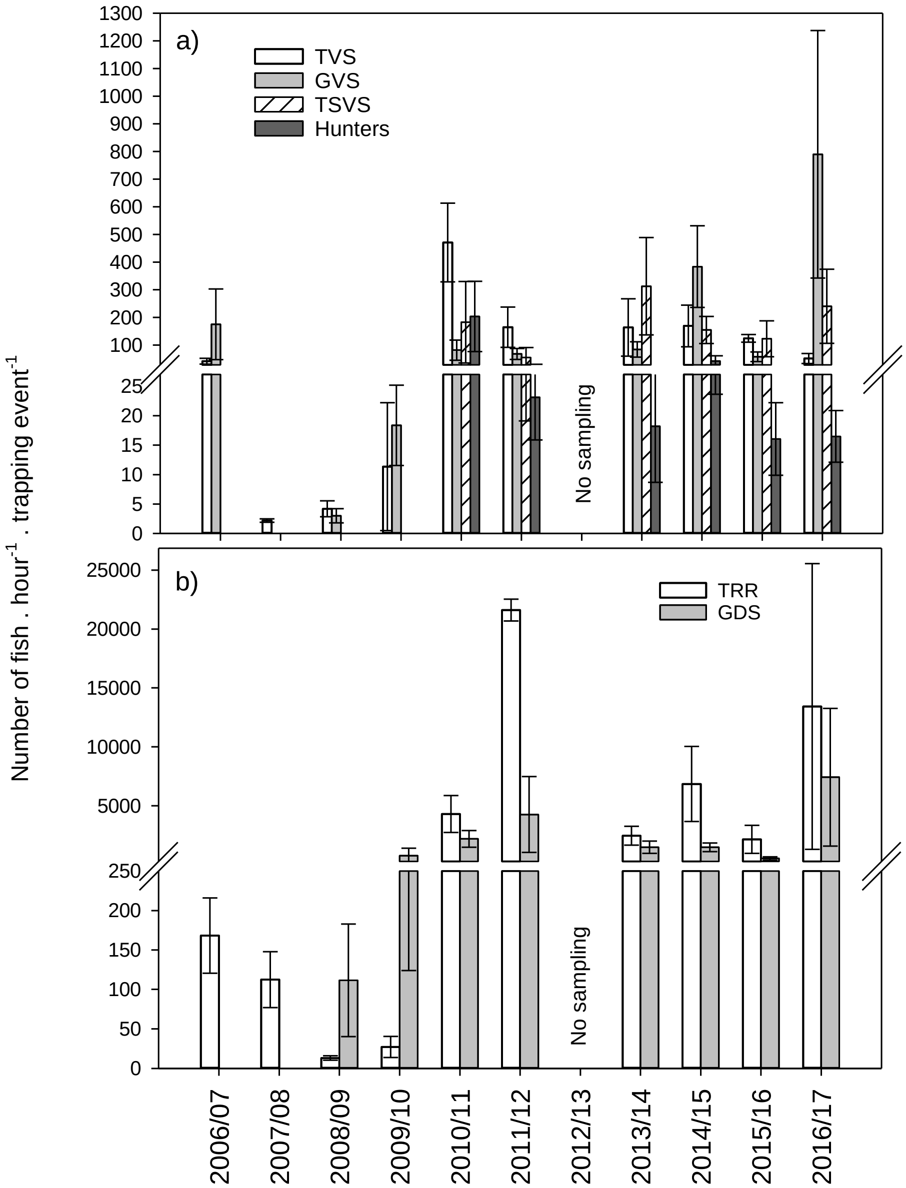

Figure 3-2. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of fish (all species combined) sampled at a) the Tauwitchere large vertical-slot (TVS), Goolwa vertical-slot (GVS), Tauwitchere small vertical-slot and Hunters Creek vertical-slot (Hunters), and b) the Tauwitchere rock ramp (TRR) and adjacent Goolwa Barrage (GDS), from 2006–2017. Goolwa vertical-slot was not sampled in 2007/08, whilst sampling at the Tauwitchere small vertical-slot and Hunters Creek vertical-slot (Hunters) commenced in 2010/11. Sampling at the site adjacent Goolwa Barrage commenced in 2008/09. No sampling was conducted at any site in 2012/13.

Species richness (all sites combined) varied little between years, except for 2007/08 when 24 species were sampled (Figure 3-3). Nevertheless, the Goolwa vertical-slot and the site adjacent

Goolwa Barrage were not sampled in this year, likely resulting in reduced overall species richness. Species richness ranged 28–34 in all other years, with greatest species richness (*n* = 34) recorded in 2011/12. Nevertheless, the number of species sampled from different estuarine use categories varied substantially (Figure 3-3). The number of species from the freshwater category (freshwater 'estuarine-opportunists' and 'stragglers' combined) was lowest from 2007–2010 (*n* = 2–3), but greatest during times of freshwater discharge and connectivity from 2010–2015 and 2016/17 (*n* = 10–11). In contrast, the number of species of marine origin (marine 'estuarine-opportunist' and 'stragglers' combined) was greatest from 2008–2010 (*n* = 19–20) and lowest in 2016/17 (*n* = 7). The number of diadromous species was reduced during 2007–2010 and 2014/15 (*n* = 2), due to the absence of both lamprey species, whilst the number of estuarine species did not differ substantially over the entire study period (*n* = 7–8).

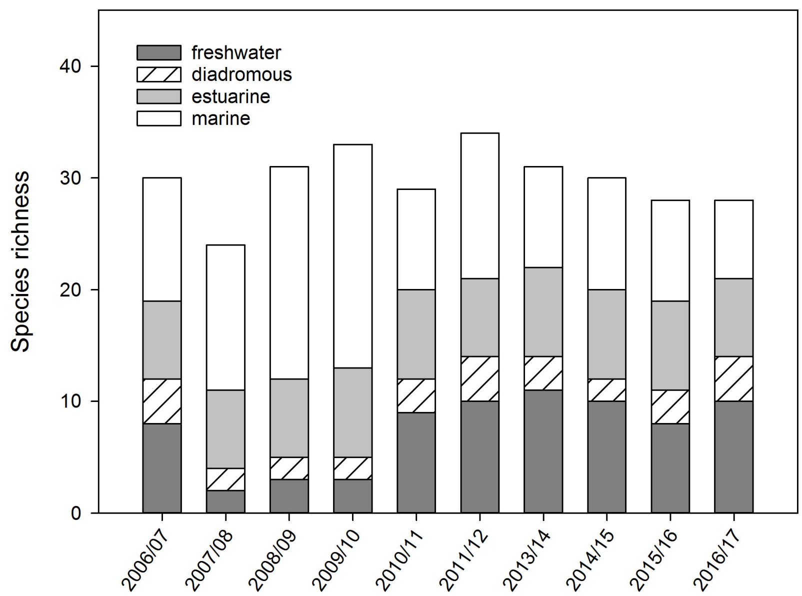

Figure 3-3. Species richness (all sites combined) from 2006–2017, including the contribution of species from different estuarine-use categories, i.e. freshwater (freshwater 'estuarine-opportunists' and 'stragglers' combined), diadromous (catadromous and anadromous combined), estuarine (solely estuarine and 'estuarine and marine' combined) and marine (marine 'estuarine-opportunists' and 'stragglers' combined). Guilds follow those proposed by Potter *et al.* (2015).

Assemblage structure

MDS ordination plots show groupings of fish assemblages by year at each sampling location (Figure 3-4). These groupings are supported by PERMANOVA, which detected significant differences in fish assemblages at the Tauwitchere rock ramp (*Pseudo-F*$_{9,\,61}$ = 14.36, p < 0.001), Tauwitchere large vertical-slot (*Pseudo-F*$_{9,\,52}$ = 11.24, p < 0.001), Tauwitchere small vertical-slot (*Pseudo-F*$_{5,\,33}$ = 2.93, p = 0.002), Goolwa vertical-slot (*Pseudo-F*$_{8,\,51}$ = 5.51, p < 0.001), adjacent Goolwa Barrage (*Pseudo-F*$_{7,\,41}$ = 7.33, p < 0.001) and Hunters Creek vertical-slot (*Pseudo-F*$_{5,\,33}$ = 5.17, p < 0.001).

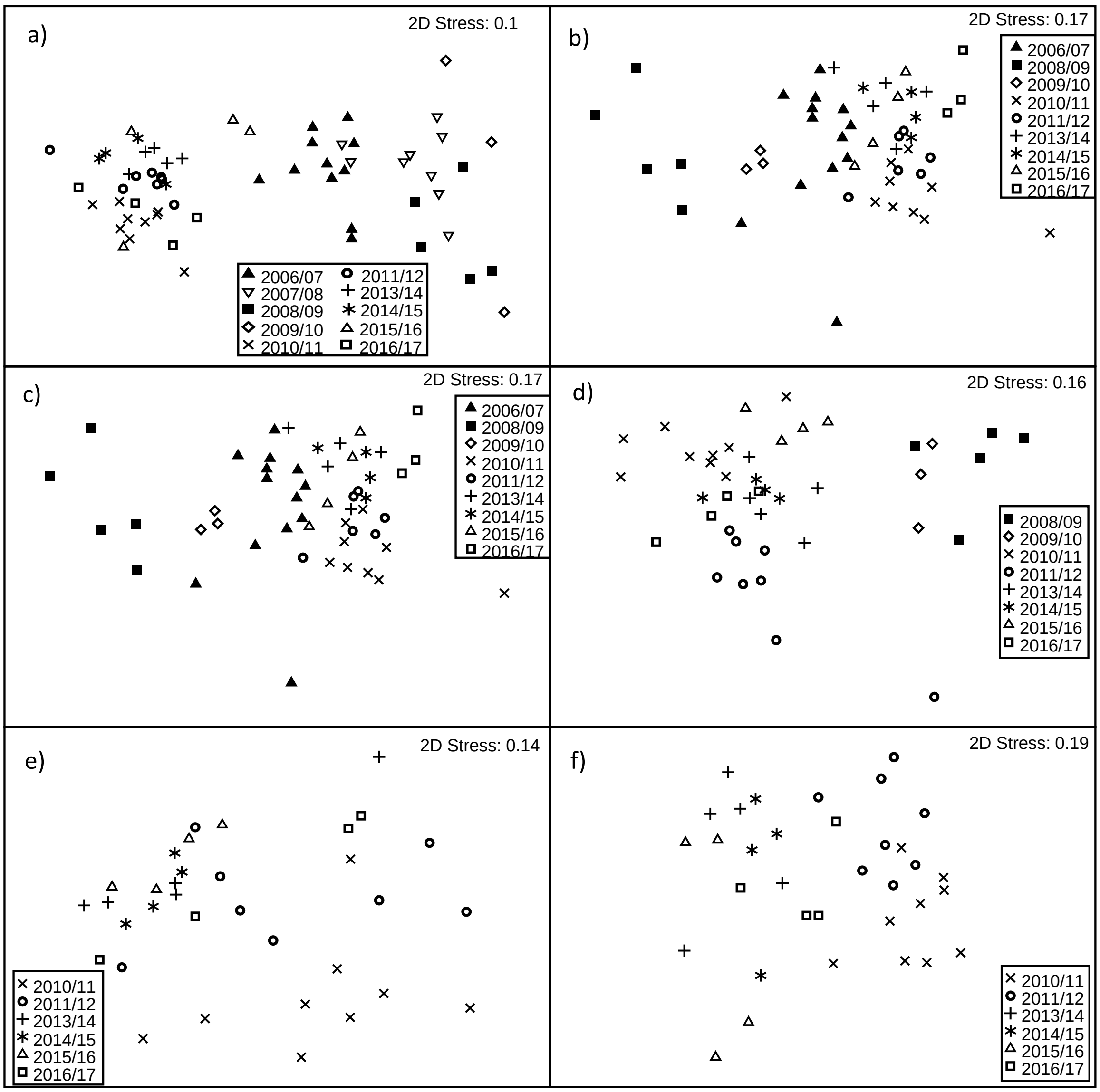

Figure 3-4. MDS ordination plots of fish assemblages sampled at a) Tauwitchere rock ramp, b) Tauwitchere large vertical-slot, c) Goolwa vertical-slot, d) adjacent Goolwa Barrage, e) Tauwitchere small vertical-slot and f) Hunters Creek vertical-slot, between 2006 and 2017.

Tauwitchere sites

Pair-wise comparisons revealed significant differences in fish assemblages at the Tauwitchere rock ramp between most years, except for 2008/09 and 2009/10, as well as 2009/10 and the years from 2013/14–2016/17 (B-Y method corrected $\alpha = 0.011$; Table 3-2). Assemblages sampled in 2011/12 and 2016/17 were also not significantly different. Fish assemblages sampled at the Tauwitchere large vertical-slot in 2006/07 differed significantly from assemblages sampled in all subsequent years (B-Y method corrected $\alpha = 0.011$; Table 3-3). No significant difference was detected between assemblages sampled in 2007/08, 2008/09, 2009/10, 2014/15, 2015/16 and 2016/17. Assemblages sampled in 2010/11 and 2011/12 were not significantly different, but both years were significantly different from all previous years, and 2010/11 was also significantly different from all subsequent years. Similarly, the assemblage sampled in 2013/14 was not significantly different from that of 2011/12, but was significantly different from all preceding years. Assemblages sampled in 2013/14, 2014/15, 2015/16 and 2016/17 were not significantly different. Fish assemblages at the Tauwitchere small vertical-slot differed significantly between 2010/11 and all proceeding years, with the exception of 2016/17, whilst assemblages sampled in 2011/12, 2013/14, 2014/15, 2015/16 and 2016/17 were also not significantly different (B-Y method corrected $\alpha = 0.015$; Table 3-4).

Table 3-2. PERMANOVA pair-wise comparisons of fish assemblages sampled from 2006–2017 at the Tauwitchere rock ramp (TRR). PERMANOVA was performed on Bray-Curtis similarity matrices. *denotes statistically significant p values; after B-Y method FDR correction α = 0.011. ns = non-significant.

Year	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2007/08	$t = 2.28$ $p < 0.001$*	-							
2008/09	$t = 2.78$ $p = 0.001$*	$t = 1.77$ $p = 0.010$*	-						
2009/10	$t = 3.06$ $p = 0.003$*	$t = 2.14$ $p = 0.007$*	$t = 2.09$ $p = 0.013$ ns	-					
2010/11	$t = 5.20$ $p < 0.001$*	$t = 6.04$ $p < 0.001$*	$t = 5.50$ $p < 0.001$*	$t = 5.30$ $p = 0.005$*	-				
2011/12	$t = 4.98$ $p < 0.001$*	$t = 5.81$ $p < 0.001$*	$t = 5.46$ $p < 0.001$*	$t = 5.27$ $p < 0.005$*	$t = 2.44$ $p < 0.001$*	-			
2013/14	$t = 3.89$ $p < 0.001$*	$t = 4.99$ $p < 0.003$*	$t = 4.73$ $p = 0.009$*	$t = 5.05$ $p = 0.022$ ns	$t = 2.77$ $p < 0.001$*	$t = 1.76$ $p = 0.002$*	-		
2014/15	$t = 3.92$ $p < 0.002$*	$t = 4.82$ $p = 0.003$*	$t = 4.48$ $p = 0.005$*	$t = 4.60$ $p = 0.026$ ns	$t = 2.59$ $p = 0.002$*	$t = 1.83$ $p = 0.003$*	$t = 1.46$ $p = 0.036$ ns	-	
2015/16	$t = 2.68$ $p = 0.003$*	$t = 3.58$ $p = 0.002$*	$t = 3.41$ $p = 0.010$*	$t = 3.34$ $p = 0.028$ ns	$t = 2.78$ $p = 0.002$*	$t = 2.49$ $p < 0.001$*	$t = 1.50$ $p = 0.067$ ns	$t = 1.40$ $p = 0.227$ ns	-
2016/17	$t = 3.53$ $p < 0.001$*	$t = 4.28$ $p < 0.001$*	$t = 3.84$ $p = 0.008$*	$t = 3.96$ $p = 0.028$ ns	$t = 1.68$ $p = 0.008$*	$t = 1.81$ $p = 0.025$ ns	$t = 1.85$ $p = 0.036$ ns	$t = 1.58$ $p = 0.058$ ns	$t = 1.70$ $p = 0.090$ ns

Table 3-3. PERMANOVA pair-wise comparisons between fish assemblages sampled from 2006–2017 at the Tauwitchere vertical-slot (TVS). PERMANOVA was performed on Bray-Curtis similarity matrices. *denotes statistically significant *p* values; after B-Y method FDR correction α = 0.011. ns = non-significant.

Year	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2007/08	$t = 2.784$ $p = 0.002$*	-							
2008/09	$t = 3.447$ $p < 0.001$*	$t = 1.597$ $p = 0.024$ ns	-						
2009/10	$t = 3.637$ $p = 0.002$*	$t = 2.662$ $p = 0.033$ ns	$t = 2.439$ $p = 0.015$ ns	-					
2010/11	$t = 4.527$ $p < 0.001$*	$t = 5.450$ $p < 0.001$*	$t = 4.693$ $p = 0.003$*	$t = 4.914$ $p = 0.002$*	-				
2011/12	$t = 3.205$ $p < 0.001$*	$t = 4.676$ $p = 0.003$*	$t = 4.290$ $p = 0.005$*	$t = 4.232$ $p = 0.011$*	$t = 1.665$ $p = 0.017$ ns	-			
2013/14	$t = 1.879$ $p = 0.011$*	$t = 3.551$ $p = 0.006$*	$t = 3.506$ $p = 0.013$ ns	$t = 3.589$ $p = 0.025$ ns	$t = 2.319$ $p < 0.001$*	$t = 1.399$ $p = 0.087$ ns	-		
2014/15	$t = 2.212$ $p = 0.010$*	$t = 4.406$ $p = 0.024$ ns	$t = 3.609$ $p = 0.013$ ns	$t = 3.723$ $p = 0.099$ ns	$t = 2.250$ $p = 0.011$*	$t = 1.730$ $p = 0.017$ ns	$t = 7.739$ $p = 0.780$ ns	-	
2015/16	$t = 2.364$ $p = 0.003$*	$t = 5.080$ $p = 0.027$ ns	$t = 3.959$ $p = 0.020$ ns	$t = 4.304$ $p = 0.105$ ns	$t = 3.350$ $p = 0.008$*	$t = 3.024$ $p = 0.006$*	$t = 1.369$ $p = 0.144$ ns	$t = 1.400$ $p = 0.097$ ns	-
2016/17	$t = 3.283$ $p < 0.001$*	$t = 4.821$ $p = 0.023$ ns	$t = 4.32$ $p = 0.011$*	$t = 4.225$ $p = 0.021$ ns	$t = 2.445$ $p = 0.006$*	$t = 2.004$ $p = 0.003$*	$t = 1.743$ $p = 0.032$ ns	$t = 1.874$ $p = 0.030$ ns	$t = 2.759$ $p = 0.035$ ns

Table 3-4. PERMANOVA pair-wise comparisons between fish assemblages sampled from 2010–2017 at the Tauwitchere small vertical-slot (TSVS). PERMANOVA was performed on Bray-Curtis similarity matrices. *denotes statistically significant *p* values; after B-Y method FDR correction α = 0.015. ns = non-significant.

Year	2010/11	2011/12	2013/14	2014/15	2015/16
2011/12	t = 1.793 p = 0.010*	-			
2013/14	t = 2.310 p = 0.003*	t = 1.476 p = 0.096 ns	-		
2014/15	t = 2.496 p < 0.001*	t = 1.594 p = 0.025 ns	t = 0.765 p = 0.733 ns	-	
2015/16	t = 2.591 p = 0.004*	t = 1.765 p = 0.033 ns	t = 0.897 p = 0.533 ns	t = 1.341 p = 0.172 ns	-
2016/17	t = 1.408 p = 0.089 ns	t = 1.206 p = 0.205 ns	t = 0.899 p = 0.375 ns	t = 1.405 p = 0.240 ns	t = 1.383 p = 0.174 ns

SIMPER indicated that fish assemblages sampled at the Tauwitchere rock ramp in 2016/17, differed from assemblages sampled in the years 2006–2009 due to greater abundance of the marine estuarine-opportunist sandy sprat, and freshwater bony herring and Australian smelt in 2016/17 (Table 3-5). Alternatively, the difference between 2016/17 and 2010/11 was driven by greater abundances of the freshwater bony herring and marine estuarine-opportunist sandy sprat in 2016/17, but greater abundances of freshwater redfin perch (*Perca fluviatilis*) and common carp (*Cyprinus carpio*), and estuarine lagoon goby in 2010/11.

At the Tauwitchere vertical-slot, assemblages sampled in 2016/17 differed from those in 2006/07 and 2008/09, due to greater abundance of the freshwater bony herring and Australian smelt, and catadromous congolli and common galaxias in 2016/17, but higher abundance of the marine estuarine-opportunist sandy sprat and estuarine small-mouthed hardyhead (*Atherinosoma microstoma*) in 2006/07 (Table 3-6). Alternatively, differences between assemblages in 2016/17 and the years 2010/11 and 2011/12 were driven by greater abundances of the freshwater Australian smelt, redfin perch and flat-headed gudgeon (*Philypnodon grandiceps*), and marine estuarine-opportunist sandy sprat in 2010/11 and 2011/12. At the Tauwitchere small vertical-slot, assemblages sampled in 2016/17 did not differ significantly from any previous years (Table 3-7).

Table 3-5. Results of similarity of percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs of years at the Tauwitchere rock ramp, deemed to be significantly different by PERMANOVA. *indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2007/08	A. microstoma* H. vittatus* T. lastii* R. semoni* A. forsterii	-							
2008/09	A. microstoma* H. vittatus* T. lastii* R. semoni* A. forsterii	A. microstoma* H. vittatus* A. forsterii R. tapirina	-						
2009/10	A. microstoma* H. vittatus* T. lastii* A. tamarensis* P. olorum* A. truttaceus A. georgianus	A. microstoma* H. vittatus* A. japonicus C. brevicaudus A. truttaceus A. georgianus	NS	-					
2010/11	R. semoni P. grandiceps N. erebi P. fluviatilis	R. semoni P. grandiceps N. erebi T. lastii	R. semoni P. grandiceps N. erebi T. lastii	R. semoni P. grandiceps T. lastii N. erebi	-				
2011/12	H. vittatus R. semoni N. erebi	H. vittatus R. semoni T. lastii	H. vittatus R. semoni T. lastii	H. vittatus R. semoni T. lastii	H. vittatus P. grandiceps* P. fluviatilis* G. maculatus	-			
2013/14	H. vittatus N. erebi P. urvillii R. semoni	H. vittatus N. erebi R. semoni T. lastii	H. vittatus N. erebi R. semoni T. lastii	NS	H. vittatus P. grandiceps* P. fluviatilis* R. semoni* C. carpio*	H. vittatus* T. lastii* R. semoni* P. urvillii	-		
2014/15	H. vittatus N. erebi P. urvillii	H. vittatus N. erebi P. urvillii T. lastii	H. vittatus P. urvillii N. erebi	NS	H. vittatus P. urvillii P. grandiceps* R. semoni* C. carpio*	H. vittatus* R. semoni* P. urvillii G. maculatus	NS	-	
2015/16	P. urvillii N. erebi R. semoni H. vittatus	P. urvillii N. erebi H. vittatus G. maculatus	P. urvillii H. vittatus N. erebi G. maculatus	NS	R. semoni* N. erebi* P. grandiceps* P. fluviatilis* T. lastii*	H. vittatus* R. semoni* N. erebi* T. lastii*	NS	NS	-
2016/17	N. erebi R. semoni H. vittatus	N. erebi R. semoni H. vittatus	N. erebi R. semoni H. vittatus	NS	H. vittatus P. fluviatilis* T. lastii* N. erebi C. carpio*	NS	NS	NS	NS

Table 3-6. Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs years at the Tauwitchere vertical-slot (TVS), deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2007/08	*P. grandiceps** *P. urvillii** *G. maculatus** *H. vittatus**	-							
2008/09	*P. grandiceps** *P. urvillii** *G. maculatus**	*NS*	-						
2009/10	*P. grandiceps** *G. maculatus** *H. vittatus**	*NS*	*NS*	-					
2010/11	*R. semoni* *N. erebi* *G. maculatus**	*R. semoni* *N. erebi* *P. grandiceps*	*R. semoni* *N. erebi* *P. grandiceps*	*R. semoni* *N. erebi* *P. grandiceps*	-				
2011/12	*R. semoni* *N. erebi* *T. lastii* *H. vittatus**	*R. semoni* *N. erebi* *T. lastii*	*R. semoni* *N. erebi* *T. lastii* *P. urvillii*	*R. semoni* *N. erebi* *T. lastii*	*NS*	-			
2013/14	*P. grandiceps* *P. urvillii* *H. vitattus* *R. semoni*	*P. urvillii* *R. semoni* *P. grandiceps* *T. lastii*	*NS*	*NS*	*R. semoni** *H. vittatus* *G. maculatus*	*NS*	-		
2014/15	*R. semoni* *N. erebi* *P. urvilii* *H. vittatus*	*NS*	*NS*	*NS*	*R. semoni** *P. urvillii* *G. maculatus*	*NS*	*NS*	-	
2015/16	*P. grandiceps* *R. semoni* *H. vittatus**	*NS*	*NS*	*NS*	*R. semoni** *P. grandiceps* *G. maculatus*	*P. grandiceps* *R. semoni** *G. maculatus* *P. fluviatilis**	*NS*	*NS*	-
2016/17	*R. semoni* *H. vittatus** *N. erebi* *A. microstoma**	*NS*	*R. semoni* *P. urvillii* *N. erebi* *G. maculatus*	*NS*	*R. semoni** *T. lastii** *P. grandiceps**	*T. lastii** *R. semoni** *H. vittatus**	*NS*	*NS*	*NS*

Table 3-7. Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs years at the Tauwitchere small vertical-slot (TSVS), deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2010/11	2011/12	2013/14	2014/15	2015/16
2011/12	*P. fluviatilis** *R. semoni* *G. maculatus*	-			
2013/14	*P. fluviatilis** *R. semoni* *P. urvillii*	*NS*	-		
2014/15	*G. maculatus* *P. urvillii* *R. semoni*	*NS*	*NS*	-	
2015/16	*P. fluviatilis** *R. semoni* *G. maculatus*	*NS*	*NS*	*NS*	-
2016/17	*NS*	*NS*	*NS*	*NS*	*NS*

At the Tauwitchere rock ramp, the fish assemblage in 2006/07 was characterised by the presence of the anadromous short-headed lamprey (*Mordacia mordax*) (Table 3-8). In contrast, the assemblage in 2007/08 was characterised by the marine estuarine-opportunist flat-tailed mullet (*Liza argentea*) and marine straggler blue sprat (*Spratelloides robustus*), whilst in in 2009/10, the assemblage was characterised by the estuarine and marine estuary catfish (*Cnidglanis microcephalus*), six marine estuarine-opportunist species (i.e. mulloway (*Argyrosomus japonicus*), Australian salmon (*Arripis truttaceus*), Australian herring (*Arripis georgianus*), prickly toadfish (*Contusus brevicaudus*), yellowfin whiting (*Sillago schomburgkii*) and Australian anchovy (*Engraulis australis*)) and three marine stragglers (i.e. big belly seahorse (*Hippocampus abdominalis*), silver spot (*Threpterius maculosus*) and Tucker's pipefish (*Mitotichthys tuckeri*). The assemblage sampled in 2010/11 was characterised by four freshwater species including carp gudgeon complex (*Hypseleotris* spp.), Australian smelt, flat-headed gudgeon and common carp, and one marine straggler (i.e. southern longfin goby (*Favonigobius lateralis*)). The assemblage in 2011/12 was characterised by the estuarine river garfish (*Hyperhamphus regularis*) and lagoon goby, whilst the assemblage in 2013/14 was characterised by the estuarine Tamar River goby (*Afurcagobius tamarensis*) and marine estuarine-opportunist long-snout flounder (*Ammotretis* *rostratus*). The assemblage in 2014/15 was characterised by the catadromous congolli and common galaxias, and estuarine and marine bridled goby (*Arenogobius bifrenatus*). There were no significant indicators of the fish assemblage sampled in 2015/16, but the assemblage in 2016/17 was characterised by the freshwater bony herring.

At the Tauwitchere large vertical-slot, there were no significant indicators of assemblages sampled in 2006/07, but assemblages from 2007/08 were characterised by the estuarine blue-spot goby (*Pseudogobius olorum*) (Table 3-9). There were no significant indicators of the assemblage in 2008/09, but in 2009/10, assemblages were characterised by the estuarine small-mouthed hardyhead. The assemblage in 2010/11 was characterised by freshwater species, namely bony herring, Australian smelt, redfin perch and common carp. The assemblage in 2011/12 was characterised by the freshwater golden perch (*Macquaria ambigua ambigua*), whilst 2013/14 was characterised by the freshwater dwarf flat-headed gudgeon (*Philypnodon macrostomus*). The assemblage in 2014/15 was characterised by the catadromous congolli and common galaxias, and in 2015/16, by the freshwater flat-headed gudgeon, but there were no significant indicators of the assemblage in 2016/17.

At the Tauwitchere small vertical-slot in 2010/11, assemblages were characterised by the freshwater flat-headed gudgeon, carp gudgeon and redfin perch, and the estuarine blue-spot goby and lagoon goby (Table 3-9). The assemblage in 2011/12 was characterised by the freshwater common carp, whilst there were no significant indicators of assemblages in 2013/14, 2014/15, 2015/16 or 2016/17.

Table 3-8. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere rock ramp from 2006 to 2017. Only significant indicators (i.e. $p < 0.05$) are presented. Species are categorised using estuarine use guilds from Elliott *et al.* (2007).

Species	Guild	Year	Indicator Value	*p* value
Tauwitchere rockramp				
Short-headed lamprey	Anadromous	2006/07	45.5	0.006
Blue sprat	Marine straggler	2007/08	44.4	0.010
Flat-tailed mullet	Marine est-opportunist	2007/08	31.1	0.023
Estuary catfish	Estuarine & marine	2009/10	33.3	0.048
Mulloway	Marine est-opportunist	2009/10	41.8	0.004
Australian salmon	Marine est-opportunist	2009/10	32.1	0.009
Australian herring	Marine est-opportunist	2009/10	55.7	0.001
Prickly toadfish	Marine est-opportunist	2009/10	90.3	<0.001
Yellowfin whiting	Marine est-opportunist	2009/10	46.1	0.007
Australian anchovy	Marine est-opportunist	2009/10	33.0	0.018
Tuckers pipefish	Marine straggler	2009/10	33.3	0.047
Big belly seahorse	Marine straggler	2009/10	33.3	0.046
Silver spot	Marine straggler	2009/10	33.3	0.046
Carp gudgeon complex	Freshwater straggler	2010/11	76.2	<0.001
Australian smelt	Freshwater est-opportunist	2010/11	21.8	0.026
Flat-headed gudgeon	Freshwater est-opportunist	2010/11	28.9	0.003
Common carp	Freshwater straggler	2010/11	53.5	<0.001
Southern longfin goby	Marine straggler	2010/11	82.9	<0.001
Lagoon goby	Solely estuarine	2011/12	21.4	0.037
River garfish	Solely estuarine	2011/12	26.3	0.044
Tamar River goby	Solely estuarine	2013/14	17.6	0.005
Long-snout flounder	Marine est-opportunist	2013/14	26.6	0.035
Common galaxias	Semi-catadromous	2014/15	23.2	0.013
Congolli	Catadromous	2014/15	21.0	0.042
Bridled goby	Estuarine & marine	2014/15	17.4	0.033
Bony herring	Freshwater est-opportunist	2016/17	23.4	0.026

Table 3-9. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere large vertical-slot from 2006–2017, and at the small vertical-slot from 2010–2017. Only significant indicators (i.e. $p < 0.05$) are presented. Species are categorised using estuarine use guilds from Elliott *et al.* (2007).

Species	Guild	Year	Indicator Value	*p* value
Tauwitchere large vertical-slot				
Blue-spot goby	Solely estuarine	2007/08	33.4	0.002
Small-mouthed hardyhead	Solely estuarine	2009/10	21.9	0.018
Bony herring	Freshwater est-opportunist	2010/11	25.0	0.048
Australian smelt	Freshwater est-opportunist	2010/11	26.2	0.003
Redfin perch	Freshwater straggler	2010/11	30.8	0.030
Common carp	Freshwater straggler	2010/11	27.7	0.026
Golden perch	Freshwater straggler	2011/12	34.1	0.027
River garfish	Solely estuarine	2011/12	34.3	0.049
Dwarf flat-headed gudgeon	Freshwater straggler	2013/14	40.0	0.027
Common galaxias	Semi-catadromous	2014/15	20.6	0.009
Congolli	Catadromous	2014/15	21.1	0.014
Flat-headed gudgeon	Freshwater est-opportunist	2015/16	27.9	0.001
Tauwitchere small vertical-slot				
Redfin perch	Freshwater straggler	2010/11	44.4	0.020
Carp gudgeon complex	Freshwater straggler	2010/11	37.5	0.033
Flat-headed gudgeon	Freshwater est-opportunist	2010/11	32.2	0.005
Blue-spot goby	Solely estuarine	2010/11	44.4	0.016
Common carp	Freshwater straggler	2011/12	38.1	0.036

Goolwa sites

Pair-wise comparisons revealed that fish assemblages sampled at the Goolwa vertical-slot in 2006/07 were significantly different from all other years, with the exception of 2009/10, 2013/14 and 2015/16 (B-Y method corrected $\alpha = 0.012$; Table 3-10). The assemblage sampled in 2008/09 was not significantly different from 2009/10 or 2016/17, but differed significantly from all other years. Fish assemblages from 2010/11 and 2011/12 were also not significantly different from one another, but both years were significantly different from other years for most comparisons. The years 2013/14, 2014/15, 2015/16 and 2016/17 were not significantly different. Fish assemblages sampled adjacent Goolwa Barrage in 2008/09 were similar to those from 2009/10, but significantly different to all other years (B-Y method corrected $\alpha = 0.013$; Table 3-11). Similarly, assemblages from both 2010/11 and 2011/12 were generally significantly different from all other years. Assemblages sampled during the years 2013/14, 2014/15, 2015/16 and 2016/17 were not significantly different.

Table 3-10. PERMANOVA pair-wise comparisons of fish assemblages sampled from 2006–2017 at the Goolwa vertical-slot (GVS). PERMANOVA was performed on Bray-Curtis similarity matrices. *denotes statistically significant *p* values; after B-Y method FDR correction α = 0.012. ns = non-significant.

Year	2006/07	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2008/09	$t = 2.805$ $p < 0.001$*	-						
2009/10	$t = 1.720$ $p = 0.022$ ns	$t = 1.865$ $p = 0.033$ ns	-					
2010/11	$t = 2.997$ $p < 0.001$*	$t = 3.974$ $p < 0.001$*	$t = 2.640$ $p = 0.006$*	-				
2011/12	$t = 2.020$ $p < 0.001$*	$t = 3.745$ $p = 0.003$*	$t = 3.044$ $p = 0.012$*	$t = 1.456$ $p = 0.051$ ns	-			
2013/14	$t = 1.644$ $p = 0.014$ ns	$t = 3.142$ $p = 0.006$*	$t = 2.580$ $p = 0.016$ ns	$t = 2.089$ $p = 0.002$*	$t = 1.615$ $p = 0.006$*	-		
2014/15	$t = 1.681$ $p = 0.020$ ns	$t = 3.450$ $p = 0.006$*	$t = 3.197$ $p = 0.023$ ns	$t = 2.065$ $p = 0.002$*	$t = 1.643$ $p = 0.032$ ns	$t = 1.017$ $p = 0.434$ ns	-	
2015/16	$t = 1.592$ $p = 0.024$ ns	$t = 3.078$ $p = 0.010$*	$t = 2.555$ $p = 0.033$ ns	$t = 1.743$ $p = 0.016$ ns	$t = 1.556$ $p = 0.009$*	$t = 0.903$ $p = 0.560$ ns	$t = 1.127$ $p = 0.331$ ns	-
2016/17	$t = 2.080$ $p = 0.003$*	$t = 3.180$ $p = 0.019$ ns	$t = 2.969$ $p = 0.111$ ns	$t = 1.925$ $p = 0.007$*	$t = 1.691$ $p = 0.013$ ns	$t = 1.302$ $p = 0.127$ ns	$t = 1.281$ $p = 0.153$ ns	$t = 1.327$ $p = 0.120$ ns

Table 3-11. PERMANOVA pair-wise comparisons of fish assemblages sampled from 2008–2017 adjacent Goolwa Barrage (GDS). PERMANOVA was performed on Bray-Curtis similarity matrices. *denotes statistically significant *p* values; after B-Y method FDR correction α = 0.013. ns = non-significant.

Year	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2009/10	t = 1.295 p = 0.154 ns	-					
2010/11	t = 4.222 p < 0.001*	t = 3.334 p = 0.006*	-				
2011/12	t = 3.370 p = 0.002*	t = 2.519 p = 0.010*	t = 2.731 p < 0.001*	-			
2013/14	t = 3.358 p = 0.009*	t = 2.614 p = 0.024 ns	t = 2.390 p = 0.003*	t = 1.859 p = 0.009*	-		
2014/15	t = 4.018 p = 0.013*	t = 3.475 p = 0.040 ns	t = 2.367 p = 0.004*	t = 2.093 p = 0.004*	t = 1.066 p = 0.342 ns	-	
2015/16	t = 3.541 p = 0.009*	t = 2.917 p = 0.020 ns	t = 2.756 p < 0.001*	t = 2.777 p = 0.003*	t = 1.665 p = 0.015 ns	t = 2.072 p = 0.028 ns	-
2016/17	t = 3.792 p = 0.006*	t = 3.156 p = 0.029 ns	t = 1.726 p = 0.002*	t = 1.768 p = 0.017 ns	t = 1.126 p = 0.281 ns	t = 1.322 p = 0.118 ns	t = 2.415 p = 0.028 ns

Fish assemblages at the Goolwa vertical-slot in 2015/16, were significantly different from only 2008/09 and 2010/11, and in both cases was due to greater abundance of the catadromous congolli, and freshwater Australian smelt and bony herring in 2016/17 (Table 3-12). Similarly at the site adjacent Goolwa Barrage, differences between assemblages in 2016/17 and 2008/09 were driven by greater abundances of marine estuarine-opportunist sandy sprat, and freshwater flat-head gudgeon and bony herring in 2016/17 (Table 3-13). Differences between 2016/17 and 2010/11 were driven by greater abundance of marine estuarine-opportunist sandy sprat in 2016/17, but greater abundances of freshwater redfin perch, estuarine small-mouthed hardyhead, and estuarine and marine bridled goby in 2010/11.

ISA of assemblage data from the Goolwa vertical-slot indicated that assemblages in 2006/07 were characterised by the anadromous short-headed lamprey (Table 3-14). The assemblage in 2008/09 was characterised by the estuarine black bream and marine estuarine-opportunist flat-tailed mullet, whilst the assemblage in 2009/10 was characterised by estuarine small-mouthed hardyhead, estuarine and marine bridled goby and soldier fish (*Gymnapistes marmoratus*), marine estuarine-opportunist Australian salmon (*Arripis truttaceus*) and marine straggler zebra fish (*Girella zebra*). The assemblage in 2010/11 was characterised by the freshwater redfin perch, and the 2011/12 assemblage by the freshwater goldfish (*Carassius auratus*). There were no significant indicators of the assemblage in 2013/14, 2014/15 or 2015/16, but the 2016/17 assemblage was characterised by the freshwater golden perch.

The assemblage sampled adjacent Goolwa Barrage in 2008/09 was characterised by the estuarine black bream and marine estuarine-opportunist yellow-eyed mullet (*Aldrichetta forsteri*), whilst the assemblage in 2009/10 was characterised by the marine estuarine-opportunist smooth toadfish (*Tetractenos glaber*) (Table 3-14). The assemblage sampled in 2010/11 was characterised by four freshwater species, namely carp gudgeon, Australian smelt, flat-headed gudgeon and redfin perch, and the estuarine and marine bridled goby. The assemblage sampled in 2011/12 was characterised by the freshwater golden perch and goldfish, and the marine estuarine-opportunist Australian salmon. There were no significant indicators of the assemblage in 2013/14, but in 2014/15, the assemblage was characterised by the freshwater dwarf flat-headed gudgeon and catadromous congolli, and in 2015/16 by the catadromous common galaxias, estuarine small-mouthed hardyhead and marine estuarine-opportunist blue-spot flathead (*Platycephalus speculator*). The assemblage in 2016/17 was characterised by the freshwater bony herring.

Table 3-12. Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs years at the Goolwa vertical-slot (GVS), deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2006/07	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2008/09	*H. vittatus** *R. semoni** *G. maculatus** *P. urvillii**	-						
2009/10	*NS*	*NS*	-					
2010/11	*R. semoni* *T. lastii* *H. vittatus** *G. maculatus** *P. urvillii**	*R. semoni* *P. grandiceps* *N. erebi* *P. fluviatilis* *L. argentea**	*R. semoni* *N. erebi* *P. fluviatilis* *T. lastii* *H. vittatus** *L. argentea**	-				
2011/12	*R. semoni* *H. vittatus** *G. maculatus** *P. urvillii**	*R. semoni* *H. vittatus* *N. erebi* *G. maculatus*	*R. semoni* *N. erebi* *G. maculatus* *A. microstoma** *L. argentea**	*NS*	-			
2013/14	*NS*	*P. urvillii* *R. semoni* *P. grandiceps* *N. erebi*	*NS*	*P. urvillii* *G. maculatus* *N. erebi* *R. semoni**	*P. urvillii* *R. semoni** *H. vittatus** *G. maculatus*	-		
2014/15	*NS*	*P. urvillii* *R. semoni* *G. maculatus*	*NS*	*P. urvillii* *G. maculatus* *H. vittatus*	*NS*	*NS*	-	
2015/16	*NS*	*P. urvillii* *R. semoni* *G. maculatus* *P. grandiceps*	*NS*	*NS*	*P. urvillii* *G. maculatus* *R. semoni** *H. vittatus** *N. erebi**	*NS*	*NS*	-
2016/17	*N. erebi* *P. urvillii* *R. semoni*	*NS*	*NS*	*P. urvillii* *N. erebi* *R. semoni*	*NS*	*NS*	*NS*	*NS*

Table 3-13. Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs of years adjacent Goolwa Barrage (GDS), deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2008/09	2009/10	2010/11	2011/12	2013/14	2014/15	2015/16
2009/10	*NS*	-					
2010/11	*H. vittatus* *P. grandiceps* *P. fluviatilus* *N. erebi*	*H. vittatus* *P. grandiceps* *P. fluviatilus* *N. erebi*	-				
2011/12	*H. vittatus* *N. erebi* *R. semoni* *T. lastii* *A. forsterii**	*H. vittatus* *N. erebi* *T. lastii* *A. forsterii** *A. bifrenatus**	*H. vittatus* *A. bifrenatus** *P. fluviatilis** *P. grandiceps** *A. microstoma**	-			
2013/14	*H. vittatus* *P. urvillii* *G. maculatus* *N. erebi* *P. grandiceps*	*NS*	*H. vittatus* *P. urvillii* *P. fluviatilis** *A. bifrenatus** *P. grandiceps**	*P. urvillii* *T. lastii* *H. vittatus** *A. truttaceus** *N. erebi**	-		
2014/15	*H. vittatus* *P. urvillii* *N. erebi* *P. grandiceps*	*NS*	*H. vittatus* *P. urvillii* *A. microstoma** *A. bifrenatus** *P. grandiceps**	*P. urvillii* *T. lastii* *N. erebi* *H. vittatus** *A. truttaceus**	*NS*	-	
2015/16	*P. urvillii* *G. maculatus* *H. vittatus* *A. microstoma* *A. forsterii**	*NS*	*P. urvillii* *H. vittatus** *N. erebi** *P. fluviatilis** *P. grandiceps**	*P. urvillii* *A. microstoma* *A. bifrenatus* *H. vittatus** *N. erebi**	*NS*	*NS*	-
2016/17	*H. vittatus* *P. grandiceps* *N. erebi*	*NS*	*H. vittatus* *P. fluviatilis** *A. bifrenatus** *A. microstoma**	*NS*	*NS*	*NS*	*NS*

Table 3-14. Indicator species analysis of fish assemblages in the Coorong at the Goolwa vertical slot from 2006–2017 and adjacent Goolwa Barrage from 2008–2017. Only significant indicators (i.e. $p < 0.05$) are presented. Species are categorised using estuarine use guilds from Elliott *et al.* (2007).

Species	Guild	Year	Indicator Value	*p* value
Goolwa vertical-slot				
Short-headed lamprey	Anadromous	2006/07	46.2	0.007
Black bream	Solely estuarine	2008/09	44.4	0.010
Flat-tailed mullet	Marine est-opportunist	2008/09	33.1	0.021
Small-mouthed hardyhead	Solely estuarine	2009/10	39.1	<0.001
Bridled goby	Estuarine & marine	2009/10	33.6	0.020
Soldier fish	Estuarine & marine	2009/10	35.3	0.034
Australian salmon	Marine est-opportunist	2009/10	37.8	0.037
Zebra fish	Marine straggler	2009/10	58.3	0.006
Redfin perch	Freshwater straggler	2010/11	20.9	0.050
Goldfish	Freshwater straggler	2011/12	46.2	0.005
Golden perch	Freshwater straggler	2016/17	38.2	0.013
Adjacent Goolwa Barrage				
Black bream	Solely estuarine	2008/09	36.2	0.012
Yellow-eyed mullet	Marine est-opportunist	2008/09	35.8	0.009
Smooth toadfish	Marine est-opportunist	2009/10	47.4	0.002
Flat-headed gudgeon	Freshwater est-opportunist	2010/11	26.8	0.009
Carp gudgeon	Freshwater straggler	2010/11	43.6	0.014
Redfin perch	Freshwater straggler	2010/11	33.5	0.004
Australian smelt	Freshwater est-opportunist	2010/11	24.2	0.021
Bridled goby	Estuarine & marine	2010/11	29.5	0.007
Golden perch	Freshwater straggler	2011/12	45.2	<0.001
Goldfish	Freshwater straggler	2011/12	35.4	0.036
Australian salmon	Marine est-opportunist	2011/12	51.3	<0.001
Dwarf flat-headed gudgeon	Freshwater straggler	2014/15	36.4	0.025
Congolli	Catadromous	2014/15	25.3	0.014
Blue-spot flathead	Marine est-opportunist	2015/16	50.0	0.023
Common galaxias	Catadromous	2015/16	27.9	0.028
Small-mouthed hardyhead	Solely estuarine	2015/16	27.6	0.016
Bony herring	Freshwater est-opportunist	2016/17	24.6	0.022

Hunters Creek

Pair-wise comparisons revealed that fish assemblages sampled at the Hunters Creek vertical-slot in 2010/11 and 2011/12 differed significantly from all proceeding years, but the years 2013/14, 2014/15, 2015/16 and 2016/17 were not significantly different (B-Y method corrected $\alpha = 0.015$) (Table 3-15). SIMPER indicated the assemblage in 2016/17 differed from the years 2010/11 and

2011/12 due to greater abundances of freshwater redfin perch and common carp in 2010/11 and 2011/12, but greater abundances of catadromous congolli, freshwater bony herring and marine estuarine-opportunist flat-tailed mullet in 2016/17. Furthermore, ISA determined that the assemblage sampled in 2010/11 was characterised by the freshwater redfin perch, flat-headed gudgeon and common carp, whilst the assemblage in 2011/12 was characterised by the freshwater golden perch (Table 3-17). There were no significant indicators of the assemblage in 2013/14, 2014/15 or 2015/16, but 2016/17 was characterised by the freshwater carp gudgeon and dwarf flat-headed gudgeon, and marine estuarine-opportunist flat-tailed mullet.

Table 3-15. PERMANOVA pairwise comparisons between fish assemblages sampled from 2010–2017 at the Hunters Creek vertical-slot fishway. PERMANOVA was performed on Bray-Curtis similarity matrices. After B-Y method FDR correction α = 0.015.

Year	**2010/11**	**2011/12**	**2013/14**	**2014/15**	**2015/16**
2011/12	t = 2.209 p = 0.002*	-			
2013/14	t = 3.049 p < 0.001*	t = 2.637 p < 0.001*	-		
2014/15	t = 2.713 p < 0.001*	t = 2.580 p = 0.002*	t = 1.238 p = 0.213 ns	-	
2015/16	t = 2.790 p = 0.004*	t = 2.630 p = 0.002*	t = 1.323 p = 0.152 ns	t = 1.481 p = 0.152 ns	-
2016/17	t = 2.052 p = 0.001*	t = 2.305 p = 0.005*	t = 1.477 p = 0.051 ns	t = 1.704 p = 0.027 ns	t = 1.734 p = 0.020 ns

Table 3-16. Results of similarity or percentages analysis (SIMPER) presenting species that cumulatively contributed >40% to dissimilarity between fish assemblages sampled in pairs of years at the Hunters Creek vertical-slot (Hunters), deemed to be significantly different by PERMANOVA. * indicates greater contribution to assemblages from the 'column year', whilst its absence represents greater contribution to assemblages from the 'row year'. *NS* = non-significant comparison.

Year	2010/11	2011/12	2013/14	2014/15	2015/16
2011/12	*P. fluviatilis** *P. grandiceps** *N. erebi**	-			
2013/14	*P. fluviatilis** *C. carpio** *P. grandiceps**	*P. urvillii* *P. fluviatilis** *C. carpio**	-		
2014/15	*P. urvillii* *P. fluviatilis** *C. carpio**	*P. urvillii* *P. fluviatilis** *C. carpio**	*NS*	-	
2015/16	*P. fluviatilis** *C. carpio** *N. erebi**	*P. urvillii* *P. fluviatilis** *C. carpio** *N. erebi**	*NS*	*NS*	-
2016/17	*P. fluviatilis** *C. carpio** *N. erebi**	*P. fluviatilis** *C. carpio** *P. urvilli* *N. erebi* *L. argentea*	*NS*	*NS*	*NS*

Table 3-17. Indicator species analysis of fish assemblages at the Hunters Creek vertical slot from 2010–2017. Only significant indicators (i.e. $p < 0.05$) are presented. Species are categorised using estuarine use guilds from Elliott *et al.* (2007).

Species	Guild	Year	Indicator Value	*p* value
Redfin perch	Freshwater straggler	2010/11	55.0	0.001
Flat-headed gudgeon	Freshwater est-opportunist	2010/11	31.2	0.003
Common carp	Freshwater est-opportunist	2010/11	43.4	<0.001
Golden perch	Freshwater straggler	2011/12	51.4	0.008
Carp gudgeon	Freshwater straggler	2016/17	41.3	0.014
Dwarf flat-headed gudgeon	Freshwater straggler	2016/17	58.1	0.006
Flat-tailed mullet	Marine est-opportunist	2016/17	69.7	<0.001

3.4. Spatial variation in fish assemblages in 2016/17

MDS ordination of fish assemblage data from the vertical-slot fishways exhibited interspersion of samples from the vertical-slot fishways at Goolwa and Tauwitchere, and separation of samples from Hunters Creek vertical-slot (Figure 3-5a), supported by PERMANOVA, which detected significant differences in fish assemblages between capture locations (*Pseudo*-$F_{3, 14}$ = 2.69, p = 0.005). Pair-wise comparisons suggest that assemblages were significantly different between the Hunters Creek vertical-slot and all other fishways, but all other comparisons were non-significant. MDS ordination of fish assemblage data from the Tauwitchere rock ramp and adjacent Goolwa Barrage (GDS) exhibited interspersion (Figure 3-5b) and PERMANOVA suggested assemblages sampled from these locations were not significantly different (*Pseudo*-$F_{1, 7}$ = 1.92, p = 0.198).

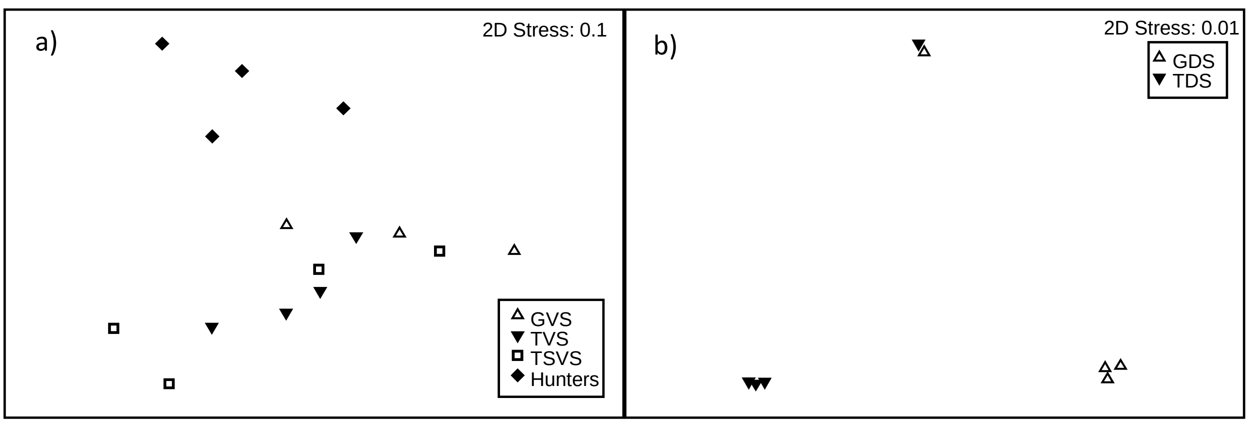

Figure 3-5. MDS ordination plot of fish assemblages sampled at the a) Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS), and Hunters Creek vertical-slot (Hunters), and b) Tauwitchere rock ramp and adjacent Goolwa Barrage (GDS) in 2016/17.

Table 3-18. PERMANOVA pair-wise comparisons of fish assemblages from the Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS) and Hunters Creek vertical-slot (Hunters) in 2016/17. PERMANOVA was performed on bray-curtis similarity matrices.

Pairwise comparison		***t***	***p* value**
Location	**Location**		
TVS	GVS	1.47	0.084 ns
TVS	TSVS	0.55	0.939 ns
TVS	Hunters	2.46	0.029*
GVS	Hunters	2.00	0.030*
GVS	TSVS	1.22	0.335 ns
Hunters	TSVS	1.86	0.028*

Indicator species analysis was used to determine species that characterised assemblages at the different vertical-slot fishways in 2016/17. Of 20 species sampled, five were significant indicators of the fish assemblage at a particular location (Table 3-19). The freshwater golden perch and catadromous common galaxias characterised the assemblage at the Goolwa large vertical-slot, whilst the freshwater carp gudgeon, estuarine small-mouthed hardyhead and marine estuarine-opportunist flat-tailed mullet characterised the assemblage at the Hunters Creek vertical-slot.

Table 3-19. Indicator species analysis of fish assemblages in the Coorong at the Tauwitchere vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS) and Hunters Creek vertical-slot, in 2016/17.

Species		**Location**	**Indicator Value**	***p* value**
Common galaxias	Semi-catadromous	GVS	37.3	0.022
Golden perch	Freshwater straggler	GVS	57.7	0.047
Small-mouthed hardyhead	Estuarine	Hunters	62.5	0.029
Flat-tailed mullet	Marine est-opportunist	Hunters	75.0	0.029
Carp gudgeon	Freshwater straggler	Hunters	75.0	0.029

3.5. Spatio-temporal variation in the abundance and recruitment of diadromous species

Inter-annual variation in abundance

Lamprey

A single pouched lamprey (Goolwa vertical-slot) was captured during sampling in spring/summer 2016/17. An additional seven pouched lamprey, were also sampled from the Goolwa vertical-slot (*n* = 5), new Goolwa vertical-slot (typically not sampled in this project, *n* = 1) and new Boundary Creek vertical-slot fishway (typically not sampled in this project, *n* = 1) during specific winter monitoring from June to August 2016 (only data from the Goolwa vertical-slot is included in Figure 3-6a below). This followed the sampling of large numbers of pouched lamprey in winter 2015 (*n* = 56), and low numbers in the winters of July 2013 (*n* = 2) and 2011 (*n* = 10).

No short-headed lamprey were captured during sampling winter or spring/summer 2016/17. Short-headed lamprey was sampled in moderate abundance across three locations from September to November 2006, but was absent from 2007–2011, before being sampled and in low abundance adjacent Goolwa Barrage in November 2011. The species was absent from sampling in 2013/14, 2014/15 and 2015/16 (Figure 3-6b).

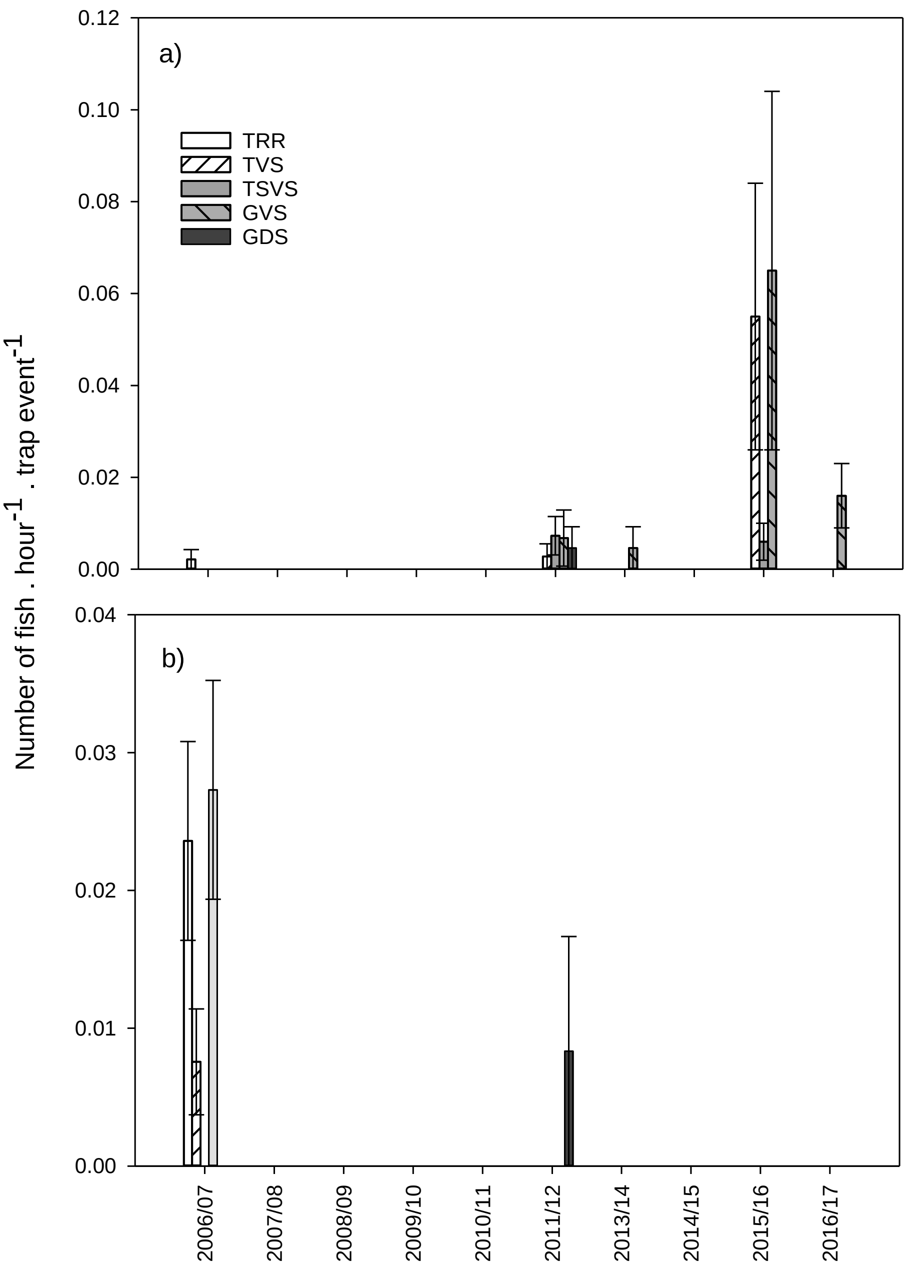

Figure 3-6. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of a) pouched lamprey and b) short-headed lamprey at the Tauwitchere rock ramp (TRR), Tauwitchere large vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS), Goolwa vertical-slot (GVS) and adjacent Goolwa Barrage (GDS) from 2006–2017. No sampling was undertaken in 2012/13, whilst Goolwa vertical-slot was not sampled in 2007/08 and the site adjacent Goolwa Barrage was not sampled in 2006/07 and 2007/08. The Tauwitchere small vertical-slot was only sampled in 2010/11, 2011/12 and 2013/14. Data from 2011/12, 2013/14, 2015/16 and 2016/17 includes supplementary sampling in winter.

Congolli and common galaxias

The abundance of the catadromous congolli and common galaxias differed significantly between years at all sampling locations (Table 3-20), with the exception of common galaxias at Hunters Creek (Table 3-20). Overall, patterns of variability in abundance were generally consistent across sites with decreased abundances over the period 2007–2010, relative to 2006/07, and a trend of gradually increasing abundance from 2010/11 through to 2014/15. The abundances of congolli recorded in 2016/17 were generally greater than all years from 2006–2012 (Figure 3-7a), but a trend of declining abundance following peaks in 2014/15 were evident at the Tauwitchere rock ramp and vertical-slot, and Hunters Creek vertical-slot. Alternatively, abundance recorded at the Goolwa vertical-slot in 2016/17 was the greatest since inception of the project.

As with congolli, common galaxias was typically sampled in low abundances through the period 2007–2010, with the exception of the Goolwa vertical-slot where this species was sampled in relatively high abundance in 2009/10 (Figure 3-7b). 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 years, with further increases occurring annually until abundance peaked in 2014/15. Abundance in 2015/16 was similar to that observed in 2014/15, but decreased slightly at most sites in 2016/17 (Figure 3-7b).

Table 3-20. Summary of results of uni-variate single factor PERMANOVA to determine differences in the relative abundance (number of $fish.hour^{-1}.trap\ event^{-1}$) of congolli and common galaxias sampled from 2006–2017 at the Tauwitchere rock ramp (TRR), Tauwitchere vertical-slot (TVS), Goolwa vertical-slot (GVS), adjacent Goolwa Barrage (GDS), Tauwitchere small-vertical-slot and Hunters Creek vertical-slot. PERMANOVA was performed on Euclidean Distance similarity matrices. α = 0.05.

		Congolli		Common galaxias	
Site	**df**	***Pseudo-F***	***P* value**	***Pseudo-F***	***P* value**
TRR	9, 102	27.22	<0.001*	30.24	<0.001*
TVS	9, 134	17.59	<0.001*	45.93	<0.001*
GVS	8, 140	14.24	<0.001*	5.69	0.002*
GDS	7, 50	15.99	<0.001*	15.49	<0.001*
TSVS	5, 88	6.92	<0.001*	14.81	<0.001*
Hunters	5, 87	4.71	<0.001*	1.51	0.192 ns

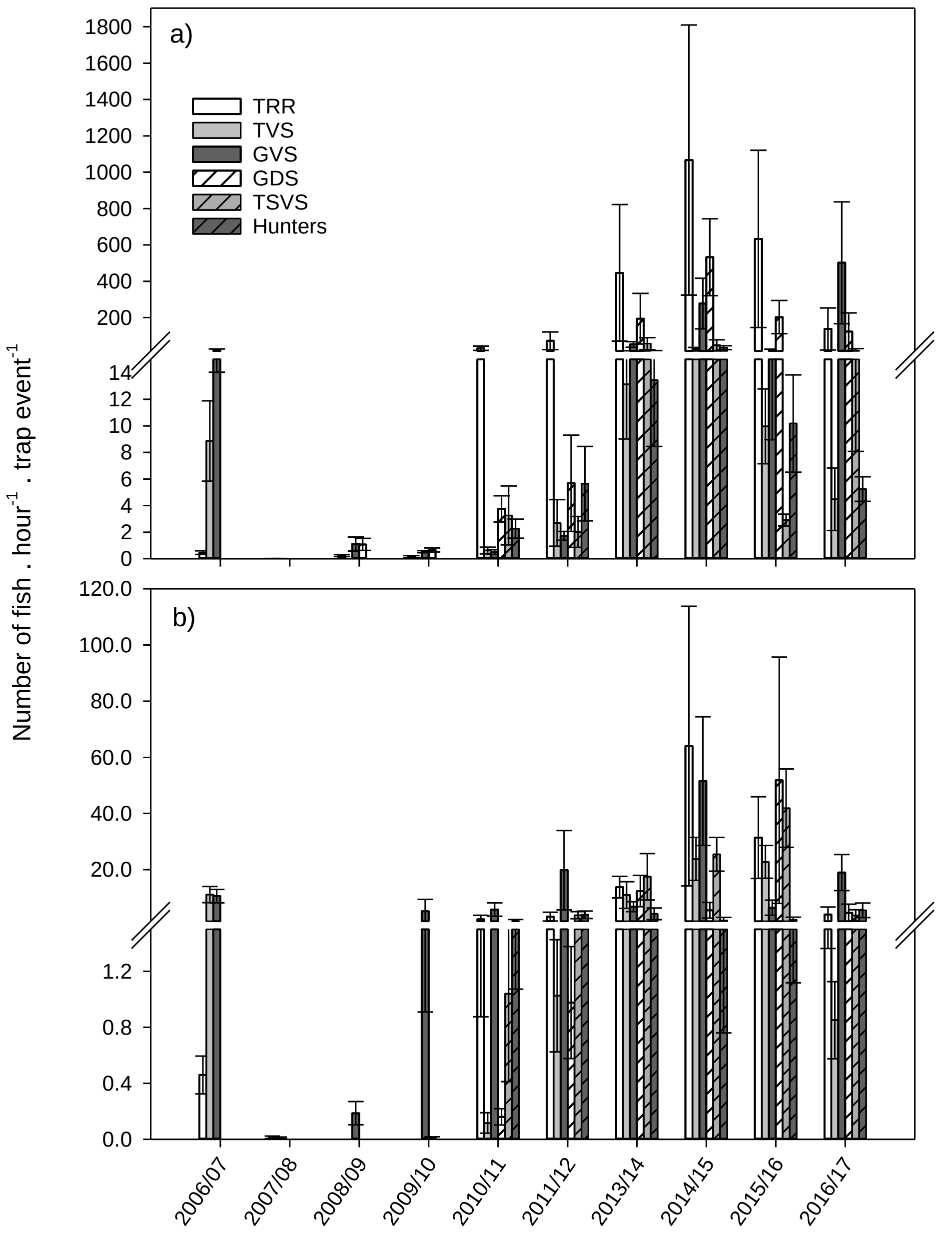

Figure 3-7. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of a) congolli and b) common galaxias at the Tauwitchere rock ramp (TRR), Tauwitchere vertical-slot (TVS), Goolwa vertical-slot (GVS), adjacent Goolwa Barrage (GDS), Tauwitchere small vertical-slot (TSVS) and Hunters Creek vertical-slot (Hunters) from 2006–2017. Goolwa vertical-slot was not sampled in 2007/08 and adjacent Goolwa Barrage was not sampled in 2006/07 and 2007/08. The Tauwitchere small vertical-slot and Hunters Creek vertical-slot were sampled from 2010/11 onwards. All sites were not sampled in 2012/13.

Intra-annual variation in abundance and recruitment of congolli and common galaxias

The abundance of upstream migrating congolli was significantly different between months at the Goolwa vertical-slot (*Pseudo*-$F_{2, 8} = 10.18$, $p = 0.006$), Tauwitchere large vertical-slot (*Pseudo*-$F_{3, 11} = 15.83$, $p < 0.001$) and Tauwitchere small vertical-slot (*Pseudo*-$F_{3, 11} = 19.84$, $p < 0.001$), but not at the Hunters Creek vertical-slot (*Pseudo*-$F_{3, 10} = 0.57$, $p = 0.65$). Statistical tests of significance could not be carried out on data from the Tauwitchere rock ramp or adjacent Goolwa Barrage, as these sites were only sampled once each week; nevertheless, abundance varied substantially between months. Abundance at Hunters Creek was consistent between months, but typically increased throughout sampling and peaked in January at all other sites. Proportional increases in abundance were similar between sites with 7- to 10-fold increases in January relative to December (Figure 3-8a). Peak abundance for congolli in 2016/17 was detected at the Goolwa vertical-slot in January when >1,400 $fish.hr^{-1}$ were detected migrating upstream.

Similarly, the abundance of upstream migrating common galaxias was significantly different between months at the Goolwa vertical-slot (*Pseudo*-$F_{2, 8} = 4.22$, $p = 0.016$), Tauwitchere large vertical-slot (*Pseudo*-$F_{3, 11} = 5.02$, $p = 0.022$) and Tauwitchere small vertical-slot (*Pseudo*-$F_{3, 11} = 39.82$, $p < 0.001$), but not at the Hunters Creek vertical-slot (*Pseudo*-$F_{3, 10} = 2.77$, $p = 0.079$), whilst abundance also appeared to vary at the Tauwitchere rock ramp and adjacent Goolwa Barrage (Figure 3-8b). Abundance peaked at the Tauwitchere rock ramp and Tauwitchere vertical-slot in December, but at all other sites in January, with 2- to 35-fold increases in abundance relative to December.

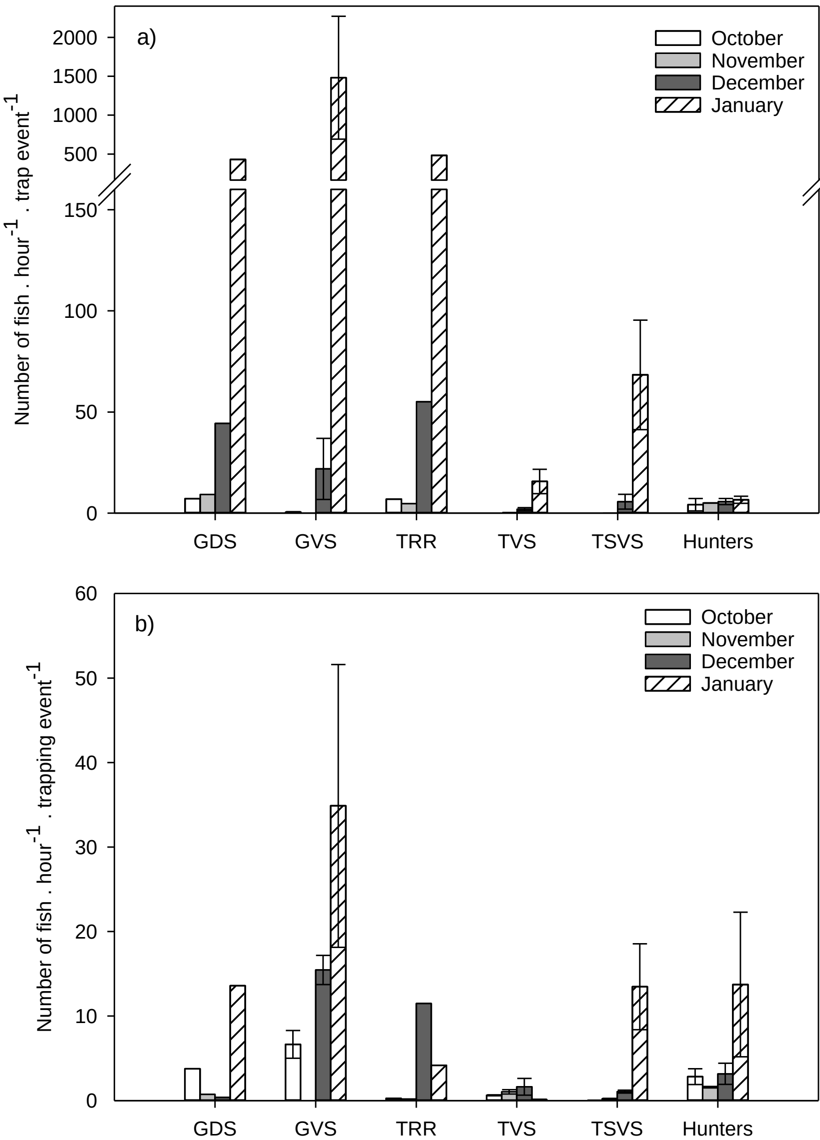

Figure 3-8. Relative abundance (number of fish.hour^{-1}.trap event^{-1}) of a) congolli and b) common galaxias at adjacent Goolwa Barrage (GDS), Goolwa vertical-slot (GVS), Tauwitchere rock ramp (TRR), Tauwitchere vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS) and Hunters Creek vertical-slot (Hunters) from October 2016–January 2017.

Below Tauwitchere Barrage (Tauwitchere rock ramp, large vertical-slot and small vertical-slot data combined) in October 2016, congolli ranged 33–132 mm TL, but the sampled population was dominated (~90%) by fish ranging 33–45 mm TL (Figure 3-9a). Whilst fish were not aged in 2016/17, fish of this size have previously been determined to represent a 0+ cohort (Bice *et al.* 2012). This cohort increased in length throughout the sampling period (November 2015: 22–

51 mm TL, December 2016: 30–55 mm TL and January 2016: 34–68 mm TL) and represented 70–90% of the sampled population during each month.

A similar pattern was evident below Goolwa Barrage (vertical-slot and adjacent Goolwa Barrage data combined) with the sampled population of fish ranging 28–149 mm TL and dominated by a YOY cohort (28–43 mm TL; ~50% of population) in October 2016 (Figure 3-9b). Growth of this cohort was evident through the following months, progressing to 35–43, 32–141 and 37–102 mm TL in November 2016, December 2016 and January 2017, respectively. This cohort remained dominant throughout sampling, comprising 50–92% of the population in all months.

Length-frequency distributions at Hunters Creek were similar to both Tauwitchere and Goolwa, with the exception of fewer fish >75 mm TL being sampled throughout the sampling season (Figure 3-9c). Sampled fish ranged 28–74, 32–144, 33–98 and 37–101 mm TL during sequential sampling events and the 0+ cohort represented >90% of the sampled population during all months.

Common galaxias ranged 25–113 mm TL at Tauwitchere in October 2016, but individuals 36–52 mm TL comprised ~82% of the sampled population (Figure 3-10a). As for congolli, whilst common galaxias were not aged in 2016/17, fish of this size have been determined to represent a 0+ cohort in previous years (see Bice *et al.* 2012). The 0+ cohort represented 55–94% of the sampled population in each sampling month.

At Goolwa in October 2016, the 0+ cohort of common galaxias ranged 41–60 mm TL and comprised ~77% of the sampled population (Figure 3-10b). Larger individuals within this range progressively comprised greater proportions of the population in subsequent months indicating growth of the 0+ cohort, whilst small individuals <35 mm remained present suggesting a persistent influx of young fish. The 0+ cohort remained dominant throughout sampling comprising >75% of the sampled population throughout sampling.

The length-frequency distributions for common galaxias at Hunters Creek in 2016/17 were similar to Tauwitchere and Goolwa, with the 0+ cohort (<60 mm TL) typically comprised 60–80% of the sampled population in all months (Figure 3-10c).

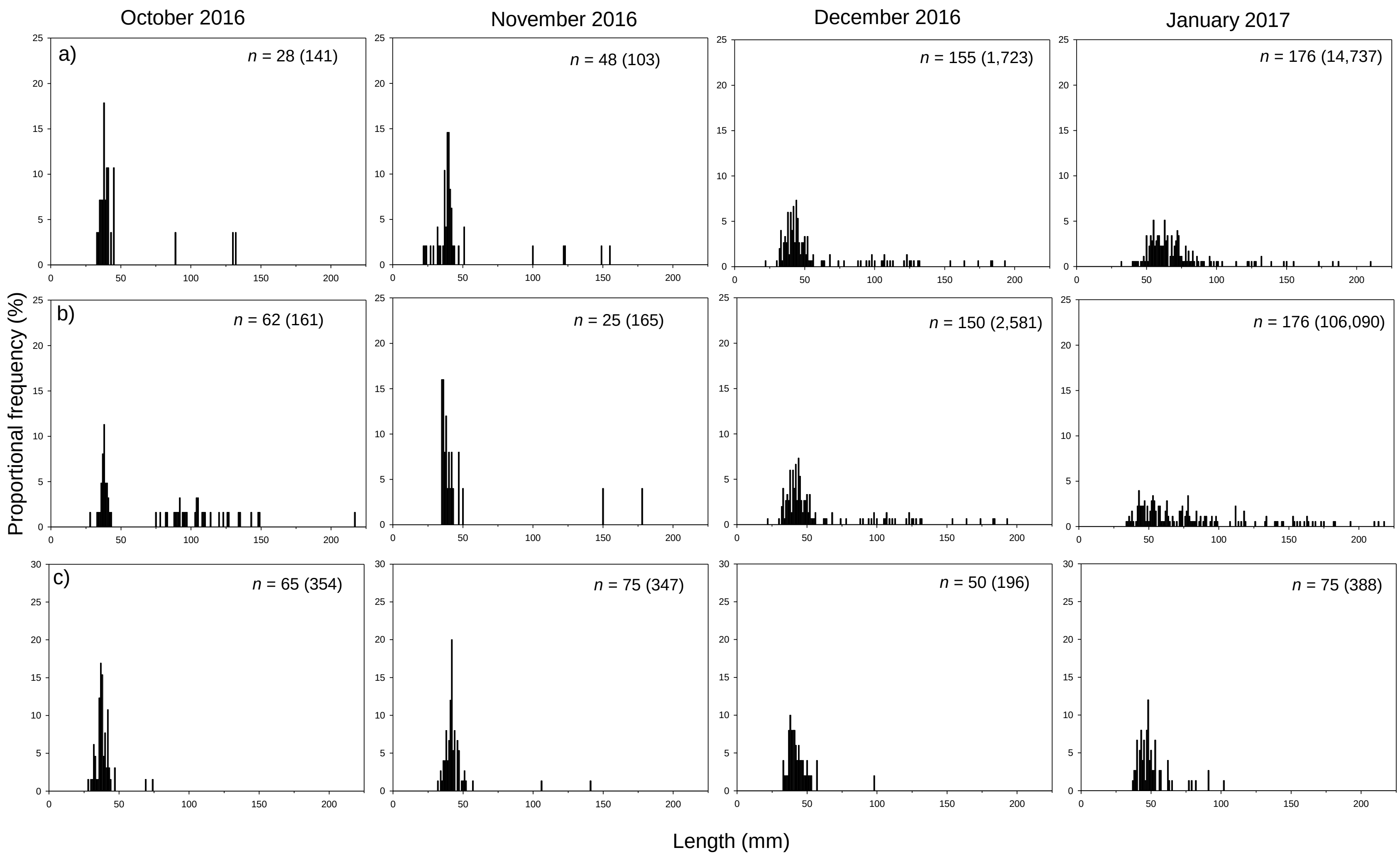

Figure 3-9. Monthly length-frequency distributions (total length, mm) of congolli sampled below a) Tauwitchere Barrage (rock ramp, large vertical-slot and small vertical-slot combined) b) Goolwa Barrage (vertical-slot and adjacent Goolwa Barrage combined) and c) at the entrance of the Hunters Creek vertical-slot from October 2016–January 2017. *n* is the number of fish measured and the total number of fish collected in each month at each site is presented in brackets.

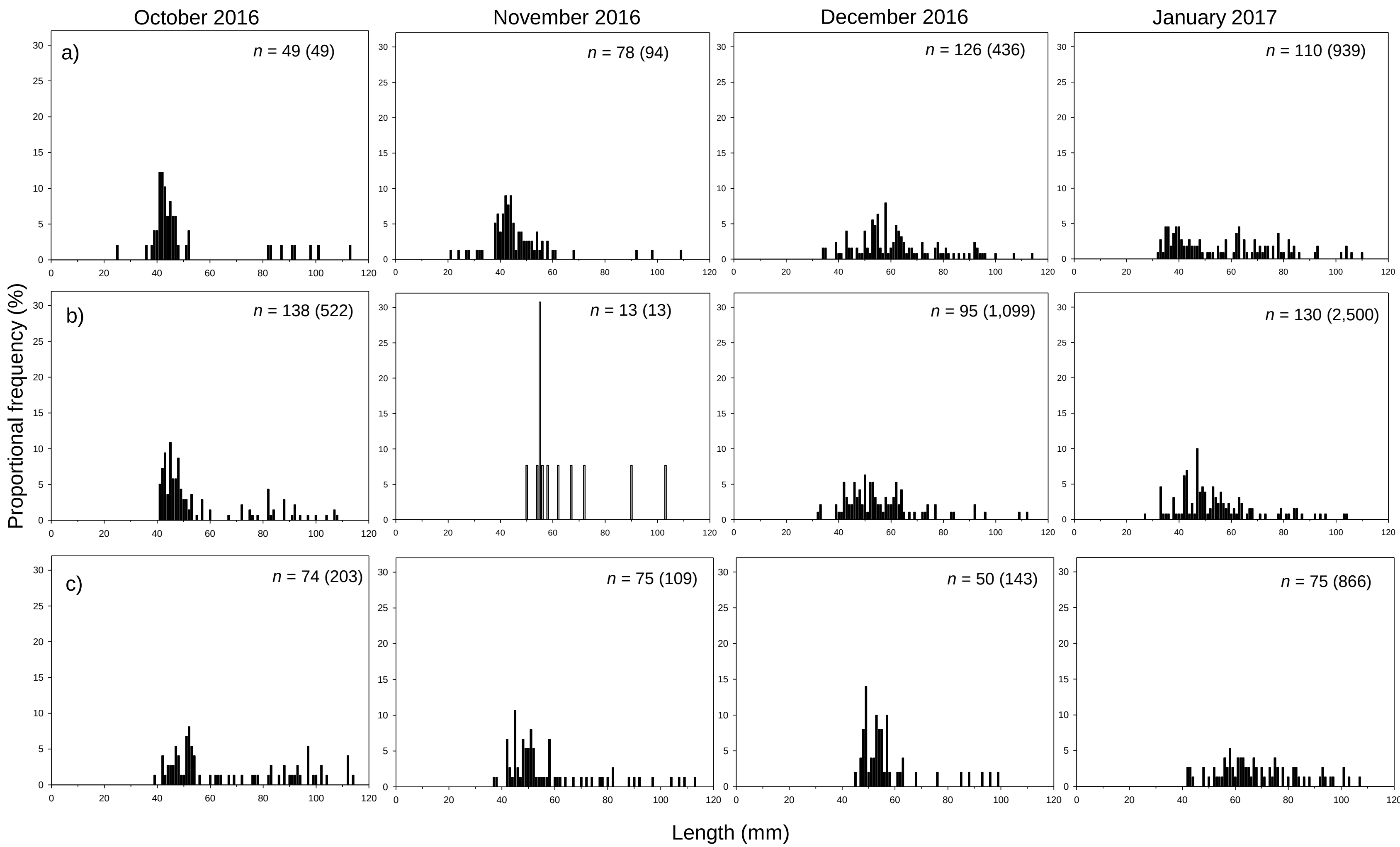

Figure 3-10. Monthly length-frequency distributions (total length, mm) of common galaxias sampled below a) Tauwitchere Barrage (rock ramp, large vertical-slot and small vertical-slot combined) b) Goolwa Barrage (vertical-slot and adjacent Goolwa Barrage combined) and c) at the entrance of the Hunters Creek vertical-slot from October 2016–January 2017. *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. Assessment of TLM condition monitoring targets

Target 1 and 2: Catadromous fish migration and recruitment

Comparison of the annual recruitment index (*RI*) against the predetermined reference value suggests that Target 1 was met for congolli in 2013/14, 2014/15, 2015/16 and 2016/17 (Figure 3-11a); however, the target was not met in 2006/07, 2007/08, 2008/09, 2009/10 and 2010/11. A similar pattern of variability in abundance of upstream migrating juveniles was evident for common galaxias; however, Target 2 was met in all years, with the exception of 2007/08, 2008/09, 2010/11 and 2016/17 (Figure 3-11b).

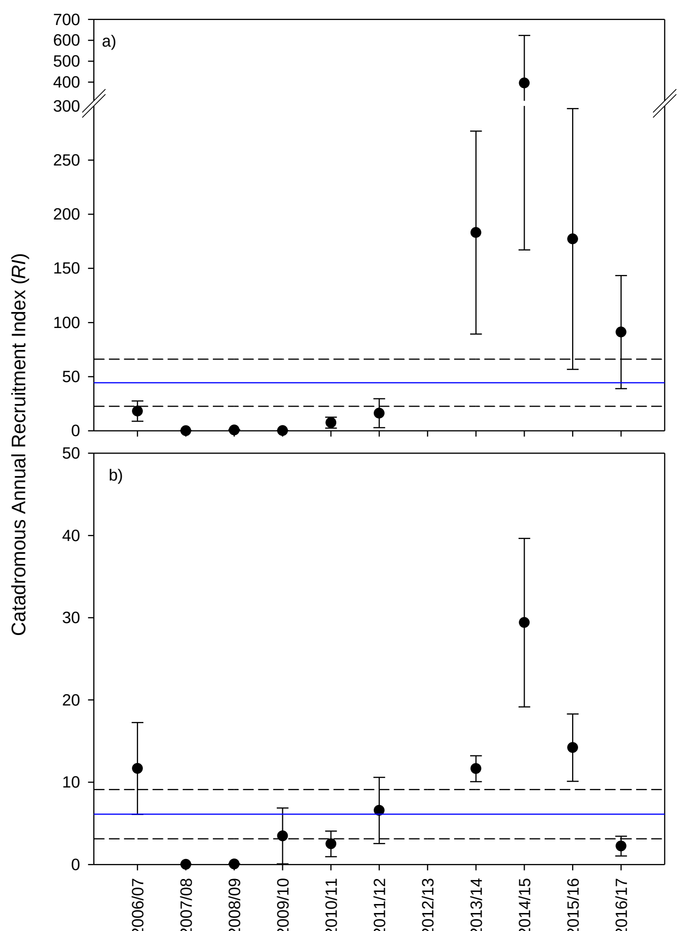

Figure 3-11. Catadromous annual recruitment index (*RI,* number of upstream migrating YOY.hour^{-1} ± half confidence interval for a) congolli and b) common galaxias from 2006/07 to 2016/17 (no sampling was conducted in 2012/13). The reference value is indicated by the blue line and half confidence intervals indicated by dashed lines.

Target 3: Anadromous migration

The migration index (*MI*) for short-headed lamprey was met in 2006/07, but not from 2007 to 2011; indeed no short-headed lamprey were sampled in these years (Figure 3-12). A slight increase in *MI* was observed in 2011/12, but not of a magnitude to meet the prescribed target, and no individuals have been sampled in the past four years (2013–2017). Pouched lamprey was only sampled from one site in 2006/07, resulting in low *MI* and failure to meet the target. Similar to short-headed lamprey, this was followed by absence from monitoring and failure to meet the target from 2007 to 2011. Individuals were subsequently sampled from four sites in 2011/12 and the target was met for this species. Individuals were sampled from one site in 2013/14 and were absent in 2014/15, resulting in failure to meet the target in both years. In 2015/16, pouched lamprey were detected at three sites, resulting in the target being met, however, the species was only sampled from one of the prescribed sites in 2016/17 (Goolwa vertical-slot) resulting in failure to meet the target. Nonetheless, single individuals were also sampled from the newly constructed vertical-slot fishway at Goolwa and the Boundary Creek small vertical slot during winter 2016. If these sites were included in metric calculation, *MI* for 2016/17 was ~0.5. Notably, *MI* is typically highest during years with specific winter monitoring.

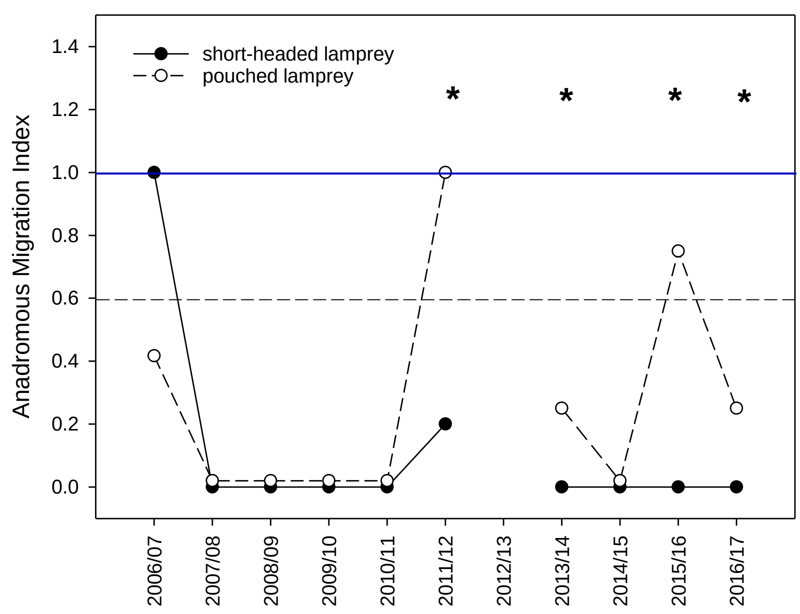

Figure 3-12. Anadromous migration index (*MI*) for short-headed lamprey (*open circles*) and pouched lamprey (*closed circles*) from 2006/07 to 2016/17 (no sampling was conducted in 2012/13). The blue line represents the reference value and dashed line indicates a 40% tolerance and level deemed to indicate target was met. * indicate years in which specific sampling for lamprey occurred during winter.

4. DISCUSSION

4.1. Fish assemblages

Inter-annual variation

From 2007–2010, a combination of drought and consumptive water use resulted in cessation of freshwater discharge to the Coorong, disconnection of the Lower Lakes and Coorong, and elevated salinities in the Coorong, to the detriment of a range of native flora and fauna (Kingsford *et al.* 2011). Nonetheless, 2016/17 represented the seventh consecutive year of continuous freshwater discharge to the Coorong and third high flow event (peak discharge >60,000 $ML.d^{-1}$) post the end of the Millennium Drought (late 2010), promoting connectivity between the Coorong and Lower Lakes, and persistence of a salinity gradient from brackish to marine in the Coorong estuary. The structure of fish assemblages was characteristic of a dynamic estuary under freshwater influence, with similarity to other high flow years (e.g. high abundances of freshwater species). Young-of-the-year (YOY) of catadromous species were abundant, albeit less so than in 2014/15 and 2015/16.

In 2016/17, 28 fish species, representing 19 families, were sampled at six sites immediately downstream of the Murray Barrages in the Coorong estuary. The fish assemblage consisted of a diverse range of life history categories including freshwater, diadromous, estuarine and marine species, with each represented by one or more species that was abundant (i.e. >20,000 individuals). This contrasts the depauperate fish assemblage during the extended period (2007–2010) of no freshwater discharge to the Coorong when marine species and some medium- to large-bodied estuarine species were dominant, and diadromous and freshwater species were absent or in low abundance (Zampatti *et al.* 2011a). The assemblage of 2016/17 exhibited similarities with the high flow years of 2010/11 and 2011/12, with the exception of certain freshwater species (i.e. redfin perch, flat-headed gudgeon and common carp) being sampled in greater abundance in 2010/11 (Zampatti *et al.* 2012). At most sites, the assemblages from 2016/17 were also statistically similar to those of 2013/14, 2014/15 and 2015/16 (Bice and Zampatti 2014, 2015, Bice *et al.* 2016), but there were slight decreases and increases of species richness of marine and freshwater species, respectively, in 2016/17 relative to 2015/16. Furthermore, total fish abundance increased substantially at several sites, relative to 2015/16. The assemblage of 2015/16 was similar to that of 2006/07 (a year of low discharge, 63 GL, and preceded by a year of low discharge in 2005/06, 770 GL), suggesting a potential trajectory towards an assemblage associated with consecutive years of low discharge, but 2016/17 has seen this trend cease, with a transition back towards a diverse abundant assemblage characteristic of high freshwater discharge.

Inter-annual variability in overall fish abundance is largely influenced by inter-annual fluctuations in the abundance of the marine estuarine-opportunist sandy sprat. This species is a small-bodied (typically <100 mm TL), pelagic, schooling clupeid, which is common in coastal bays and estuaries across southern Australia (Gaughan *et al.* 1996, Gomon *et al.* 2008). Whilst considered a marine estuarine-opportunist species, it exhibits a positive association with freshwater inflows to the Coorong, being caught in greatest abundance during years of freshwater flow (i.e. 2006/07 and 2010–2015, 2016/17) and lowest during years of low or zero freshwater inflow (2007–2010) (Zampatti *et al.* 2011, 2012, Bice *et al.* 2012, Bice and Zampatti 2014). Indeed, from 2011/12 to 2014/15, sandy sprat was the dominant species sampled, numerically comprising 72–92% of the catch downstream of the barrages (i.e. Tauwitchere rock ramp and adjacent Goolwa Barrage), but in 2015/16, coincident with declining flow, comprised <10% of the catch. In contrast in 2016/17, of 1,543,040 fish sampled from these two sites, 1,329,405 (~86%) were sandy sprat. Sandy sprat is zooplanktivorous and a recent study, utilising gut content and stable isotope analyses, has documented both the direct predation of freshwater zooplankton transported to the Coorong in freshwater discharge, and assimilation of organic matter of freshwater origin (Bice *et al.* 2016). Bice *et al.* (2016) proposed this trophic subsidy as a potential mechanism driving the abundance–discharge association for the species, which is consistent with observation of low abundance in 2015/16 and increased abundance in 2016/17. Sandy sprat is fundamental to trophic dynamics in the Coorong (Giatas and Ye 2016), particularly the Murray estuary and upper North Lagoon, where, contrary to the South Lagoon, it supplants small-mouthed hardyhead as the most abundant small-bodied fish (Ye *et al.* 2012). Increases in the abundance of sandy sprat are likely to have flow on effects to higher trophic organisms, including juvenile mulloway (Giatas and Ye 2015).

The influence of salinity on spatio-temporal variation in estuarine fish assemblage structure has been documented widely (Lonergan and Bunn 1999, Barletta *et al.* 2005, Baptista *et al.* 2010). Indeed the results of this study, from 2006–2017, 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 promoted 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, such as those present in the Murray estuary in 2006/07, 2011/12, 2013/14, 2014/15 and 2016/17 result in high species diversity, with a range of freshwater, diadromous, estuarine and marine migrant and straggler species present (Baptista *et al.* 2010). In contrast high salinities (e.g. marine and greater), such as those resulting from diminished freshwater inflows to the Coorong estuary from 2007–2010, result in decreased species diversity and an assemblage characterised by the loss of freshwater species and increases in marine species (Martinho *et al.* 2007).

Intra-annual spatial variation

In 2016/17, fish assemblages sampled at vertical-slot fishways were generally similar, with the exception of the Hunters Creek vertical-slot fishway. Differences among assemblages from the Hunters Creek fishway and other sites have been detected in previous years (e.g. 2014/15 and 2015/16) (Bice and Zampatti 2015, Bice *et al.* 2016) and are likely due to differences in habitat upstream and downstream of the fishways. Both upstream and downstream of the Hunters Creek causeway, aquatic habitat is characterised by small sheltered streams and wetlands, in contrast to the other fishways, which are situated on the barrages and characterised by open water habitats both upstream and downstream. During high discharge, salinities downstream of the Hunters Creek causeway are likely lower and less variable than at other sites. As such, several pelagic freshwater species (e.g. Australian smelt) and marine species are typically uncommon at Hunters Creek, whilst the assemblage is often dominated by YOY catadromous species (congolli and common galaxias). Furthermore, overall fish abundance is typically lower at Hunters Creek than the other sites, which likely reflects the lower relative discharge from this structure and subsequently, lower attraction of fish. Similarity among assemblages from all other fishways suggests spatial homogeneity in fish migration during the high flow conditions experienced in 2016/17.

Whilst not compared statistically, the fish assemblages sampled at the vertical-slot fishways and sites adjacent the barrages (i.e. Tauwitchere rock ramp and adjacent Goolwa Barrage) vary substantially. This variation reflects potential behavioural differences between species and the specificity of sampling locations at these sites. Sampling in the entrance of vertical-slot fishways typically collects fish in the process of undertaking ‘driven’ migrations between the Coorong and Lower Lakes, whilst sampling at sites adjacent to the barrages captures accumulations of such species but also, large numbers of species from estuarine and marine life history categories residing adjacent the barrages. As such, species richness and overall abundance are typically greatest at the sites adjacent the barrages (Zampatti *et al.* 2011, 2012, Bice *et al.* 2012). Indeed, species richness and overall fish abundance varied from 11 species at the Tauwitchere small vertical-slot and 3,965 individuals (<1% of all fish sampled in 2016/17) at the entrance of the Hunters Creek vertical-slot to 22 species and a total of 1,025,009 individuals (~57% of all fish sampled in 2016/17) at the Tauwitchere rock ramp.

4.2. Abundance, recruitment and assessment of ecological targets for diadromous fish

Catadromous species

Total numbers and relative abundances of congolli in 2016/17, were among the highest since the inception of this monitoring program in 2006/07 (Zampatti *et al.* 2010, 2011, Bice *et al.* 2012, Bice and Zampatti 2014). Indeed, congolli was the third most abundant species and when excluding the highly abundant sandy sprat, represented 28% of all remaining fish sampled. Total number (*n* = 126,986) and standardised abundance at most sites had increased from 2015/16 (*n* = 76,729), but remained less than recorded in 2014/15 (*n* = 212,284). Common galaxias was also sampled in moderate abundance, relative to most previous sampling years, but a decline in total number (*n* = 6,973) and standardised abundance at several sites was observed relative to 2016/17 (*n* = 22,733) and 2014/15 (*n* = 30,367). Whilst no ageing of fish was conducted in 2015/16, length-at-age data from previous years (Zampatti *et al.* 2010, 2011, Bice *et al.* 2012), indicate that typically >80% of all individuals sampled for both species, in each month, were newly recruited YOY.

Substantial variability in the abundance of congolli and common galaxias was observed among months in 2016/17, with both species typically increasing in abundance at sites throughout sampling and peaking in January. Peak abundance of congolli in January has been detected in some previous years, but abundance in December is also often comparably high (Bice and Zampatti 2014, Bice *et al.* 2016). Furthermore, abundance of common galaxias in the past has typically peaked between October and December (Zampatti *et al.* 2010, Bice and Zampatti 2014, 2015). Total barrage discharge from late-October to early-January was often >50,000 ML.day^{-1}, which comprises large releases from all barrages, predominantly ‘fresh’ salinities downstream and conditions under which attraction to fishway entrances may be limited (Bice *et al.* 2017). Conversely, immediately preceding and during sampling in January, total barrage discharge was typically 6,000–8,000 ML.day^{-1} and salinity was gradually increasing. Such conditions are more conducive to attraction of fish to fishway entrances (Bice *et al.* 2017). As such, intra-annual variability in the abundance of upstream migrant catadromous fishes was likely a result of prolonged estuarine residence with reduced salinity and potentially difficulty in locating fishway entrances during high flows. Importantly, this intra-annual variability in abundance may influence calculation of condition monitoring metrics and assessment of ecological targets.

Given high abundance of newly recruited YOY congolli, the annual recruitment index in 2016/17 was similarly high and the condition monitoring target was achieved. Nonetheless, the recruitment index target for common galaxias was not met despite moderate overall abundance in 2016/17. This was due to a combination of intra-annual variability in abundance and the defined period over which the annual recruitment index is calculated. For common galaxias, the annual recruitment index, and associated reference value, are calculated for the period October–December, as this three-month period has typically encompassed the peak upstream migration period in past years. In the case of 2016/17, abundances were low in October and November and peaked in January, leading to an overly deflated estimate of the recruitment index. Thus, despite the index not matching or exceeding the prescribed reference value, we suggest recruitment in 2016/17 was of a level that satisfies the overarching Icon Site ecological objective, and highlights the importance of thorough interpretation of ecological target metrics against raw data.

Successful recruitment of catadromous species in 2016/17, relative to most preceding years, was likely a result of a combination of two mechanisms: 1) hydrological connectivity between freshwater, estuarine and marine environments throughout 2016/17 and subsequently, favourable conditions for migration, spawning and survival of larvae/juveniles under brackish salinities (Whitfield 1994, Gillanders and Kingsford 2002); and 2) relatively high spawning output as a result of high abundance of reproductively mature adults. Recruitment and subsequent YOY abundance steadily increased from 2010/11 to 2014/15, following reinstatement of freshwater discharge and high levels of connectivity. A trend of increasing abundance of YOY over this period likely reflected cumulative benefits of multiple consecutive years of enhanced connectivity. The lack of connectivity and reduced recruitment of congolli and common galaxias from 2007–2010 may have resulted in a depleted population of reproductively mature adults. As such, while recruitment was enhanced following the resumption of freshwater flow in 2010/11, the number of juveniles produced may have been limited by the adult spawning biomass. Congolli typically mature at 3–4 years of age (Hortle 1978) and thus, the adult spawning population post–2014 was likely abundant and comprised of fish that recruited and migrated into freshwater habitats from 2010/11 to 2014/15. These results highlight the importance of providing freshwater discharge to the Coorong on an annual basis and the influence of consecutive ‘favourable’ years on population dynamics of diadromous fishes.

Anadromous species

No short-headed lamprey were sampled in spring/summer 2016/17, but eight pouched lamprey were sampled across winter (*n* = 7) and spring/summer (*n* = 1) monitoring. Based on criteria for calculation of the annual migration index for pouched lamprey, the Icon Site ecological target for this species was not achieved in 2016/17. Nonetheless, two individuals were sampled at new fishways that were not included in the original metric calculation that would have raised the annual migration index from 0.25 to 0.47. Whilst this still results in failure to meet the ecological target, we suggest calculation of the annual migration index includes data from all fishways sampled during winter in future years. The target was not met for short-headed lamprey, but sampling may not have been appropriately timed for the detection of short-headed lamprey.

Whilst the migration of pouched lamprey and short-headed lamprey at the Murray Barrages, and more broadly in the MDB, is poorly understood, a model for the movement of these species is beginning to emerge. Capture of pouched lamprey in all years in which specific winter monitoring (June–August) has been undertaken, as well as knowledge of migration from other river systems (McDowall 1996), suggests winter is the key upstream migration period for this species. Alternatively, we suspect peak upstream migration of short-headed lamprey at the Murray Barrages likely occurs slightly later, in late winter–early spring, which is consistent with peak migration in other systems in southeastern Australia (McDowall 1996). This period is typically not sampled during specific winter monitoring or annual spring/summer sampling, which generally commences from mid-October.

Assessment of the status of lamprey species is reliant on sampling during specific periods. As such, we propose that in years when monitoring is conducted from June to August, a confident assessment of pouched lamprey status may be achieved. Nonetheless, rigorous assessment of the status of short-headed lamprey likely requires sampling from August to November. Knowledge of the key migration periods and sampling regime in any given year must be considered when assessing the achievement of ecological targets related to lamprey.

4.3. Implications for management and operation of the barrages and fishways

Data collected from this project from 2006–2017 (Bice *et al.* 2007, 2012, 2016, Jennings *et al.* 2008, Zampatti *et al.* 2010, 2012, Bice and Zampatti 2014, 2015) and related projects (Jennings *et al.* 2008, Zampatti *et al.* 2011, Bice *et al.* 2016, 2017) provide fundamental knowledge to inform the operation of the Murray Barrages and associated fishways to aid in the conservation and restoration of native fish populations in the MDB. Indeed specific periods of peak migration can be identified for different life stages of diadromous species, which require movement between freshwater and marine/estuarine environments to complete their lifecycle. These periods should be prioritised for freshwater releases and fishway operation.

Newly recruited YOY congolli and common galaxias migrate upstream during spring/summer, but there are often subtle differences in the timing of peak migration. Peak migration of congolli and common galaxias in 2016/17 occurred during January, consistent with previous years for congolli, but later than usual for common galaxias (i.e. 2006/07 and 2010–2015) (Bice *et al.* 2007, 2012, Zampatti *et al.* 2012, Bice and Zampatti 2015). Timing of peak upstream migration in 2016/17 was potentially influenced by hydrology and barrage operation, and highlights the importance of fishway operation on the descending limb of hydrographs following high discharge events. Whilst both of these species typically migrate upstream in greatest numbers during specific months, migrations can generally occur over a protracted period from September–March.

Adult congolli and common galaxias must also migrate downstream to spawn. The key downstream migration period for adult congolli occurs from June–August (Zampatti *et al.* 2011). The downstream migration of adult common galaxias has not been directly observed in the Lower Lakes and Coorong, but the presence of reproductively active fish (i.e. 'running ripe') near the barrages in winter (SARDI unpublished data) suggests peak downstream migration also occurs at this time. Additionally, analyses of the otolith microstructure of newly recruited upstream migrants suggests peak spawning activity of congolli in July–August and common galaxias in August–September (Bice *et al.* 2012). The provision of open 'barrage gates', rather than just open fishways, is likely important over this period. Vertical-slot fishways, like those present at the Murray Barrages, are designed to facilitate upstream migrations and thus, are generally poor at facilitating downstream migrations (Clay 1995, Larinier and Marmulla 2004). Rates of downstream migration are likely to be far greater through open barrage gates.

Peak upstream migration of pouched lamprey also appears to occur during winter, with peak migration of short-headed lamprey likely extending into spring. However, this species is rare and there is limited empirical data on timing of migration. Furthermore, timing of downstream migration of newly metamorphosed juveniles in the region is unknown, but in other regions also occurs in winter (McDowall 1996).

Periods of peak migration for diadromous species indicate important seasons and months for barrage and fishway operation, but prioritising locations (i.e. specific barrages) for freshwater releases, in relation to fish migration, is more difficult. Whilst there were specific differences in the abundance of upstream migrating congolli and common galaxias between sites, overall, abundances downstream of Goolwa and Tauwitchere Barrages were not substantially different. YOY catadromous fish are likely to respond to salinity and olfactory cues from freshwater discharge during their upstream migration, and moderate–high abundances at Goolwa and Tauwitchere potentially reflect consistent freshwater discharge, and thus, attraction at both of these locations during the study period. In support of this hypothesis, in 2009/10, upstream migrating common galaxias were moderately abundant at the Goolwa vertical-slot, but absent from sites at Tauwitchere Barrage (Zampatti *et al.* 2011). No freshwater was discharged from Tauwitchere in 2009/10 but small volumes were released at Goolwa during navigation lock operation, which occurred in association with the Goolwa Channel Water Level Management Plan (Bice and Zampatti 2011). This suggests that these species migrate and accumulate where freshwater is being discharged and thus, the actual release location (i.e. barrage) may not be of major importance, but rather releases should be prioritised to barrages where effective fish passage is facilitated.

New fishways were recently constructed on Goolwa, Mundoo, Boundary Creek and Ewe Island Barrages, with a further fishway planned for Tauwitchere Barrage. A subset of these fishways have been assessed for biological effectiveness and all are successfully passing YOY common galaxias and congolli, among other species (Bice *et al.* 2017). As such, releases should currently be prioritised to these barrages, and in particular the fishways and gates immediately adjacent the fishways. Upon completion of all assessments of fishways effectiveness (two remain) and determination of differences in species utilisation between fishways, an operations plan could be developed to inform the order of closing/opening fishways during times of water scarcity, to maximise fish passage benefits.

Operating the barrages and their respective fishways in a manner that enhances fish migration is fundamental to the sustainability of fish populations, particularly diadromous species in the MDB. Suggestions for future barrage and fishway operation, considering fish migration, are summarised below:

1) Freshwater discharge and operation of all fishways on Goolwa and Tauwitchere Barrages should occur, at a minimum, from June–January to: 1) allow for downstream spawning migrations of congolli and common galaxias and upstream migrations of pouched lamprey from June to August; 2) allow for upstream migrations of short-headed lamprey from August to November; and 3) allow for the upstream migrations of YOY congolli and

common galaxias (and other species) from October to January. Where possible, attraction flow should be provided from barrage gates immediately adjacent to each fishway. If discharge is being decreased at Tauwitchere, gates adjacent the small vertical-slot fishway should be the last to 'shut-down' as this fishway is the most effective at passing small-bodied fishes.

2) In addition to the operation of fishways from June to August, barrage gates should be opened on each of these barrages to facilitate downstream migrations of catadromous species and provide attraction flow for upstream migrations of anadromous species. Barrage gates are likely to far better facilitate downstream movement than fishways.
3) Fishways should remain open for at least two months following the complete closure of barrage gates to facilitate the return migrations of freshwater fishes (and other species). Catches of freshwater (e.g. Australian smelt, bony herring and flat-headed gudgeon) and diadromous fish were greater in January than preceding months in 2016/17, following decreased barrage discharge and increasing salinity within the Coorong.
4) Following the construction and assessment of the final new fishways on the Murray Barrages, the knowledge generated under the current project, and related studies, should be incorporated into the Barrage Operating Strategy.

5. CONCLUSION

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, among other species, in the Coorong estuary. During 2006–2010, the cessation of freshwater discharge to the Coorong estuary led to increases in salinity, a loss of fish species diversity and reduced abundances, particularly in the case of diadromous and estuarine species. Alternatively, 2016/17 represented the third high flow event since the inception of the monitoring program, and followed several consecutive years of consistent low-volume freshwater inflows. Fresh to brackish salinities prevailed in the Coorong estuary and fish assemblages were typical of a spatio-temporally dynamic temperate estuary under the influence of freshwater flow.

Abundances of catadromous congolli and common galaxias remained high, albeit less so than 2014/15, with the majority of individuals sampled representing newly recruited YOY. Whilst no fish were aged in 2016/17, high levels of connectivity and freshwater inflows throughout 2016/17 likely facilitated protracted spawning seasons and provided conditions conducive to larval/juvenile survival and subsequently recruitment. The species-specific recruitment target was met for congolli, but not common galaxias. Nevertheless, this was likely an artefact of atypical intra-annual variability in abundance, rather than diminished recruitment and abundance. As such, the results of the current study suggest the revised ecological objective (F-1) – '*Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong'* (Robinson 2014), and more specifically (a) – '*promote the successful migration and recruitment of catadromous fish species in the Lower Lakes and Coorong',* was achieved in 2016/17. The objective (b) – '*promote the successful spawning migration of anadromous fish species in the Lower Lakes and Coorong',* was not achieved for pouched lamprey or short-headed lamprey, in 2016/17.

The current project has contributed to a greater understanding of the dynamics of fish assemblages in the Coorong in association with variable freshwater discharge. Such data will form a basis for determining the status and trajectories of fish assemblages and populations in the Coorong estuary into the future.

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