Fish Movement and Recruitment in the Coorong and Lower Lakes: 2007/08 Progress Report

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Table of Contents

List of Figures

List of Tables

1. Executive Summary

Several fishways have recently been constructed on the Murray barrages to reinstate connectivity between the Coorong and the Lower Lakes of the River Murray. The fishways facilitate fish movement between estuarine and freshwater environments, whilst efficiently delivering environmental flows to the Coorong. Currently, there are no specific guidelines for environmental water releases through the barrages and fishways to maintain estuarine conditions and inturn maximise the ecological benefits of freshwater inflows. To address these knowledge gaps a three-year project was initiated in August 2006, investigating spatial and temporal variation in fish movement and recruitment. This report details findings from the second year (2007/08) of this project.

Critical changes in freshwater flow regimes to the Coorong were observed between sampling seasons. Low volumes of freshwater delivered through the Murray barrage fishways in 2006/07 attracted a suite of freshwater and estuarine/marine fish species, facilitating spawning, recruitment and upstream migration of young-of-the-year (YOY) and adult diadromous species. These releases created and maintained estuarine conditions below the barrages.

Fishways were closed in 2007/08 as drought continued within the Murray-Darling Basin (MDB) and water levels in the Lower Lakes decreased. Leakage through the barrages provided attraction flows, directly above and below Tauwitchere barrage, depending on headloss conditions. Sites were sampled fortnightly between September and January to identify patterns in fish movement between the Lower Lakes and Coorong.

A total of 177,093 fish representing 33 species were sampled from six sites at and around the Tauwitchere and Ewe Island barrages in 2007/08. Fish assemblages varied spatially. The assemblage observed upstream of Tauwitchere barrage was characterised by high abundances of freshwater and estuarine species, including common galaxias. In contrast, the assemblage downstream of Tauwitchere barrage was characterised by several marine species and a higher relative abundance of congolli.

Fish assemblages differed between years. Samples downstream of Tauwitchere barrage in 2006/07 were characterised by diadromous species, common galaxias, congolli and short-headed lamprey, whilst assemblages in 2007/08 were characterised by the opportunistic marine species, Australian salmon, Australian herring, Australian anchovy and blue sprat.

A 96% and 99% decline in the abundance of migrating YOY common galaxias and congolli was observed between seasons downstream of Tauwitchere barrage. Common galaxias adapted flexible spawning and recruitment strategies to utilise estuarine conditions above the barrage. However, the physical barrier created by Tauwitchere barrage appeared to prevent migrating adult congolli from reaching the estuary to spawn and together with a lack of estuarine conditions may have contributed to the absence of recruits in 2007/08.

No adult lamprey were sampled attempting to migrate at fishways or leakages along the barrages. In comparison, in 2006/07 with freshwater inflows through the fishways, 41 individual lampreys from two species were sampled undertaking upstream spawning migrations.

Mulloway and black bream were sampled below Tauwitchere and Ewe Island barrages in 2007/08, yet numbers were lower than in 2006/07. No YOY black bream were sampled in 2007/08, whereas in 2006/07, a small number of recruits were sampled from Goolwa and Tauwitchere barrages in association with low freshwater inflows. The presence of mulloway and black bream in 2006/07 coincided with periods of regular reverse flow between the Coorong and Lower Lakes in late summer.

Cessation of freshwater discharge and fishway operations in 2007/08 significantly reduced the abundance and diversity of freshwater and estuarine dependant species in the Coorong downstream of Tauwitchere barrage. Of note was the decline in abundance of diadromous fishes, and increases in the abundance of marine opportunists. Elevated salinities exposed an estuarine adapted ecosystem to predominantly marine conditions and an increasingly hypersaline environment.

2. Background and Introduction

As part of the Murray-Darling Basin Commission's 'Native Fish Strategy' (MDBC 2006), a program is being undertaken to install fishways on all main-channel weirs and barrages of the River Murray in order to re-instate connectivity from Lake Hume to the sea (Barrett and Mallen-Cooper 2006). This has included the installation of three experimental fishways on the Murray barrages, with further fishway construction planned for key sites.

Construction of experimental fishways at the barrages primarily facilitates fish passage between estuarine/marine and freshwater habitats. A secondary benefit is the efficient delivery of environmental flows to the Coorong to enhance key ecological processes (DWLBC 2008). In response to critical drought, the barrages have remained closed since 2006, with the fishways providing the only significant delivery of freshwater or connectivity between the Coorong and Lower Lakes.

At present there is very little information to describe the requirements of fish communities in the Coorong and Lower Lakes and in particular fish species that move between the two environments. Fishway assessments have described migratory fish communities over relatively short and fragmented time scales, with a greater focus on optimising fishway performance than quantifying ecological processes (Stuart *et al.* 2005; Jennings *et al.* 2008). Consequently, there is a paucity of ecological information to inform management decisions guiding freshwater releases through the barrages and fishways. Furthermore, there is little data on the link between freshwater inflows and the spawning and recruitment of fish species in the Coorong (Molsher *et al.* 1994; Arthington and Marshall 1999; Pellizari 2002).

This project investigates the migration and recruitment ecology of freshwater, diadromous and estuarine fish species at the interface between the Coorong and the Lower Lakes. The fishways are being used as ready-made sampling tools for capturing fish attempting to move between the Coorong and Lower Lakes.

The specific aims of the project are to:

- determine the species composition, and spatial and temporal variability of fish assemblages attempting to move between the Coorong and Lower Lakes via the barrage fishways;
- investigate the ecological processes (e.g. spawning and recruitment) of fish in response to freshwater inflows to the Coorong through length frequency analysis and ageing by examination of otoliths;

- utilise the above data to inform barrage and fishway operation, including timing and location of freshwater releases.

This progress report represents the second year of a three-year project funded by the Murray-Darling Basin Commission (MDBC) Environmental Works and Measures program. Data collected will contribute to the assessment of several interim ecological targets in the Lower Lakes Coorong and Murray Mouth Environmental Management Plan (DWLBC 2008), including increased fish passage for diadromous fish, and increased spawning and recruitment of estuarine fish. Sites below Tauwitchere barrage sampled in 2006/07 were again sampled in 2007/08. However, with the fishways shutdown and zero inflows to the Coorong, objectives in 2007/08 were broadened to document the response of fish to unprecedented (since river regulation) drought conditions. This work focused on:

- the response of migratory fish communities, specifically diadromous fishes to drought conditions. In particular, the effective isolation of freshwater and estuarine/marine habitats that are considered essential for successful spawning and recruitment;
- an investigation of fish community structure, abundance and recruitment above Tauwitchere barrage in response to localised reverse estuarine conditions;
- a comparison of fish community structure, abundance and recruitment between flow and non-flow years below Tauwitchere barrage.

2.1. Study site

The Murray-Darling River system discharges into a shallow expansive terminal lake system, comprised of Lakes Alexandrina and Albert before flowing into the Coorong and finally the Southern Ocean via the Murray Mouth (Figure 1). The Coorong is a narrow (2-3 km wide) estuarine lagoon running southeast from the river mouth and parallel to the coast, for ~140 km. The region was designated a Wetland of International Importance under the RAMSAR convention in 1985, based upon it's unique ecological character and importance to migratory wading birds (DEH 2000). In addition, it has been designated as one of six 'Living Murray Icon Sites' in the Murray Darling Basin (MDB) based upon its unique ecological qualities, hydrological significance, cultural and economic values (DWLBC 2008).

In the 1940's, five tidal barrages with a total length of 7.6 km, were constructed to prevent saltwater intrusion into the Lower Lakes and maintain stable freshwater storage for water extraction (Figure 1). The construction of the Murray Barrages dramatically reduced the extent of the Murray estuary, creating an impounded freshwater environment upstream and an abrupt ecological barrier between marine and freshwater habitats. Pool level upstream of the barrages is regulated for most of the year at an average of 0.75 m AHD (Australian Height Datum). Seiche (short term water level changes caused by wind stress) can cause this water level to vary by as much as 0.6 m.

Water level fluctuations below the Murray barrages are dynamic and complex. The behaviour of tides is influenced directly by sedimentation and in particular water exchange through the Murray Mouth. Since the construction of the Murray Barrages tidal exchange has been reduced by an estimated 87-96% (Harvey 1996), significantly impacting on the hydrodynamic and littoral transport systems within the estuary. Water level fluctuations are also influenced by freshwater inflow and local meteorological conditions (DWLBC 2008).

Following the construction of the barrages there has been an increased frequency of zero freshwater inflow to the estuary and this has contributed to a reduction in estuary depth, hyper-marine salinity and lower than average dissolved oxygen levels, due to reduced tidal incursion and inadequate freshwater flushing (Geddes 1987; Walker 2002). Typically salinity ranges from normal marine levels near the Murray Mouth to hyper-marine at the lower end of the Southern Lagoon (Geddes and Butler 1984). In the absence of controlled freshwater releases, estuarine conditions are restricted to the region directly below the barrages due to leakage through the barrages and through a complex series of island wetlands.

Exacerbating this, the MDB is experiencing ongoing drought and river flows are among the lowest in recorded history. Over allocation of existing water resources for irrigation and human demands upstream has seen little or no water available for environmental flows at the Lower Lakes since late 2006. The Lower Lakes are now at critical low water levels and freshwater and marine habitats have become effectively isolated as Lake Alexandrina contracts. In the absence of freshwater inflows to counteract sand deposition, complex sandbars formed across the Murray mouth in 2002, which effectively isolated the remaining Coorong estuary from the Southern Ocean. Since this time the implementation of a dredging program to artificially keep the Murray mouth from closing has allowed some tidal exchange within the system to maintain water quality and movement.

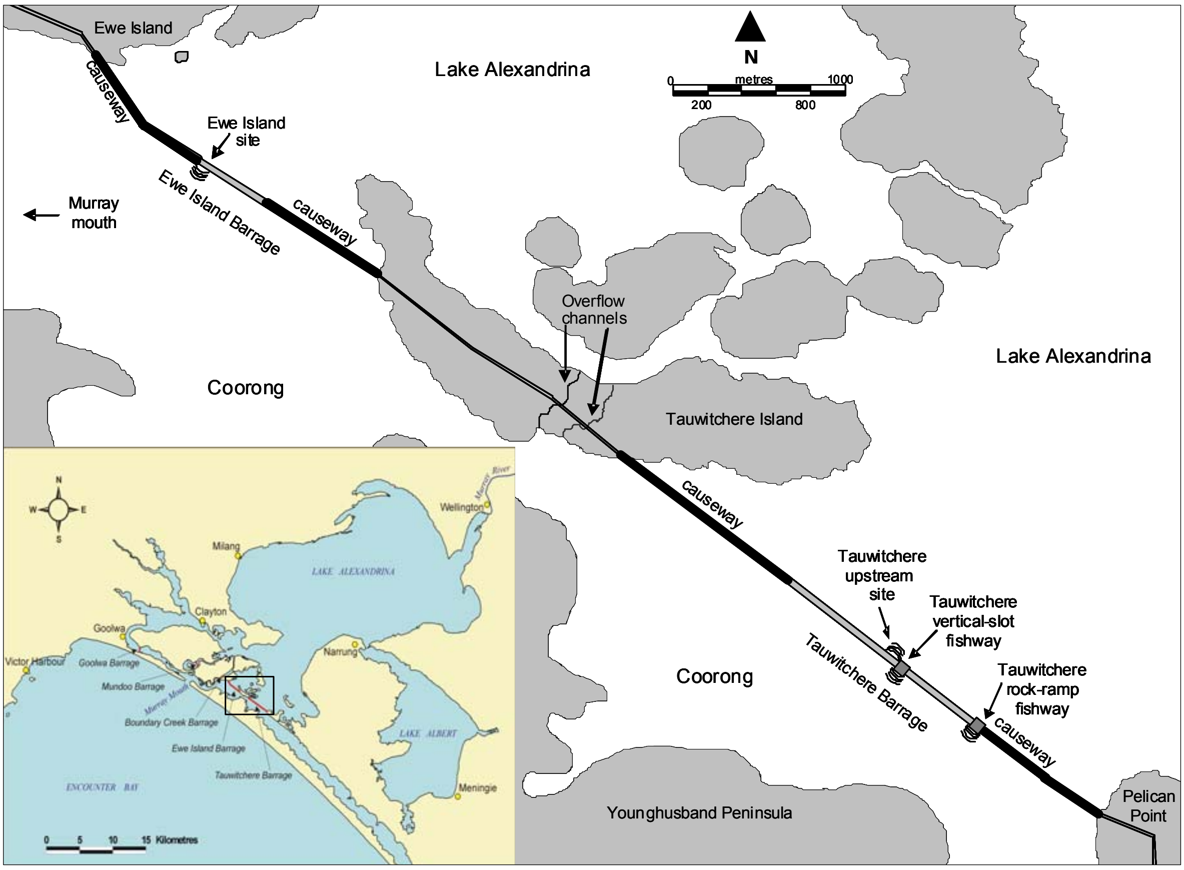

Figure 1. (inset) Coorong and Lower Lakes, showing the location of the five tidal barrages. Main map of Ewe Island and Tauwitchere barrages showing sampling sites upstream and downstream of the barrages.

2.2. Diadromous fishes

Diadromous fishes are migratory species that move between freshwater and saltwater at specific stages of their life cycle and include, freshwater spawning marine species (anadromous) and saltwater spawning freshwater species (catadromous). Due to their estuarine dependency, diadromous species can act as important indicators to the health and function of estuary systems (Bortone 2005). These species have suffered severe declines in abundance and distribution worldwide due in part to the installation of regulatory structures which act as migration barriers, altered flow regimes and highly modified habitats (Cowx and Welcomme 1998; Porcher *et al.* 2002; Lintermans 2007). Six Diadromous species have been recorded historically from the Coorong, Lower Lakes and further upstream in the River Murray (Higham *et al.* 2002; Stuart *et al.* 2005). This number has declined since construction of the barrages and today only four species are recorded, two rarely and two currently under threat from drought conditions, these include;

2.2.1 Common galaxias

Common galaxias are arguably the worlds most widespread freshwater fish being found in South-eastern and South-western Australia, New Zealand, South America and the Falkland, Chatham and Lord Howe Islands (Lintermans 2007). Riverine populations of common galaxias typically exhibit marked catadromy, nevertheless, in Australia, some land-locked lake populations complete their lifecycle wholly within freshwater (Pollard 1971). The lifecycle of catadromous populations involves a downstream spawning migration of adult fish, tide-dependent spawning in estuaries, extra-aquatic egg development, a marine larval stage and a post-larval upstream migration (Pollard 1971).

2.2.2 Congolli

Congolli are a catadromous species endemic to south eastern Australia (Eckert and Robinson 1990). Barriers, such as the Murray barrages, and regulation of flows are recognised as key threats to this species, once abundant in the lower Murray, Lakes and Coorong (Evans 1991; Lintermans 2007). Little is known of the ecology or reproductive biology of this species in the MDB or more broadly across its range (Lintermans 2007). However, adults are thought to undergo downstream spawning migrations from freshwater habitats into coastal estuaries in autumn and winter, followed by a corresponding upstream migration of YOY fish in spring and summer (Hortle 1978).

2.2.3 Lamprey

Both short-headed and pouched lamprey are anadromous species, exhibiting a freshwater larval stage, metamorphosis into non-parasitic juveniles, down-stream migration of young adults and marine residence, followed by a return upstream spawning migration of adults (Morgan *et al.* 1995). In the MDB adults have been recorded to migrate over 2000 km upstream to spawn. Obstruction of migratory pathways has potentially resulted in declines in both lamprey species in the MDB (Barrett 2004). Now rare, in the past large spawning migrations have been observed in the lower Murray at barriers to fish movement such as barrages and weirs (Wedderburn *et al.* 2003).

3. Methods

3.1. Fishway location and design

Experimental fishways have been built at three locations on the Murray barrages (Figure 1). In 2004, two fishways were constructed at the Tauwitchere barrage. A vertical-slot fishway designed to pass large-bodied fish (>150 mm TL) was constructed approximately halfway along the barrage, whilst a rock-ramp fishway was built at the south-eastern end to compliment the vertical-slot by providing passage for small-bodied fish (<150 mm; Mallen-Cooper 2001). The vertical-slot consists of two pools (2.30 m long x 3.96 m wide) and is designed for a maximum water velocity of 1.98 $m.s^{-1}$ and a discharge rate of ~ 31 $ML.d^{-1}$ at median flows (Mallen-Cooper 2001). The rock-ramp is designed to an overall longitudinal grade of 1:27 and to be operational for the upper 0.89 m (89%) of the tide (SKM 2002). The exit sill shuts off flow to the rock-ramp at a lake level of 0.65 Australian height datum (AHD).

A partial-depth vertical-slot fishway, also designed to pass large bodied fish (>150 mm TL), was completed at the Goolwa barrage in 2005, consisting of three cells 2.57 m long x 3.58 m wide and vertical-slots 0.3 m in width. This fishway was designed to operate with a maximum water velocity of 2.0 $m.s^{-1}$ and a discharge rate at median flows of 40 $ML.d^{-1}$.

3.2. Fish community sampling

Vertical-slot fishways were sampled at the entrance to capture fish attempting to migrate upstream. Both vertical slot fishways were designed to facilitate the passage of large bodied fish and as such had design hydraulics that exceeded the swimming abilities of most small-bodied fish (<150 mm). To mitigate this and enable small-bodied fish to enter the fishways head loss at the entrance was reduced to between 0 and 80 mm. This reliably enabled fish as small as 17 mm to enter the fishways.

No freshwater was discharged through the fishways in 2007/08. As a consequence, the entrance of the Tauwitchere vertical-slot fishway was only sampled for a short period (September–October) to allow comparison with data collected in 2006/07. Additional sites were selected for sampling at Tauwitchere and Ewe Island barrages. At Ewe Island, leakage through the western abutment gate provided freshwater attraction flow during positive headloss conditions and allowed assessment of the migratory fish community (Figure 1.). No trapping was undertaken at the Goolwa vertical-slot fishway due to restricted access to the barrage.

During reverse flow conditions at Tauwitchere barrage, saltwater incursion was evident at several locations. This created a localised reverse estuarine gradient that extended into Lake Alexandrina.

These sites provided the opportunity to sample the only estuarine conditions in the Coorong and Lower Lakes. Two overflow channels on Tauwitchere Island were also sampled. These channels connect freshwater and estuarine habitats at normal lake levels of ~0.75 m (AHD), providing unregulated connectivity and have been an important migratory route for diadromous species, such as common galaxias and congolli. This connectivity, however, is now compromised by the recent construction of a concrete wall to prevent saltwater incursion during king tides and storm events.

Samples were collected fortnightly between 10/09/2007 and 25/01/2008. Each site was sampled overnight 1-3 times per sampling trip. At Tauwitchere vertical-slot fishway an aluminium framed cage trap (dimensions as to fit within the first cell of the fishway) covered with a double cone-shaped entrance configuration (each 0.39 m high x 0.15 m wide) was used to maximise entry and minimize escapement. Cage traps were deployed and retrieved using a mobile crane with assistance from SA Water staff. Two 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 6mm knotless mesh were used to sample the Tauwitchere rock-ramp fishway, freshwater attraction flows at Ewe Island and saltwater incursion into Lake Alexandrina at Tauwitchere barrage (Figure 2). Smaller single winged fyke nets (3.0 m long x 0.7 m wide x 0.7 m high with 5.0 m long leader) were used to sample the two overflow channels. Nets were set overnight for ~24 hours.

All fish were removed and placed in large aerated holding tanks. Each individual was then identified, counted, measured and released alive. For abundant species a random sub-sample of 50 individuals were measured to represent the size structure. Fish were measured to the nearest mm by total length (TL) or caudal fork length (CFL) depending on the species tail morphology.

Water physicochemical parameters (temperature, salinity, pH and dissolved oxygen) were measured during each sampling event with a model 90 FL-T TPS water quality meter. Hourly water-level, salinity and temperature data, for each sampling location along the Murray Barrages, were obtained from the Department of Water, Land and Biodiversity Conservation (DWLBC) surface water monitoring stations archive.

(a)

(b)

(c)

(d)

Figure 2. Sampling sites. (a) View below Tauwitchere rock-ramp showing fyke net set alongside fishway. (b) Lake Alexandrina above Tauwitchere barrage, estuarine conditions were present directly above the barrage in response to saltwater incursion. (c) Western end of Ewe Island barrage, with fyke net set directly downstream of freshwater attraction flow. (d) Connecting channel between Lower Lakes and Coorong (in the distance) with small fyke net set at low tide.

3.2.1. Data analysis

Spatial and temporal variation in the composition of fish assemblages was assessed between sampling locations and years. Plymouth Multivariate Routines in Primer v. 5.2 were used to perform statistical comparisons on relative abundance (number of fish/hour) and species composition (after Clarke and Warwick 2001). Relative abundance data was normalised using fourth root transformations. Non-Metric Multi-Dimensional Scaling was used to graphically represent factors (i.e. sampling sites) in two dimensions. Factors were subjected to a Bray-Curtis (1957) analysis of similarities (ANOSIM) one-way analysis in order to detect significant differences between sites.

Indicator species analysis (Dufrene and Legendre 1997) was used to calculate the indicator value (site fidelity and relative abundance) of species between groups and sites using the package PCOrd v 5.0 (McCune and Mefford 2005). A perfect indicator remains exclusive to a particular group or site and exhibits strong site fidelity during sampling (Nicol *et al.* 2007). Statistical significance was determined for each species indicator value tested by the Monte Carlo (randomisation) technique.

Relationships between fish assemblages and environmental parameters were assessed using protocols of Clarke and Ainsworth (1993). The routine BIOENV in software PRIMER v.5.2 was used for this correlation analysis (Clarke and Ainsworth 1993; Clarke and Warwick 2001). The rank similarity matrices (Bray-Curtis for fish assemblages and Euclidean distance for environmental parameters) were compared using the weighted Spearman rank correlation. The rank correlation coefficient (ρ_w) lies between –1 and +1, corresponding to the cases where the fish assemblage and environmental patterns are in complete opposition or complete agreement. Values around 0 correspond to the absence of any match between the two patterns.

3.3. Assessing spawning and recruitment of diadromous species

Temporal variation in the size-structure of the diadromous, common galaxias (*Galaxias maculatus*) and congolli (*Pseudaphritis urvillii*) was investigated using length frequency analysis. Length frequency distributions were compared monthly between seasons to describe spawning and recruitment trends between low flow (2006/07) and non-flow (2007/08) years.

4. Results

4.1. Trapping conditions

4.1.1. Water levels

Goolwa and Tauwitchere vertical-slot fishways have remained closed since early March 2007, whilst the Tauwitchere rock-ramp was shut off in late November 2006, when the lake level fell below the upstream sill height of 0.65 m (AHD). Leakages at both Tauwitchere and Ewe Island barrages, provided freshwater attraction flows for trapping during positive headloss conditions. However, as the water level in Lake Alexandrina continued to fall, the lake edge retreated, drying above Ewe Island barrage in early November and irregularly at Tauwitchere barrage after this time during strong SW winds.

At Ewe Island and Tauwitchere barrages, Lake Alexandrina water levels ranged between +0.47 and -0.43 m (AHD) whilst, Coorong water levels fluctuated between +0.64 and -0.28 m (AHD). Head differences between Lake Alexandrina and the Coorong ranged between +0.52 and -1.0 m. Negative headloss (i.e. Coorong water levels higher than Lake water levels) was recorded ~75% of the time during the sampling season (Figure 3). The greatest headloss fluctuation in a 24-hour period, between Lake Alexandrina and Coorong was 0.75 m (from -0.249 to -0.997 m) on the 28 September 2007. Approaching frontal systems and corresponding strong northerly winds caused freshwater to overtop the sill at the Tauwitchere rock-ramp prior to November 2007 causing low levels of freshwater discharge into the fishway.

4.1.2. Water temperature

Coorong surface water temperatures at Tauwitchere barrage ranged from 11.5 – 29 °C and at Ewe Island barrage ranged from 7 – 30.3 °C (Figure 4). Above Tauwitchere barrage, in Lake Alexandrina, freshwater surface temperatures ranged from 10.8 – 31.8 °C.

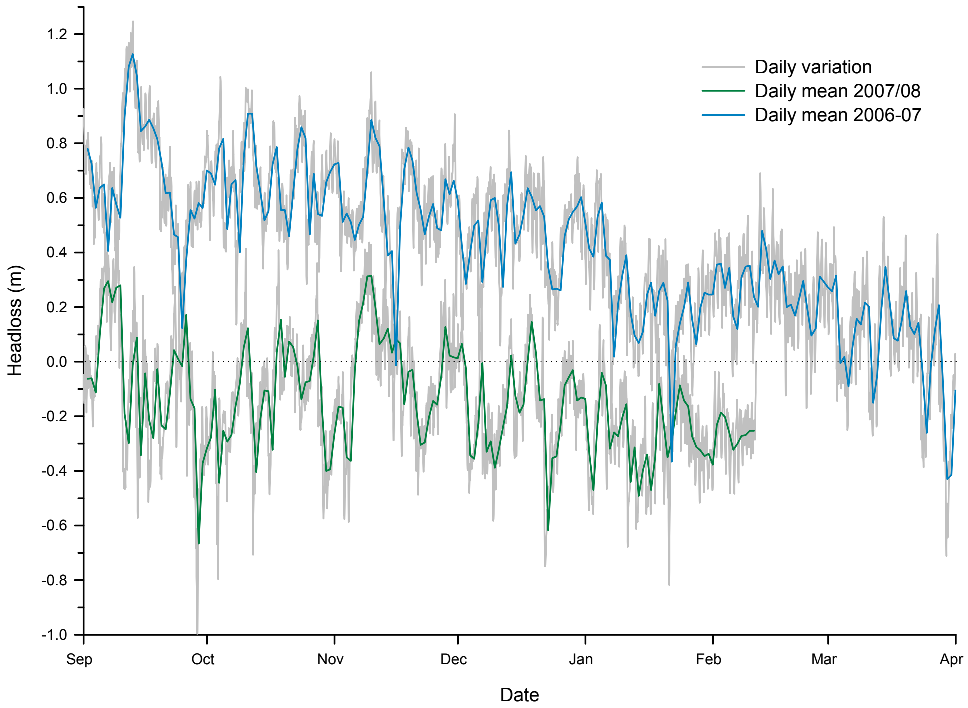

Figure 3. Headloss at Tauwitchere barrage in 2006/07 and 2007/08. Solid lines represent daily means and grey bars show daily variation.

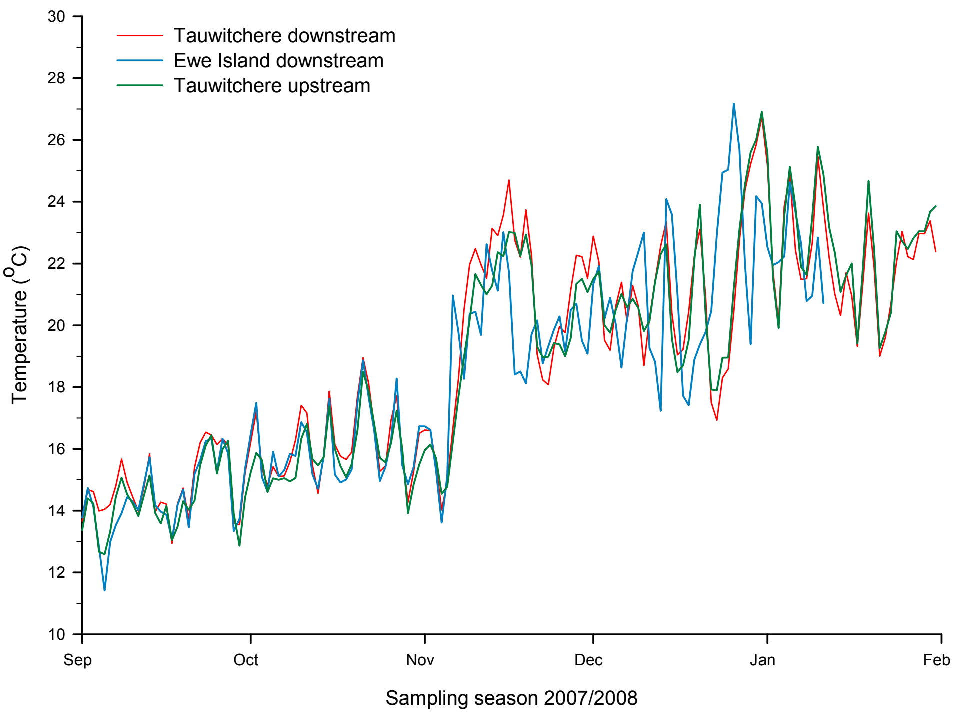

Figure 4. Mean daily water temperatures (°C) recorded at Tauwitchere and Ewe Island barrages between September 2007 and February 2008.

4.1.3. Salinity

Substantial variation in salinity was observed at all sampling sites in 2007/08 (Figure 5). Coorong salinity at Tauwitchere barrage ranged from 29,458 – 86,357 µS.cm^{-1}, and at Ewe Island barrage salinity ranged from 18,874 – 76,275 µS.cm^{-1}. Above Tauwitchere barrage, salinity in Lake Alexandrina ranged from 1,753 – 72,039 µS.cm^{-1}. In the absence of freshwater releases from the barrages and high evaporation during spring and summer, salinities in the Coorong became increasingly hypersaline, exceeding typical seawater values (>50,000 µS.cm^{-1}) 99.4% of the time.

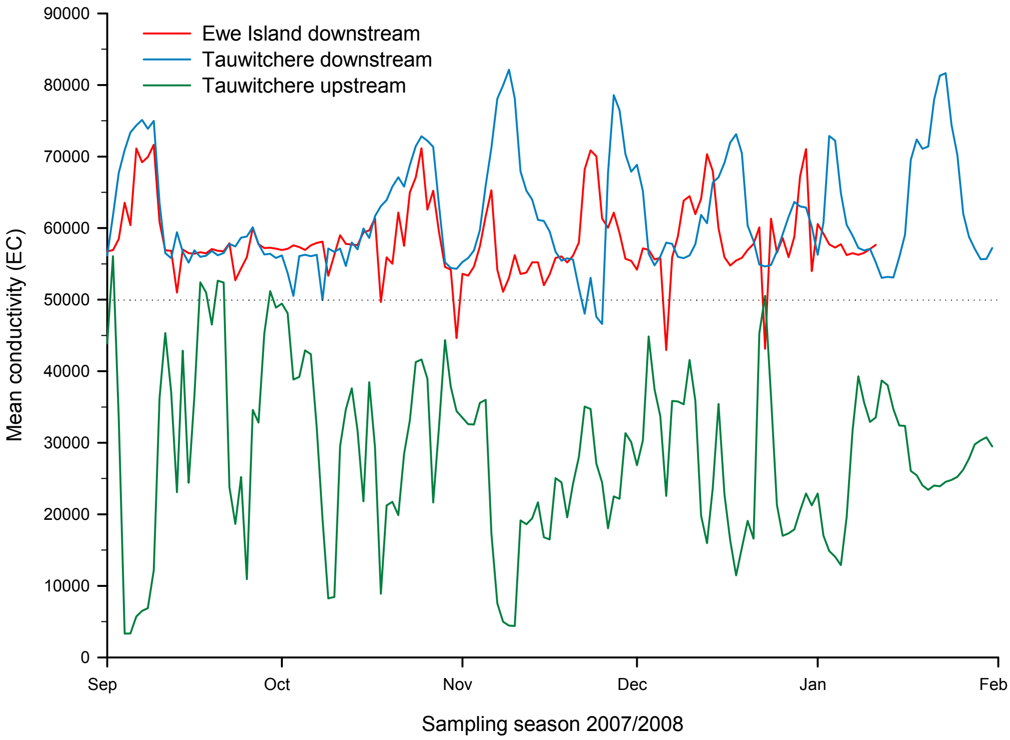

Figure 5. Mean daily electrical conductivity (EC, µS.cm^{-1}) recorded from the main sampling sites at Tauwitchere and Ewe Island barrages between September 2007 and February 2008. 50,000 EC (µS.cm^{-1}) represents typical seawater value at 25 ^{o}C.

Salinity in Lake Alexandrina, directly above Tauwitchere barrage, was often elevated as a result of saltwater incursion, during negative headloss conditions. On several occasions in September, early October and late December 2007 salinity exceeded typical seawater values (Figure 5).

Distinct differences where observed in salinities between years (Figure 6). Freshwater discharge in 2006/07 maintained estuarine conditions (<50,000 µS.cm^{-1}) below Tauwitchere barrage until mid October. After this time salinity generally reflected typical seawater values, often peaking at around 60,000 µS.cm^{-1} during the summer. In comparison, extended no-flow periods and closure of barrages and fishways in 2007/08 resulted in Coorong salinities that were consistently above seawater concentrations and at times exceeded 80,000 µS.cm^{-1}.

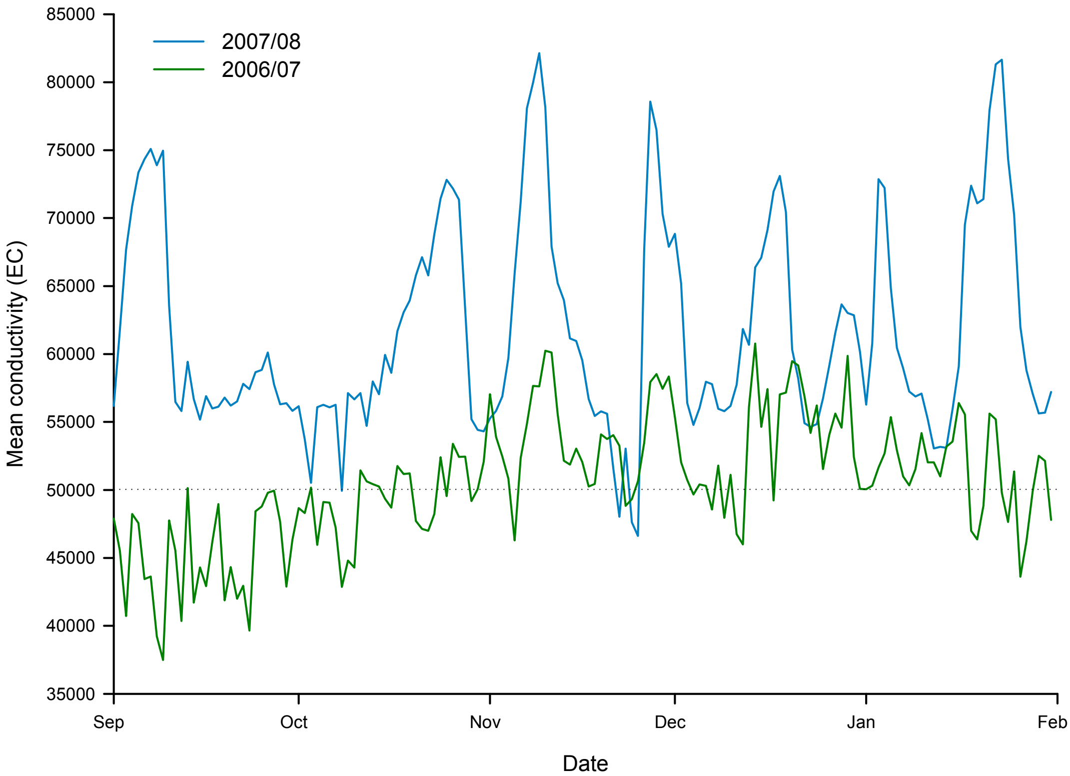

Figure 6. Mean daily electrical conductivity (EC, µS/cm-1) in 2006/07 and 2007/08 below Tauwitchere barrage. 50,000 EC (µS/cm-1) represents typical seawater value at 25 °C.

4.2. Species Abundance

A total of 177,093 fish representing 33 species were collected across six sampling sites at Tauwitchere and Ewe Island barrages (Table 1). Species diversity and abundance were highest at Tauwitchere rock-ramp (22 species, *n* = 21 sampling nights) and directly upstream of Tauwitchere barrage (21 species, *n* = 15 sampling nights). The small-mouthed hardyhead was the most abundant species, with a total of 138,220 individuals collected, which comprised 78% of the total abundance for all species. Other species present in significant numbers were Tamar River goby, bony herring, Australian smelt and sandy sprat, which contributed 5.1%, 4.5%, 3.3% and 2.8%, respectively to total abundance.

A total of 28 fish species were sampled from Coorong sites, comprising six marine opportunists, three freshwater, five estuarine/marine and eight estuarine/freshwater, which include two diadromous species. Upstream of Tauwitchere barrage, 21 species were sampled, comprising one marine opportunist, eight freshwater, nine estuarine/marine and three estuarine/freshwater, which include two diadromous species.

Table 1. Summary of species and number of fish sampled from sites at Tauwitchere and Ewe Island barrages between September 2007 and January 2008. Symbols represent <> diadromous, * freshwater, ▲ estuarine/freshwater, ▼ estuarine/marine and @ introduced species.

Common name	**Scientific name**	Tauwitchere rock ramp	Ewe Island	Tauwitchere freshwater	Tauwitchere vertical-slot	Overflow channel deep	Overflow channel shallow	**Total**
	sampling events	21	19	15	12	14	14	**95**
	no. of species	22	19	21	16	12	10	**33**
Small-mouthed hardyhead▲▼	*Atherinosoma microstoma*	44836	7042	43526	360	20084	22372	**138220**
Tamar River goby▲▼	*Afurcagobius tamarensis*	271	172	8433	97	10	17	**9000**
Bony bream*	*Nematalosa erebi*	0	0	8036	0	0	0	**8036**
Australian smelt*	*Retropinna semoni*	12	0	5787	1	0	0	**5800**
Sandy sprat▼	*Hyperlophus vittatus*	4311	121	446	17	78	1	**4974**
Common galaxias<>	*Galaxias maculatus*	7	3	3202	78	83	1	**3374**
Redfin perch*@	*Perca fluviatilis*	0	1	2351	0	0	0	**2352**
Yellow-eyed mullet▼	*Aldrichetta forsteri*	780	85	132	17	3	6	**1023**
Flathead gudgeon*	*Philypnodon grandiceps*	1	0	1021	0	0	0	**1022**
Congolli<>	*Pseudaphritis urvillii*	407	45	44	3	186	78	**763**
Bluespot goby▲▼	*Pseudogobius olorum*	299	46	85	29	43	77	**579**
Australian anchovy#	*Engraulis australis*	495	2	0	4	10	5	**516**
Lagoon goby▲▼	*Tasmanogobius lasti*	3	0	308	1	0	0	**312**
Australian salmon▼	*Arripis trutta*	210	81	8	2	3	0	**304**
Bridled goby▲▼	*Arenogobius bifrenatus*	50	3	175	0	3	3	**234**
Flat-tail mullet▼	*Liza Argentea*	71	1	15	1	99	23	**210**
Australian herring#	*Arripis georgianus*	139	16	0	3	0	0	**158**
Blue sprat#	*Spratelloides robustus*	81	0	0	0	0	0	**81**
Soldierfish#	*Gymnapistes marmoratus*	7	0	49	0	0	0	**56**
Greenback flounder▼	*Rhombosolea tapirina*	27	12	6	0	0	0	**45**
Smooth toadfish#	*Tetractenos glaber*	7	2	0	0	0	0	**9**
Dwarf flathead gudgeon*	*Philypnodon sp.*	0	0	5	0	0	0	**5**
Silver spot (Kelpfish)#	*Threpterius maculosus*	0	2	0	0	1	0	**3**
Southern pygmy perch*	*Nannoperca australis*	0	0	2	0	0	0	**2**
Murray hardyhead*	*Craterocephalus fluviatilus*	0	0	2	0	0	0	**2**
Eastern gambusia*@	*Gambusia holbrooki*	0	0	2	0	0	0	**2**
Mulloway▼	*Argyrosomus japonicus*	1	1	0	0	0	0	**2**
Pugnose pipefish#	*Pugnaso curtirostris*	0	2	0	0	0	0	**2**
Sea sweep#	*Scorpis aequipinnis*	1	0	0	1	0	0	**2**
King George whiting#	*Sillaginodes punctata*	2	0	0	0	0	0	**2**
Black bream▼	*Acanthopagrus butcheri*	0	0	0	1	0	0	**1**
Australian sardine#	*Sardinops sagax*	0	0	0	1	0	0	**1**
Weeping toado#	*Torquigener pleurogramma*	0	1	0	0	0	0	**1**
Total		**52018**	**7638**	**73635**	**616**	**20603**	**22583**	**177093**

4.3. Spatial and temporal variation in fish movement

4.3.1. 2007/08 sampling season

Non-metric multi-dimensional scaling (MDS) ordination showed distinct groupings of fish assemblages by sampling location (Figure 7). Samples from the Tauwitchere vertical-slot fishway and upstream of Tauwitchere barrage separated into distinct groups. Coorong sites at Tauwitchere rock-ramp and Ewe Island barrage formed an overlapping group, indicating similar assemblages at these sites. Two early samples from the Tauwitchere rock-ramp show separation from the main grouping towards above Tauwitchere barrage samples. Freshwater leakage was present at this site during these sampling trips (September and early October 2007).

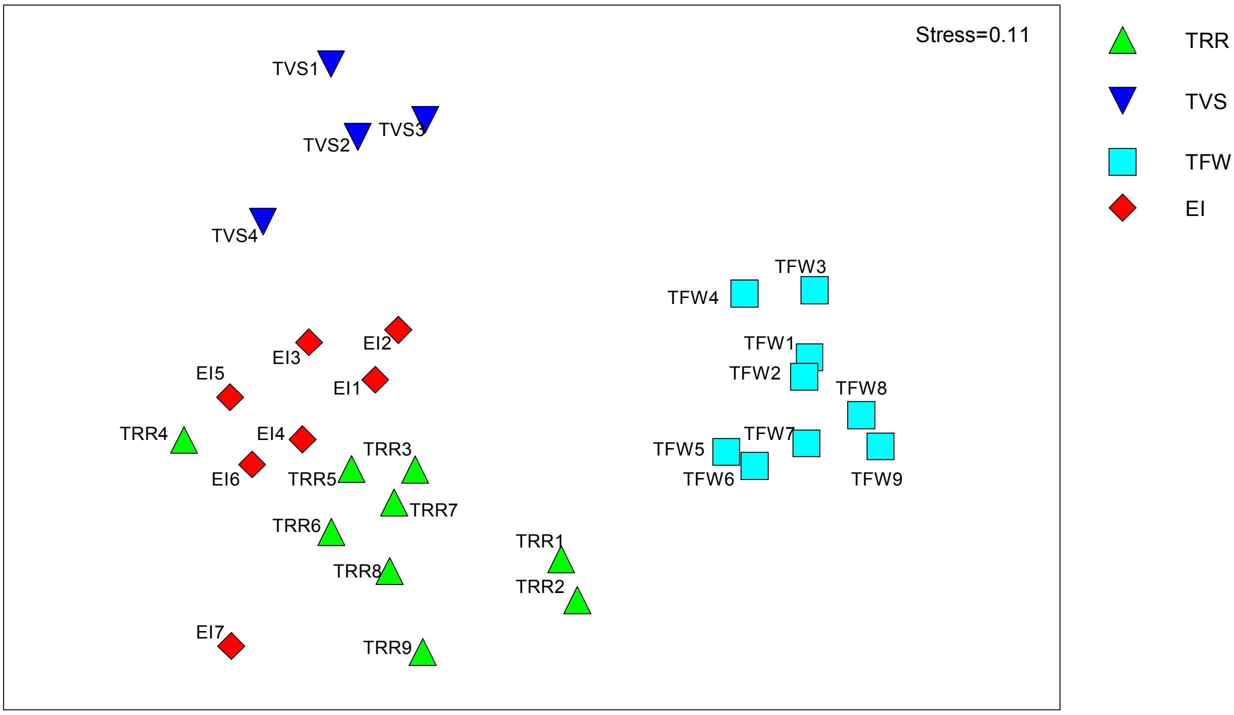

Figure 7. MDS plot of fish assemblages sampled from the Tauwitchere vertical-slot (TVS), Tauwitchere rock-ramp (TRR), upstream Tauwitchere barrage (TFW) and Ewe Island barrage (EI) in 2007/2008.

Analysis of similarities (ANOSIM) indicated that there were differences in fish assemblages between sampling locations (Global R=0.863, p <0.001). Pairwise comparisons revealed significant differences between the fish assemblages collected from all sites except Tauwitchere rock-ramp and Ewe Island barrage (after Bonferroni correction, corrected α=0.008; Table 2).

Table 2. Results of analysis of similarities (ANOSIM) pairwise comparisons between fish assemblages captured at Tauwitchere vertical-slot (TVS), Tauwitchere rock-ramp (TRR), upstream Tauwitchere barrage (TFW) and Ewe Island barrage (EI). Bonferroni corrected α=0.008.

Comparison	Global R	*P* value
TRR v TVS	0.951	0.001*
TRR v TFW	0.967	0.001*
TRR v EI	0.281	0.012
TVS v TFW	1.0	0.001*
TVS v EI	0.725	0.003*
TFW v EI	0.999	0.001*

Of the 33 fish species sampled across all sites in 2007/08, nine were significant indicator species and characteristic of a particular site (Table 3). A combination of freshwater (Australian smelt, flat-headed gudgeon, bony herring and redfin perch), estuarine (Tamar River goby, lagoon goby and bridled goby) and diadromous (common galaxias) species sampled upstream of Tauwitchere barrage (TFW) comprised eight of the nine indicator species, while the diadromous congolli was strongly associated with the Tauwitchere rock-ramp (TRR) (Table 3).

Table 3. Indicator-species analysis comparing fish assemblage compositions for sites sampled in 2007/08. A significant difference (P<0.05) indicates that a species occurs in a higher relative abundance at a site and hence is contributing to differences between fish assemblages of the sites. Non-significant species were either sampled in low numbers or sampled consistently across habitats.

Species	Site	Observed Indicator Value (IV)	*P*
Australian smelt	TFW	90.7	0.0002
Common galaxias	TFW	61.0	0.0002
Flathead gudgeon	TFW	97.0	0.0002
Tamar goby	TFW	46.7	0.0002
Lagoon goby	TFW	81.8	0.0002
Bridled goby	TFW	51.8	0.0002
Redfin perch	TFW	96.4	0.0002
Bony herring	TFW	100.0	0.0002
Congolli	TRR	42.7	0.0002

Many species were captured in comparatively greater numbers at particular sites, without being significant indicators at those sites. Most notably, blue-spot goby, Australian anchovy, Australian herring, and yellow-eyed and flat-tailed mullet were detected in greater abundances at the Tauwitchere rock-ramp (Table 1). Similarly, lagoon goby and bridled goby were most abundant above the Tauwitchere barrage (Table 1). Ten species (sea sweep, soldierfish, silver spot kelpfish, pugnose pipefish, Australian sardine, weeping toado, smooth toadfish, King George whiting, blue sprat and Australian herring) that generally inhabit the coastal zone were sampled from the Coorong and upstream of Tauwitchere barrage.

Fish assemblages in 2007/08 correlated well with conductivity (BIOENV ϱ = 0.535). Figure 8 shows the same ordination observed in Figure 7, with superimposed circles representing values of conductivity at each site. The site upstream of Tauwitchere barrage was characterised by lower salinities than the other sites, and a predominantly freshwater fish assemblage.

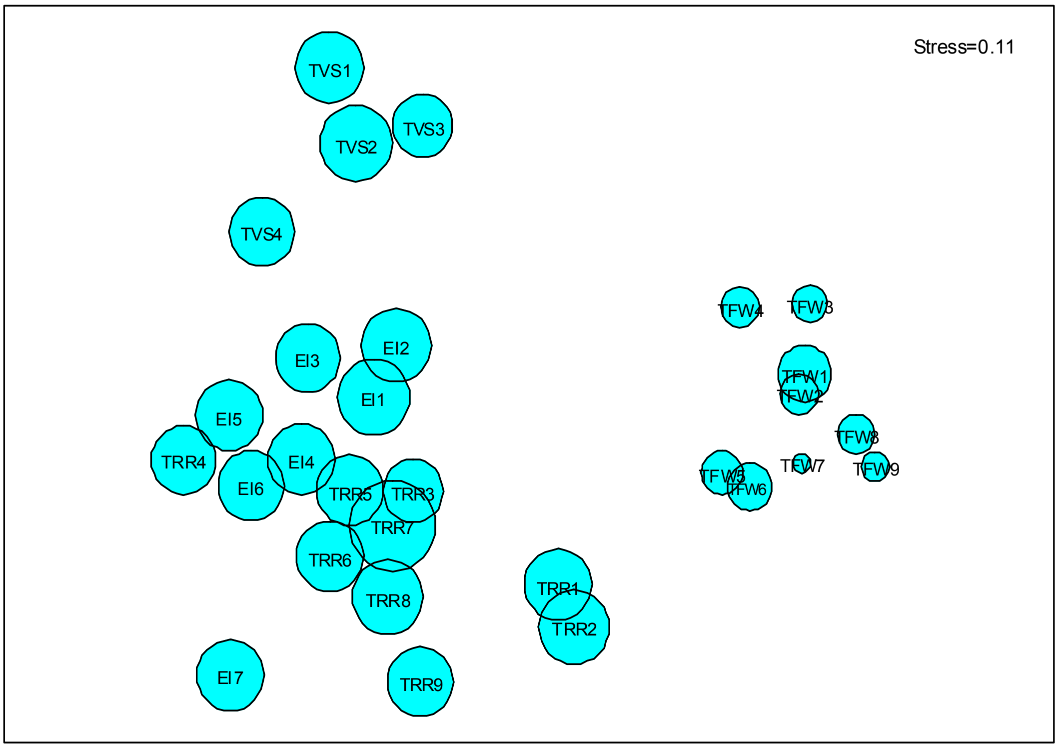

Figure 8. MDS plot for fish assemblages sampled at the Tauwitchere rock ramp (TRR), Tauwitchere vertical-slot (TVS), upstream Tauwitchere barrage (TFW) and Ewe Island (EI) in 2007/08. Superimposed circles represent differing values of conductivity (salinity).

4.3.2. Inter-annual comparison

Non-metric multi-dimensional scaling (MDS) ordination showed distinct groupings of fish assemblages by year at the Tauwitchere rock ramp (Figure 9) and vertical-slot fishways (Figure 10a). Analysis of similarities (ANOSIM) indicated differences between fish assemblages captured in 2006/07 and 2007/08 at the Tauwitchere rock ramp (Global R = 0.446, p = 0.001) and vertical-slot (Global R = 0.755, p = 0.002). The cessation of freshwater flows and fishway operation resulted in distinct changes in fish communities at the same sites between years. Two early samples from the Tauwitchere rock-ramp in 2007/08 showed separation from the main grouping towards Tauwitchere rock-ramp 2006/07 (Figure 9). Freshwater leakages were present at this site during these sampling trips in September and early October 2007.

At the Tauwitchere vertical-slot, temperature, conductivity (salinity) and headloss (difference between upstream and downstream water levels) were correlated with (BIOENV ϱ = 0.681) variations in the fish assemblages. Figure 9b, c and d show the MDS ordination with superimposed circles representing each environmental variable associated with site samples. The relationship between temperature and conductivity with fish assemblages was unclear. Temperature was slightly cooler whilst, conductivity was slightly elevated compared to samples taken during the same period in the previous season. Headloss correlated well with samples between years, high positive headloss observed at the beginning of 2006/07 had declined substantially by the end of the sampling season and by 2007/08 had reached close to zero and into negative values (Figure 9d).

At the Tauwitchere rock ramp fishway environmental variables were poorly correlated to the dissimilarities in observed fish assemblages over time and between seasons. Headloss was the highest ranked correlating environmental parameter (ϱ = 0.470).

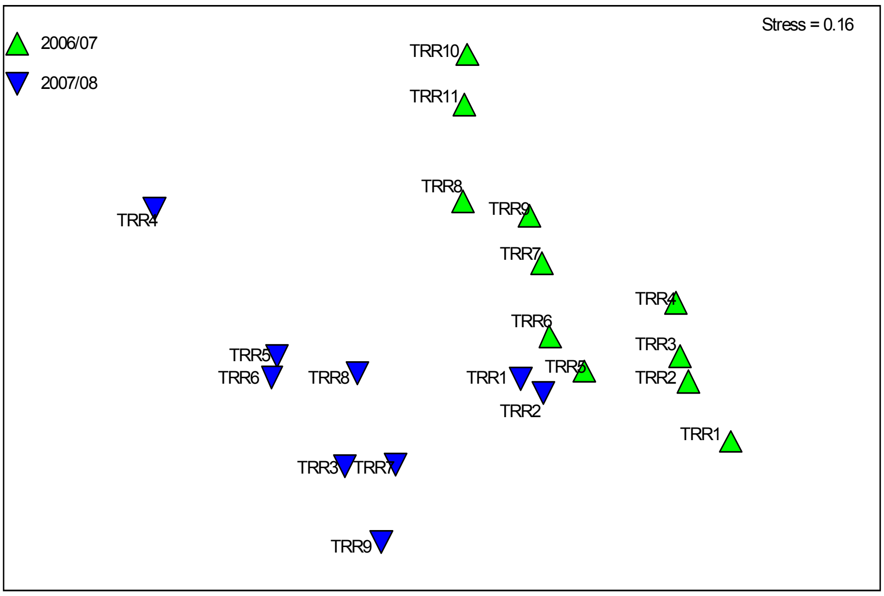

Figure 9. MDS ordination of fish assemblages sampled at the Tauwitchere rock-ramp (TRR) in 2006/07 and 2007/08. Numbers in symbols represent replicate series throughout the season.

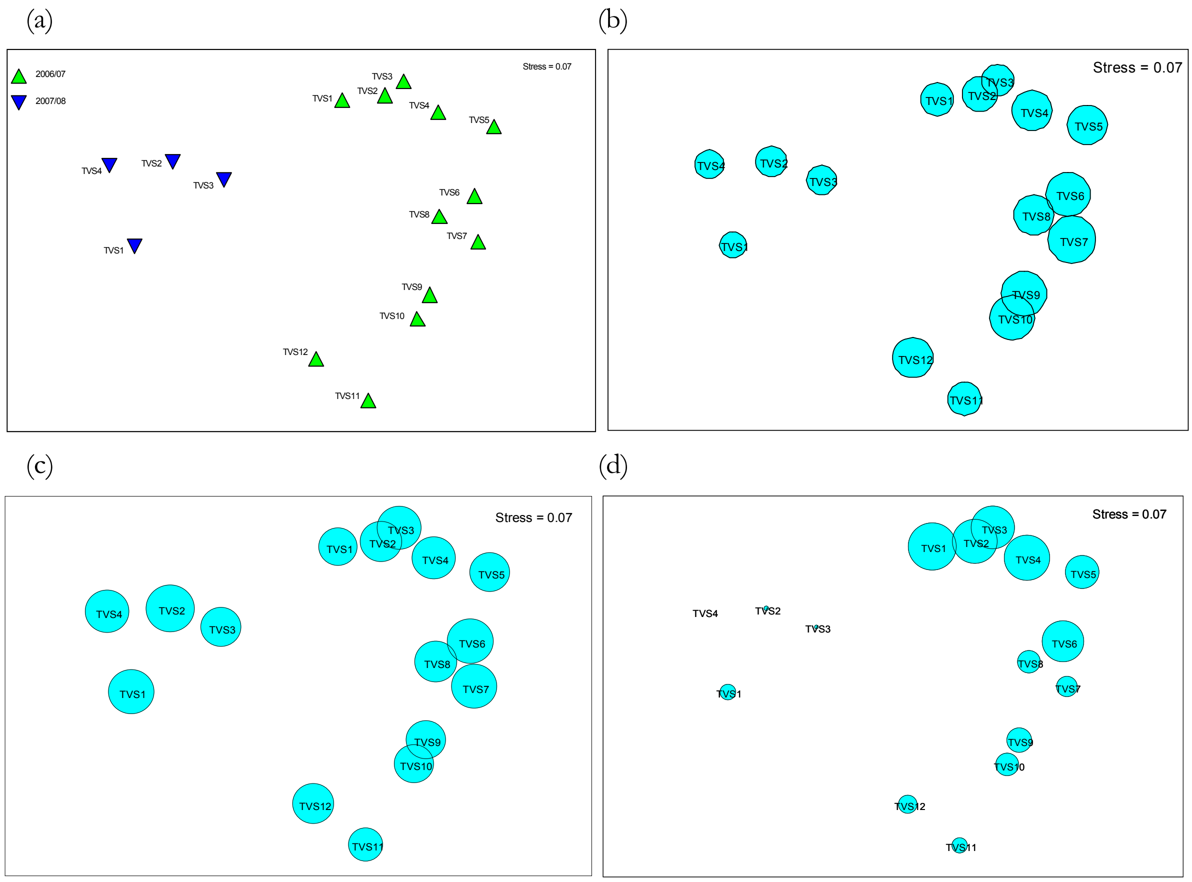

Figure 10. (a) MDS ordination of fish assemblages sampled from the Tauwitchere vertical-slot (TVS) in 2006/07 and 2007/08. Superimposed circles represent the values of (b) temperature, (c) conductivity and (d) headloss. Numbers within symbols represent replicate series throughout the season.

Of 32 species sampled from the Coorong at Tauwitchere barrage in 2006/07 and 2007/08 (TRR and TVS combined), ten were significant indicators (Table 4). Six freshwater and estuarine species, including three diadromous species, were significant indicators during low flows in 2006/07, whilst four estuarine/marine species were significant indicators following the cessation of freshwater inflows in 2007/08 (Table 4).

Table 4. Indicator-species analysis comparing estuarine fish assemblage compositions below Tauwitchere barrage between sampling seasons. Year 1 = 2006/07 and Year 2 = 2007/08. A significant difference (*P*<0.05) indicates that a species occurred in a higher relative abundance in a year and hence is contributing to differences in fish assemblages between years. Non-significant species were either sampled in low numbers or consistently across years.

Species	Year	Observed Indicator Value (IV)	*P*
Australian smelt	1	77.3	0.0012
Common galaxias	1	98.2	0.0002
Congolli	1	81.2	0.0426
Flathead gudgeon	1	95.6	0.0002
Lagoon goby	1	91.2	0.0010
Short-headed lamprey	1	39.1	0.0178
Australian salmon	2	67.2	0.0026
Australian anchovy	2	45.6	0.0336
Australian herring	2	37.8	0.0238
Blue sprat	2	30.8	0.0132

4.4. Diadromous species

Two diadromous species, congolli and common galaxias were collected in 2007/08. The numbers of individuals attempting to migrate at any given time for both species varied substantially, yet distinct periods of movement were detected. No adult lamprey (short-headed or pouched) were sampled attempting to migrate at fishways or leakages along the barrages.

4.4.1. Common galaxias

Extremely low numbers of common galaxias were sampled from the Coorong at Tauwitchere and Ewe Island barrages in 2007/08. Abundances were highest in early October at the Tauwitchere vertical-slot, however numbers declined significantly by the end of October and trapping was ceased in the absence of attraction flows (Figure 11). Common galaxias were absent from Coorong samples in November and January 2007/08. This was in contrast to 2006/07, when individuals were collected during every month sampled (Figure 11). Common galaxias were most abundant upstream of Tauwitchere barrage in 2007/08, and were collected every month. Highest abundances were observed in December and January. Sampling was discontinued beyond January 2008, as Lake levels were too low for trapping.

The mean number of common galaxias sampled each hour from the Coorong at Tauwitchere barrage declined substantially between years, from 2.5 to 0.03 individuals. In contrast, the mean number sampled upstream of Tauwitchere barrage (2.5/hour) was comparable to that sampled from the Coorong in 2006/07. The highest abundance sampled in 2007/08 was 18.5 individuals per hour in early January from upstream of Tauwitchere barrage. By comparison, 32.3 individuals per hour were sampled from the Tauwitchere vertical-slot fishway in early December 2006.

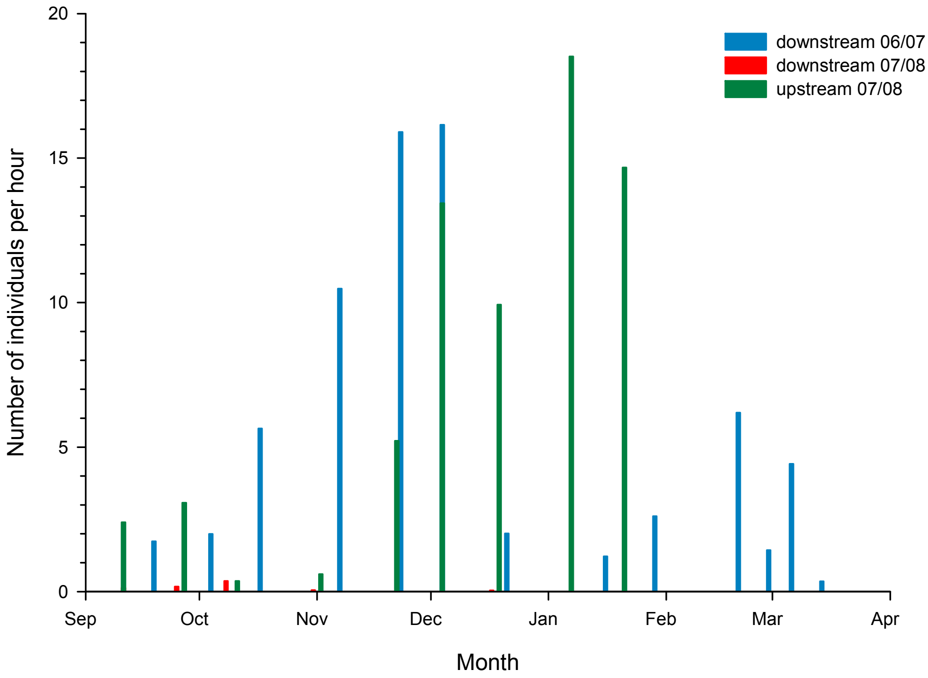

Figure 11. The relative abundance (number of fish captured/hour) of common galaxias between sampling sites and years at Tauwitchere barrage. Blue bars represent below in 2006/07, black bars represent below in 2007/08 and red bars represent above in 2007/08.

4.4.2. Congolli

Congolli were collected every month between September and January 2007/08, yet abundances were low in the Coorong downstream of Tauwitchere and Ewe Island barrages. Consistently low numbers were present at Tauwitchere rock-ramp from September to late November, before increasing slightly during December and reaching a peak in late January (Figure 12.). Abundances of congolli were also very low upstream of Tauwitchere barrage. Numbers were highest in September followed by substantial declines through the subsequent spring and summer.

The mean number of congolli sampled each hour from the Coorong downstream of Tauwitchere barrage declined substantially between years, from 2.2 to 0.21 individuals. Mean abundance upstream of Tauwitchere barrage was significantly lower than Coorong sites from both years at 0.08 fish/hr. The highest abundance sampled in 2007/08 was 1.7 fish/hr in early September from upstream of Tauwitchere barrage. In comparison 43.2 fish/hr were sampled at the Tauwitchere vertical-slot fishway in late December 2006 during a peak movement period.

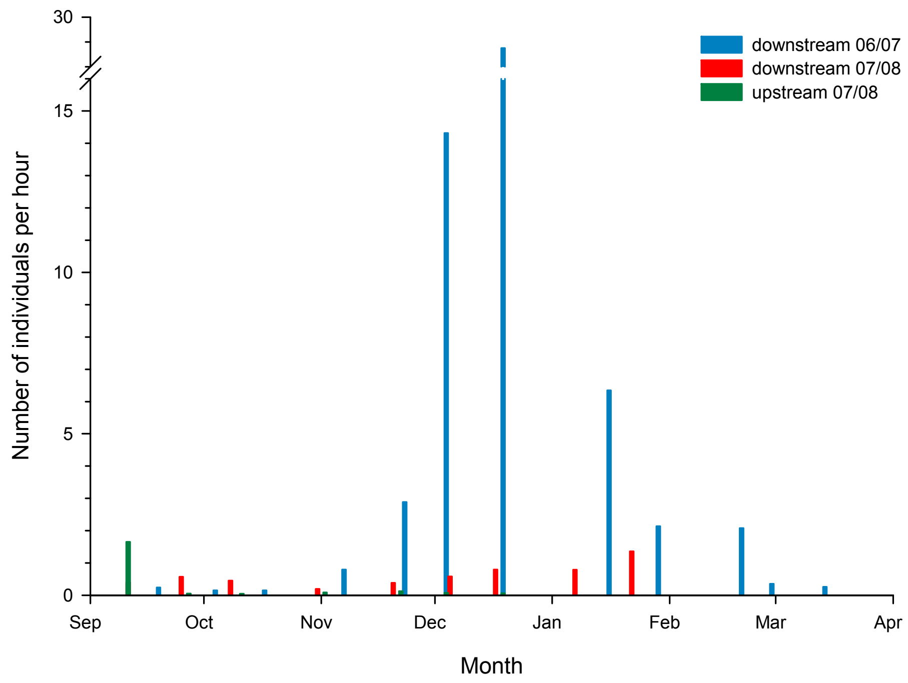

Figure 12. The relative abundance (number of fish captured/hour) of congolli between sampling sites and years at Tauwitchere barrage. Blue bars represent below in 2006/07, black bars represent below in 2007/08 and red bars represent above in 2007/08.

4.5. Length frequency of diadromous species

4.5.1. Common galaxias

In 2007/08, common galaxias ranged in length from 34 to 102 mm (CFL). Below Tauwitchere barrage, young of the year (YOY) between 34 and 49 mm were only present in September and October, none were sampled in either November or January, and only two fish were collected in December (Figure 13.). YOY contributed 90% and 98% of samples collected in September and October, respectively.

In 2006/07, common galaxias were present in all samples collected in the Coorong downstream of Tauwitchere barrage (Figure 11.). Large individuals were present in September and their abundance declined during subsequent samples until they were absent after December. The presence of YOY in October and the subsequent progression of this cohort accounted for >90% of individuals sampled throughout the remainder of the season. YOY ranged between 30–50 mm by March. Growth of this cohort was supplemented by the presence of new recruits throughout summer, which ranged between 40–70 mm (Figure 13).

Larger individuals were present upstream of Tauwitchere barrage in 2007/08 during September and October (Figure 12.). YOY between 35–63 mm were dominant for the remainder of the sampling season and accounted for 84%, 97% and 97% of total abundance in November, December and January, respectively. A transition of YOY was evident between the Coorong and upstream of Tauwitchere barrage between October and November (Figures 13. and 14.).

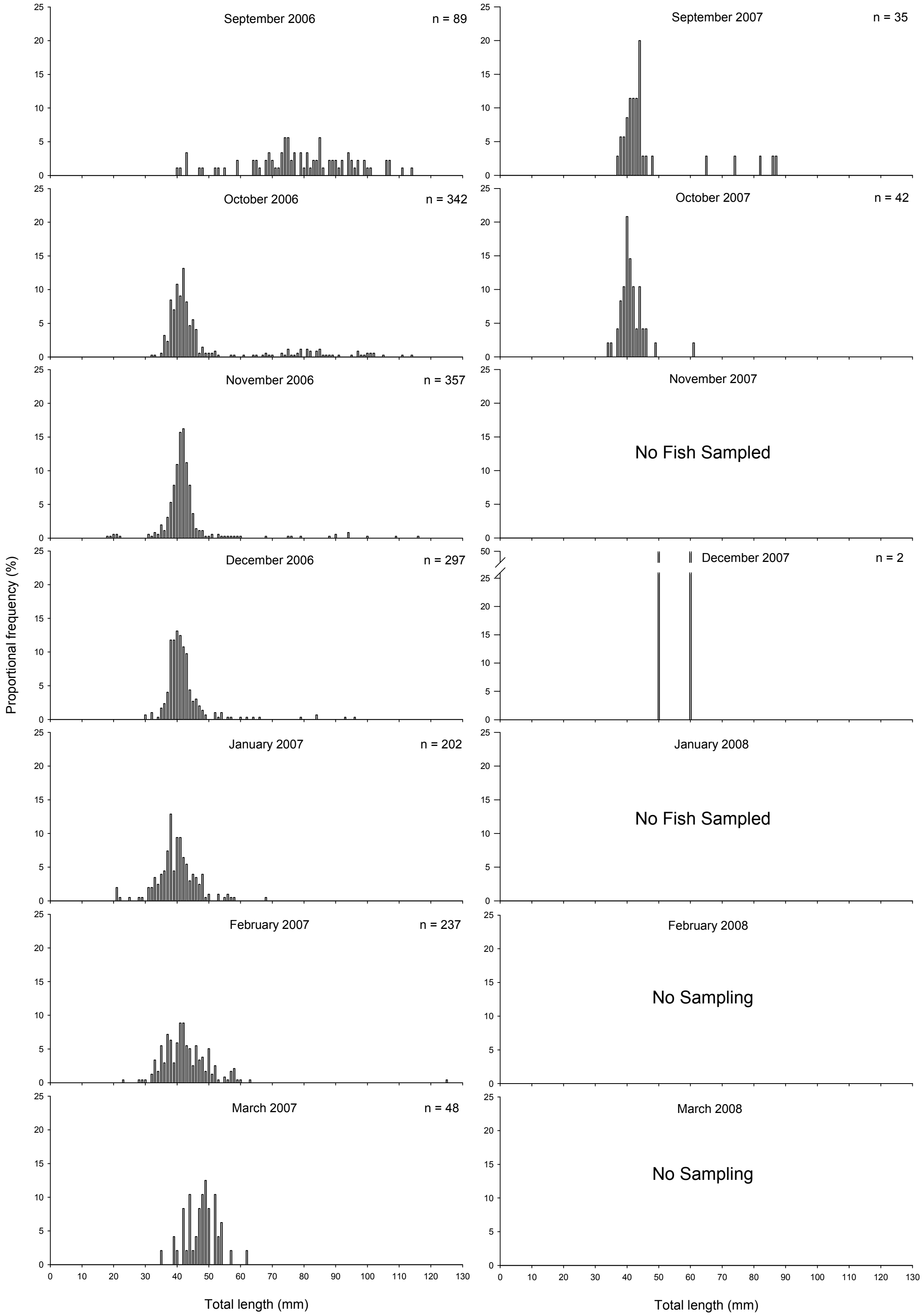

Figure 13. Length frequency distribution of common galaxias sampled from the Coorong at Tauwitchere barrage in 2006/07 left column and 2007/08 right column.

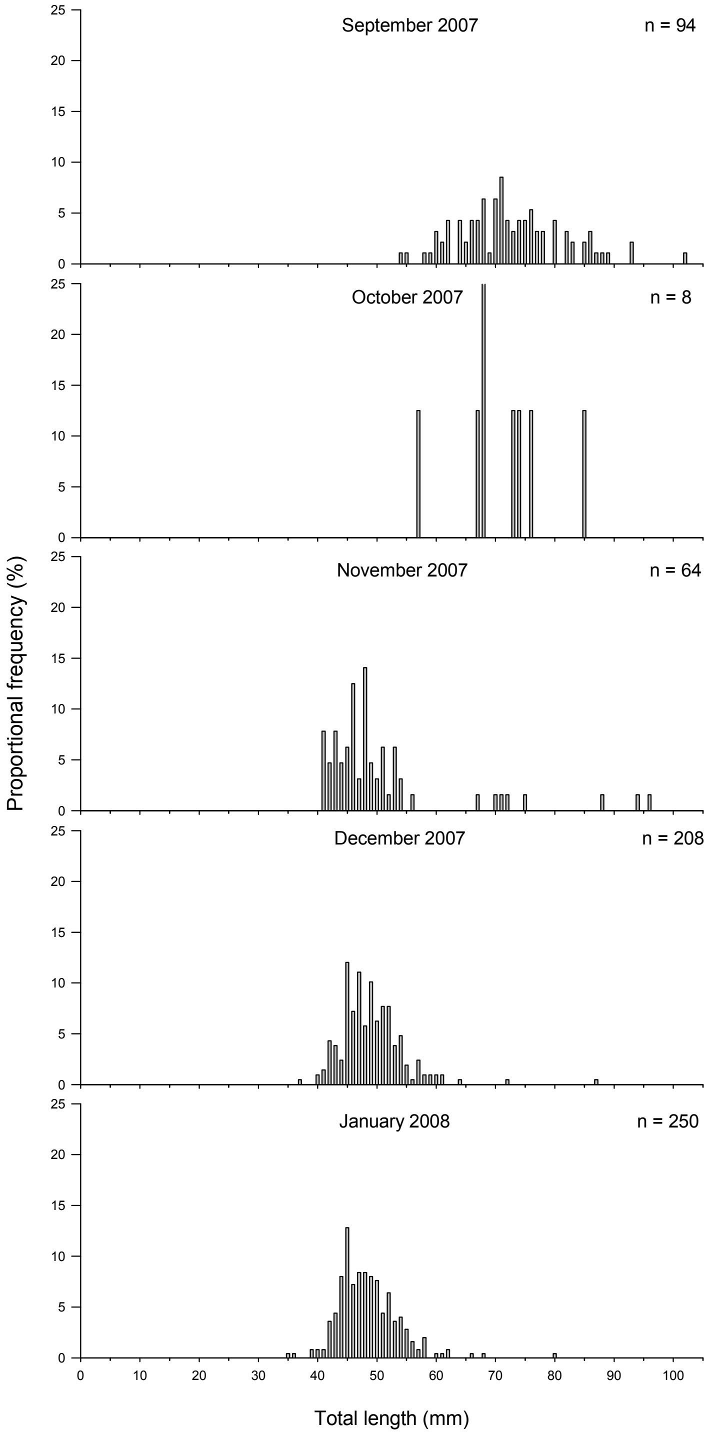

Figure 14. Length frequency distribution of common galaxias sampled upstream of Tauwitchere barrage in 2007/08.

4.5.2. Congolli

In 2007/08 congolli ranged in length from 23 to 304 mm (TL). Samples from the Coorong downstream of Tauwitchere barrage exhibited a broad size distribution between 36–207 mm, with fish ranging in size between 70–150 mm being most common (Figure 15). YOY were first sampled in November at 40–57 mm and were present also in December and January. YOY (<70 mm) comprised only 16% of the sampled population, compared to >90% in 2006/07.

In 2006/07, congolli were present in all samples collected from the Coorong downstream of Tauwitchere barrage. Large fish were present in September, and combinations of large and intermediate sized fish were present in low abundances during subsequent samples in spring and summer (Figure 15). YOY were first present in low numbers in October. The proportion of YOY (20–40 mm) increased substantially in November and accounted for >90% of samples. Progression of this cohort in December and January, accounted for almost 100% of individuals sampled. By the end of January recruits ranged between 35–50 mm. A broad size distribution was sampled in February and March, as the proportion of YOY in samples declined.

Large congolli 200–305 mm (*n* = 25) were sampled upstream of Tauwitchere barrage in September 2007 (Figure 16). Numbers declined significantly in October and remained extremely low for the remainder of the sampling season. Very few YOY were captured over the sampling period, with only a single fish collected in November and January, and two fish in December.

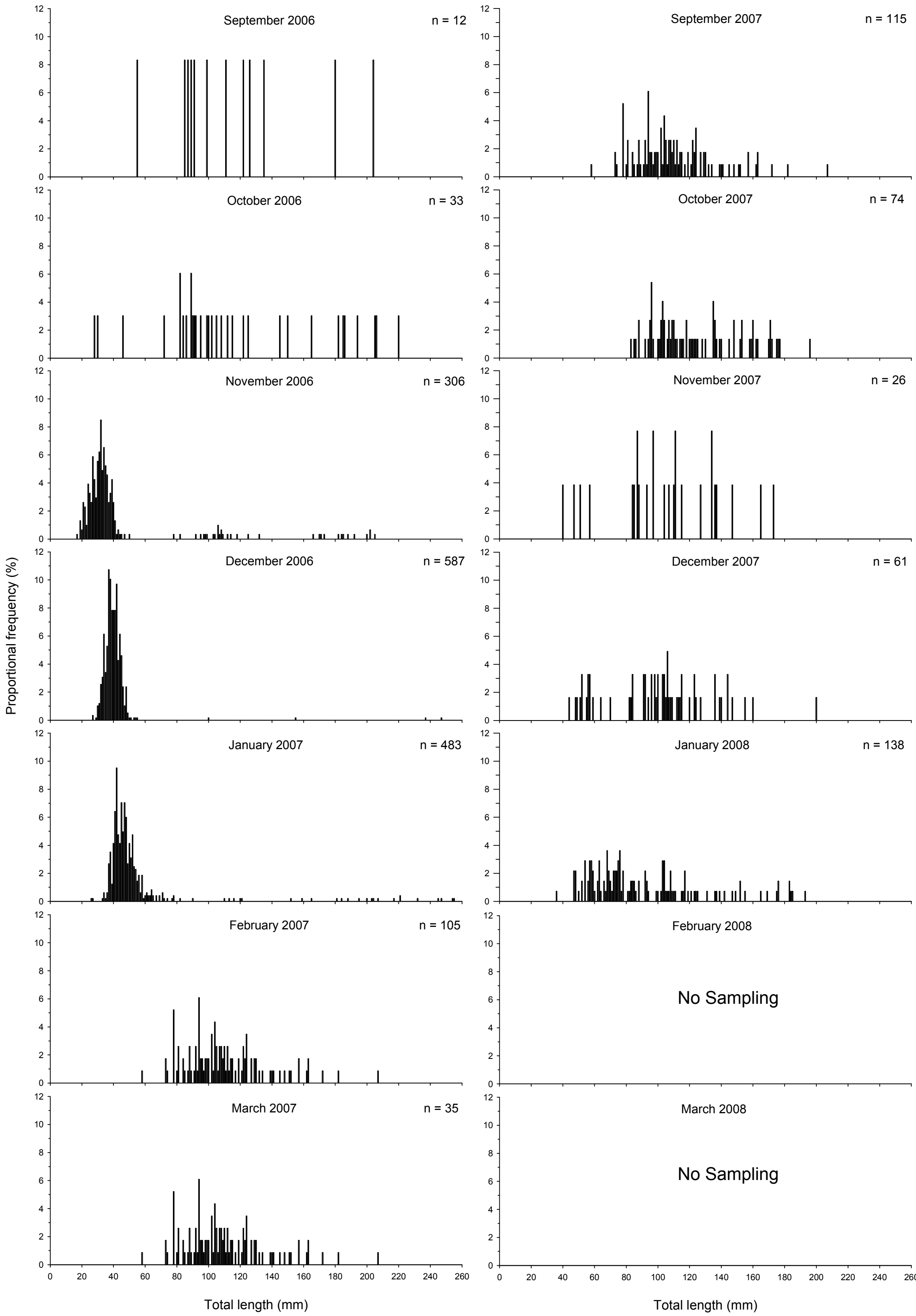

Figure 15. Length frequency distribution of congolli sampled from the Coorong at Tauwitchere barrage in 2006/07 left column and 2007/08 right column.

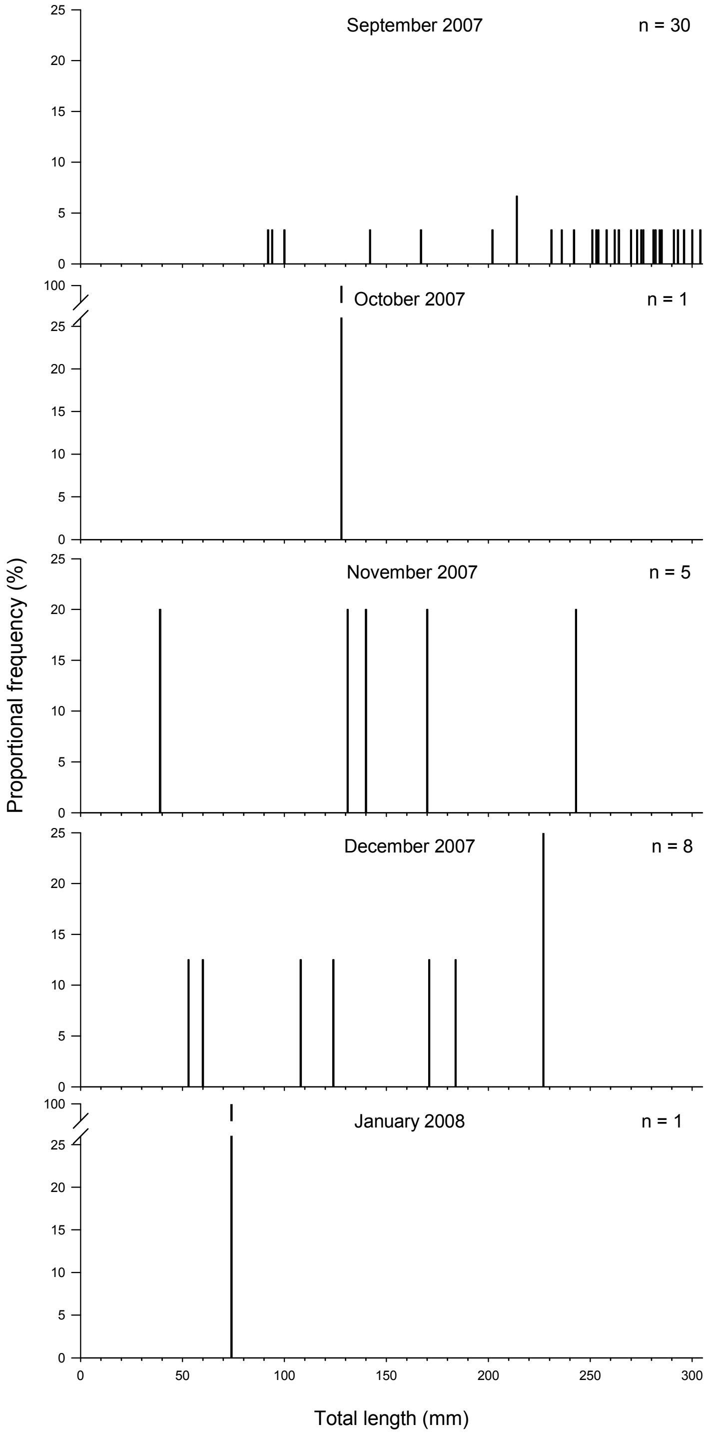

Figure 16. Length frequency distribution of congolli sampled upstream of Tauwitchere barrage in 2007/08.

4.6. Movement of large-bodied species

In 2007/08, large bodied fishes were sampled in lower numbers than in 2006/07. Individual mulloway were sampled from the Coorong at Ewe Island barrage in December and Tauwitchere barrage in January, whilst a single adult black bream was sampled from Tauwitchere vertical-slot fishway in September.

YOY black bream (27–30 mm, FL) were collected from the Tauwitchere rock-ramp in December (n = 6) 2006 but were not present in 2007/08. Single adult fish were collected from the Tauwitchere vertical-slot fishway in December 2006 (410 mm) and January 2007 (450 mm).

Low numbers of juvenile mulloway (135-428 mm, TL) were sampled at the Tauwitchere rock-ramp in November (n = 4) and December 2006 (n = 1) and January 2007 (n = 1). One mulloway (480 mm, TL) was collected from the Tauwitchere vertical-slot fishway in January 2007.

5. Discussion

5.1. Trapping conditions

The fishways were closed in 2007/08 and this required a more opportunistic approach to be adopted to assess fish assemblages and the recruitment of diadromous species at the Coorong and Lower Lakes interface. Leakages at the barrages created confined estuarine zones, both in the Coorong and Lower Lakes, and provided attraction flows for fish.

Low water levels in Lake Alexandrina exacerbated the already highly dynamic water physicochemistry in the Coorong and Lower Lakes. In the absence of freshwater from the Lower Lakes, water in the Coorong became solely influenced by the mixing of hypersaline water from the southern lagoon and incoming tidal and storm driven coastal waters. Variations in headloss and salinity become more pronounced as lake level fell exposing an estuarine adapted ecosystem to increasingly hypersaline conditions. Localised meteorological conditions such as wind seiche acted further to exaggerate these extremes.

Conditions upstream of Tauwitchere barrage were highly dynamic over relatively short time periods in response to fluctuating Coorong and Lake Alexandrina water levels. Salinity was influenced directly by headloss and ranged between freshwater and estuarine values and occasionally marine, within a 24 hr trapping period. This constantly changing water physicochemistry supported a diverse fish community.

5.2. Spatial and temporal variation in fish assemblages

5.2.1. Spatial variation in 2007/08

Differences in fish assemblages were evident between all sampling locations, except downstream of the Tauwitchere rock ramp and Ewe Island barrage. These two sites provide similar habitats that include a combination of sand flats, calcareous reef and shallow-channels. They are close geographically and experienced similar levels of freshwater leakage through the barrages, and as such were expected to have similar fish assemblages.

The assemblage observed upstream of Tauwitchere barrage was characterised by high abundances of freshwater and estuarine species, including common galaxias. In contrast, the assemblage at the Tauwitchere rock ramp was characterised by a higher relative abundance of congolli.

Salinity was well correlated with the observed fish assemblages. Salinities upstream of Tauwitchere barrage were highly dynamic, yet were generally lower than downstream of the barrage. The fish assemblage at this site was characterised by freshwater and estuarine species, whilst estuarine/marine species were typically more abundant downstream in the Coorong.

5.2.2. Inter-annual variation

The low flows delivered through the Murray barrage fishways in 2006/07 provided passage for a suite of freshwater and estuarine/marine fish species, most importantly facilitating spawning and recruitment migrations for diadromous species. In addition, these flows created and maintained estuarine conditions below the barrages. In comparison, cessation of flows and loss of connectivity between the Lower Lakes and Coorong in 2007/08 reduced the abundance and number of freshwater and estuarine dependant species, in particular diadromous fishes and increased the presence of marine opportunistic species.

Overall species richness downstream of Tauwitchere barrage remained similar between years. However, a significant shift was observed in the species composition between years. In 2006/07, fish assemblages below Tauwitchere barrage were characterised by freshwater and estuarine dependant species. Amongst these, diadromous species, common galaxias, congolli and short-headed lamprey were significant indicators. In 2007/08, significant indicators were of marine origin or estuarine opportunists. Adult small-bodied pelagic species, Australian anchovy and blue sprat, and juvenile coastal migrants, including Australian salmon and herring characterised assemblages at this site.

Temperature, salinity and headloss explained differences observed in fish assemblages between years. Positive, although decreasing headloss was characteristic in 2006/07, which contrasted with the negative headloss experienced through the majority of 2007/08. Despite fishways being closed, headloss conditions remain extremely important at the Murray barrages. Water incursion along this interface, both above and below the barrages, maintained localised zones of reduced salinities and refuge habitats for estuarine adapted fish. At the Tauwitchere rock ramp fishway the relationship was less clear, and it is possible that other parameters, not examined in this study, may better explain the relationship observed in fish assemblages.

5.3. Movement and recruitment of diadromous fishes

The unique life history requirements of diadromous species have made them extremely vulnerable to current environmental stresses (SAMDBNRM 2008). Loss of connectivity between the Lower Lakes and Coorong and hydrological alterations present a serious risk for the future viability of these populations. The presence or absence of diadromous species, either as spawning or recruiting individuals may act as important indicators for the wider ecological health and function of estuaries (Bortone 2005).

5.3.1. Common galaxias

Previous data indicated that common galaxias found in the Coorong and Lower Lakes represent a catadromous population, utilising estuarine gradients for successful spawning and recruitment (Bice *et al.* 2007). In 2006/07, YOY common galaxias were extremely abundant downstream of Tauwitchere barrage and were collected during every sampling event. Peak migration was observed from mid November through early December. In 2007/08, peak abundance of YOY was later and occurred in late December, and particularly in January. Similar periods of peak movement have been documented in coastal rivers in south-eastern Australia and New Zealand (McDowall *et al.* 1994; Zampatti *et al.* 2001).

In 2006/07, reproductively mature common galaxias were sampled below the Tauwitchere barrage in September and October but were absent in 2007/08 and were only present above Tauwitchere barrage in September. However, YOY were sampled below Tauwitchere barrage in September and October, but were not present after this time. In November YOY recruits were sampled above the Tauwitchere barrage and increased in abundance throughout the remainder of the season.

There are several possible explanations for the disappearance of YOY common galaxias from downstream of Tauwitchere barrage in association with a considerable increase in abundance of YOY recruits upstream of the barrage.

- As freshwater leakage decreased YOY recruits may move away from sampling sites downstream of the barrages to more suitable sites in the Coorong.
- YOY recruits from downstream of the barrages may have passed upstream through the barrages using leaking gates for passage.
- High mortality of YOY fish downstream of the barrage as water quality decreased (i.e. hypersaline).
- Common galaxias may have completed their lifecycle in the estuarine gradient upstream of Tauwitchere barrage.

It is highly likely that common galaxias successfully recruited upstream of Tauwitchere barrage in the estuarine gradient created by reverse flows into Lake Alexandrina. This suggests that common galaxias utilised a flexible spawning and recruitment strategy to take advantage of the dynamic physicochemical environment at the Coorong and Lower Lakes interface.

5.3.2. Congolli

As with common galaxias, peak movement of YOY was delayed from December in 2006/07 to December–January in 2007/08. In 2007/08 YOY recruits comprised just 16% of the population sampled compared to >90 % in November, December and January 2006/07. Overall abundance and size frequency distributions of congolli suggest poor recruitment for this species at Tauwitchere barrage in 2007/08.

Large adult fish were present upstream of Tauwitchere barrage in early spring 2007 and it is likely these individuals were attempting to migrate into the Coorong. Intermediate size fish were most abundant directly below Tauwitchere barrage throughout the sampling season and preliminary investigation of the sex of fish above and below the barrage suggests habitat segregation by sex. The larger fish above the barrage were predominantly mature females whilst the intermediate size fish below the barrage were predominantly male. In 2006/07, fishways and island channels connected the Lower Lakes and Coorong and facilitated spawning and recruitment migrations for congolli. This is demonstrated by the presence of both intermediate and large individuals below the barrages in September and October 2006 and substantial recruitment of YOY in subsequent months.

Fish passage has generally been available to this species through the operation of barrage gates and a network of channels connecting the Lower Lakes and Coorong. Under current drought conditions, no options for fish passage exist and estuarine and freshwater environments have become isolated. If habitat segregation of sexes exists in this population, loss of connectivity between freshwater and estuarine environments above and below the Tauwitchere barrage and at all of the Murray barrages may result in recruitment failure for this species. Unlike common galaxias, congolli were unable to utilise estuarine conditions above the barrages and the continuation of current conditions will potentially contribute to further declines in the abundance and distribution of this species.

5.3.3. Lamprey

In 2007/08, no lamprey were sampled attempting to migrate at fishways or leakages along the barrages. In 2006/07, 40 short-headed lampreys and one pouched lamprey were collected from mid September till mid December. Short-headed lamprey were most abundant in September, at the beginning of the sampling period, and therefore it is likely the upstream migration began before sampling commenced. This finding was similar to that of Potter (1995), who suggested that upstream spawning migrations typically occur in late winter and spring in Victorian rivers.

5.4. Large bodied species

Mulloway and black bream were collected in both years, albeit in lower numbers in 2007/08. In 2006/07, the presence of these species coincided with periods of reverse flow between the Coorong and Lower Lakes in late summer. Such conditions were prevalent in 2007/08, but with the fishways closed, no option was available for large bodied fish passage. Prior to the construction of the barrages, these conditions resulted in movement of mulloway and bream into the Lower Lakes (Sim and Muller 2004). Upstream movements were observed in 2006/07, which suggests that reverse flows may serve an important ecological function facilitating the movement of these and other large bodied species, such as sea mullet between the Coorong and Lower Lakes.

No YOY black bream were sampled in 2007/08, whereas in 2006/07 a small number were sampled from Goolwa and Tauwitchere barrages during freshwater flows. This was consistent with (Chaplin *et al.* 1998), who indicated freshwater inflows were important to trigger spawning by this species.

5.5. Ewe Island fish passage

Similarities were observed between fish assemblages at this site and the Tauwitchere rock-ramp, although abundances were significantly lower at Ewe Island. The shallow approach to Ewe Island barrage suggests it is unlikely to be an important habitat for large bodied fishes attempting to move between Coorong and Lower Lake habitats. Nevertheless, complex reef habitat and shallow sand/mud channels exist near the barrage and provide suitable refuge habitat for small-bodied species.

If provision of fish passage was an option at Ewe Island, a small-bodied fish fishway would be suitable to pass the majority of the migratory fish community present at this site. The low numbers of diadromous species collected at this site is likely to be a symptom of drought conditions and almost zero freshwater inflows, in combination with long-term reduction in barrage flows at this site. Monitoring during significant flow periods is recommended at this site.

5.6. Proposed work for third year of project (2008/09)

A key focus of the third year of this project will be to monitor the response of fish to current drought conditions. A flexible sampling regime will be adopted in 2008/09 that targets estuarine conditions created through leakages at the barrages. This approach will provide comparable inter-annual data on fish movement, spawning and recruitment, and will provide a scientific basis to make decisions regarding operation of the barrage fishways and targeted delivery of environmental water to the Coorong in the future.

We also propose a pilot study to monitor the movement of congolli using acoustic tracking technology. This project will investigate spawning movements and behaviour of reproductively mature fish to identify critical migration periods and habitats required for spawning. Under current conditions diadromous species, in particular congolli, will require provision of passage at key times to maintain existing low population levels.

Further otolith analysis of YOY common galaxias and congolli will be conducted to provide detailed information on the spawning and recruitment ecology of these species in the Coorong and Lower Lakes. The age structure of fish from the 2006/07 low flow year will be compared to the fish collected during the subsequent no flow years.

6. Conclusion

Cessation of flows and fishway operation resulted in a reduction in the number and abundance of freshwater and estuarine dependant species, in particular diadromous fishes, and an increase in opportunistic marine species within the Coorong. A significant decline in the abundance of migrating YOY common galaxias and congolli was observed between 2006/07 and 2007/08. Common galaxias were able to adapt flexible spawning and recruitment strategies to utilise estuarine conditions above the Tauwitchere barrage. However, the physical barrier created by Tauwitchere barrage disrupted the spawning migration of adult congolli and together with the lack of estuarine conditions, likely contributed to the failure of this species to recruit in 2007/08.

Elevated salinities in the Coorong are subjecting an estuarine adapted ecosystem to a predominantly marine and increasingly hypersaline environment, and in the continued absence of freshwater inflows, the Coorong now resembles a marine embayment driven solely by coastal processes. Continued drought within the MDB will expose this highly modified estuarine ecosystem to unprecedented environmental extremes, in which recovery in the absence of adequate environmental flows is highly uncertain.

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Images this page: Tauwitchere barrage in November 2006 (top) and in January 2008 (bottom), showing the recession of Lake Alexandrina.

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