Inland Waters & Catchment Ecology

Salt Creek and Morella fishway assessment 2021-22




Q.Ye, L. Bucater, D. Short and C.Bice

SARDI Publication No. F2022/000401-1
SARDI Research Report Series No.1164

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

December 2022

Report to the Department for Environment and Water

Government of South Australia
Department of Primary Industries and Regions

Government of South Australia
Department for Environment and Water

SARDI
South Australian Research and Development Institute

Salt Creek and Morella fishway assessment 2021-22

Report to the Department for Environment and Water

Q.Ye, L.Bucater, D. Short and C.M Bice

SARDI Publication No. F2022/000401-1
SARDI Research Report Series No. 1164

December 2022

The South Australian Research and Development Institute respects Aboriginal people as the state's first people and nations. We recognise Aboriginal people as traditional owners and occupants of South Australian land and waters. We pay our respects to Aboriginal cultures and to Elders past, present and emerging

This publication may be cited as:
Ye, Q., Bucater, L., Short, D. and Bice, C.M. (2022). Salt Creek and Morella fishway assessment 2021-22. Report to the Department for Environment and Water. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2022/000401-1. SARDI Research Report Series No. 1164. 35pp.

Author(s): Q. Ye, L. Bucater, D. Short and C.M. Bice

Reviewer(s): K. Frahn (SARDI), A. Rumbelow and L. Vial (DEW)

Approved by: S. Nayar
Aquaculture Program Leader

Signed: 

Date: 25 January 2023

Distribution: Department for Environment and Water, SARDI Aquatic Sciences, Parliamentary Library, State Library and National Library

Circulation: OFFICIAL

ALL ENQUIRIES
South Australian Research and Development Institute - SARDI Aquatic Sciences
2 Hamra Avenue West Beach SA 5024
PO Box 120 Henley Beach SA 5022
P: (08) 8207 5400 **F:** (08) 8207 5415
E: pirsa.sardiaquatics@sa.gov.au **W:** http://www.pir.sa.gov.au/research

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

This project was funded by the South Australian Department for Environment and Water (DEW) as part of its ongoing responsibilities for effective use and management of water for the environment in South Australia. The project was managed by Adrienne Rumbelow, Kirsty Wedge and Luke Vial (DEW). We acknowledge the people of the Ngarrindjeri Nation and First Nations of the South East as the traditional custodians of the land on which this study was undertaken. Thanks to Rick Hartman and Candice Love of the Ngarrindjeri Aboriginal Corporation and Kirsty Wedge (DEW) for organising field work collaboration, and to Trevor Sumner, Brad Hartman, Russell Rigney, Brian Kropinyeri and Malcolm Aston for working together with us on Country. The authors would like to thank SARDI staff (Arron Strawbridge, Jonathan Western and Sarah-Lena Reinhold) for assistance with fieldwork. Special thanks to Mark de Jong (South Australian Limestone Coast Landscape Board) and Richard Palmer (South Eastern Water Conservation and Drainage Board) for their constant support including the provision of relevant information of fishway design, construction history and modified fishway configurations, ongoing advice on the hydrological conditions, structure operation and assistance with fieldwork logistics. Also, thanks to Chrissie Bloss (DEW) for her support to this project. Finally, we thank Adrienne Rumbelow, Luke Vial (DEW) and Kate Frahn (SARDI) for constructive reviews of a draft of this report. The report was formally approved for release by Dr Mike Steer, Research Director, SARDI Aquatic and Livestock Sciences.

EXECUTIVE SUMMARY

The restoration of biological connectivity and facilitation of fish passage between the Coorong and South East is one of the ecological objectives of the *South East Flows Restoration Project* (SEFRP). This included upgrades of the Salt Creek and Morella flow regulators and the construction of associated rock-ramp fishways. These fishways were designed to facilitate the passage of six key species: congolli (*Pseudaphritis urvillii*), common galaxias (*Galaxias maculatus*), yelloweye mullet (*Aldrichetta forsteri*), smallmouth hardyhead (*Atherinosoma microstoma*), bluespot goby (*Pseudogobius olorum*) and black bream (*Acanthopagrus butcheri*), anticipating that functional fishways for these species would facilitate passage of the whole fish community in the region. The current study aimed to assess fish passage efficiency against biological design objectives for both fishways and was the first formal fish monitoring at these structures since construction was completed in 2019. Specifically, fish trapping was conducted at the entrance and exit of each fishway to compare species composition, and species-specific abundances and length distributions.

From 3 to 26 November 2021, 13 paired-day sampling events were undertaken at the entrances and exits of the two fishways. A total of 61,361 fish were captured from seven species, comprising the majority of fishes that occur in the Coorong South Lagoon and expected to use the fishways. At both fishways, catches were overwhelmingly dominated (>99% by number) by smallmouth hardyhead.

The Salt Creek fishway effectively facilitated passage of congolli and yelloweye mullet. Passage efficiency appeared limited, however, for the small-bodied estuarine smallmouth hardyhead (<40 mm TL) and bluespot goby (<60 mm TL) particularly for smaller individuals. This was likely due to a combination of poor swimming ability, fishway internal hydraulics, and potentially, lack of drive for upstream movement. During the monitoring, Salt Creek discharge was 50–95 $ML.day^{-1}$ and the fishway exit water depth ranged 0.3–0.38 m, which is near the maximum of the optimal design range (depths 0.1–0.4 m).

The Morella fishway provided effective fish passage for congolli >100 mm TL and seemed to accommodate the passage of larger sized yelloweye mullet. Nevertheless, passage efficiency for congolli <100 TL mm was reduced, and the passage for smallmouth hardyhead (particularly individuals <40 mm TL) and bluespot goby appeared to be impeded. During monitoring, water depth at the Morella fishway exit ranged 0.35–0.46 m, which was slightly above the designed optimal functional range (depths 0.1–0.4 m). This at least partially explained the reduced passage efficiency of this fishway. Moreover, the conspicuous absence

of young-of-year congolli (<60 mm TL) at the Morella fishway (even at the entrance), while they were abundant at the Salt Creek fishway exit, suggests potential obstruction of upstream movement by the crump weir within Salt Creek and warrants further investigation.

Overall, initial fishway monitoring in 2021 suggested generally efficient passage for congolli and yelloweye mullet at both fishways, but poor passage for small-bodied estuarine species. Upstream movements of estuarine species are not life history driven, and rather, high abundance at fishway entrances may reflect use of the rock-ramp fishways as habitat for these species. Nonetheless, facilitating effective passage may be important for estuarine species to access upstream refuge habitats (e.g. lower salinities) when environmental condition deteriorates in the South Lagoon (e.g. increase to unfavourable salinities). Further monitoring of both fishways will be required to assess passage efficiency under the full range of hydrological conditions (flow discharge and water levels) and seasons. This data, in conjunction with improved understanding of fish movement ecology (direction and timing for different species and life stages), will inform the regulator/fishway operations, potential structural modifications, and the development of flow management plans/guidelines to optimise fishway function, considering the broader context of ecological objectives for the Coorong and South East region.

Keywords: Fish passage, Coorong South Lagoon, Morella, connectivity, rock-ramp.

1. INTRODUCTION

1.1. Background

The South East Flows Restoration Project (SEFRP) was implemented to improve the health of the Coorong by managing salinity in the South Lagoon via the diversion of excess freshwater from the Upper South East of South Australia. Flows from the drains of the Upper South East are diverted in a northerly direction, discharging into the Coorong South Lagoon via Salt Creek. The works for SEFRP include approximately 93 km of open drains which extend from Blackford on the Blackford Drain in the south to the Salt Creek outfall in the north (Figure 1.1).

As part of the SEFRP, two rock-ramp (or 'nature-like') fishways were designed and constructed in conjunction with regulator upgrades at the Salt Creek outfall and Morella Basin outlet (Figure 1.2) (KBR 2019). These structures regulate upstream water levels and flows between the South East drainage system and the Coorong. Previous structures had no consideration for fish passage and were barriers to the upstream movement of fish from the Coorong into the South East drainage system and wetlands. Improved fish movement/migration will enhance population connectivity between the Coorong and South East, promoting population resilience and associated ecological (e.g. food webs), fishery and cultural benefits.

A diverse range of fish species have been recorded from the Coorong (Bice et al. 2018), a subset of which, are commonly present in the hypersaline South Lagoon. This includes the solely estuarine smallmouth hardyhead (*Atherinosoma microstoma*) and bluespot goby (*Pseudogobius olorum*); marine-estuarine opportunist yelloweye mullet (*Aldrichetta forsteri*) and catadromous[a] congolli (*Pseudaphritis urvillii*) (Ye et al. 2020). These species are commonly found in the vicinity of Salt Creek and may seek to move between the Coorong South Lagoon and Southeast drainage system in order to complete their lifecycle (i.e., congolli) or to access low salinity refuge habitat when salinities in the Coorong South Lagoon are elevated (commonly summer/autumn) and unfavourable (i.e., all species). The aforementioned species, along with black bream (*Acanthopagrus butcheri*), a large-bodied estuarine species, and common galaxias (*Galaxias maculatus*), another catadromous species, were included in the consideration of fishway design (KBR 2019). It was anticipated

[a]Catadromous: This guild refers to species whose adult life is spent in fresh water, prior to downstream migration into the marine environment for spawning (Potter et al. 2015). Larvae and juveniles develop in the ocean before migrating upstream into freshwater habitats.

that these six species well-represented fish passage needs, and fishway design specifications for them would accommodate the passage of other species potentially present in this region.

Critical to any fishway construction program is the assessment of the effectiveness of the fishways against their design specifications and biological objectives. This project provided assessment of the biological effectiveness of the Salt Creek and Morella fishways. Advice is provided on future operation of the regulators and associated fishways, potential structure improvements, and further investigations.

1.2. Objectives

The overall aim of this project was to assess the effectiveness of Salt Creek and Morella rock-ramp fishways with a focus on fish passage efficiency. Specific objectives were to:

- Design and construct nets/traps for sampling the entrances and exits of the two fishways.
- Undertake ‘entrance and exit trapping’ of each fishway and compare data on fish species composition, abundance and length between entrance and exit samples to determine passage efficiency against fishway-specific biological objectives; and
- Inform future regulator/fishway operation to maximise fish passage.

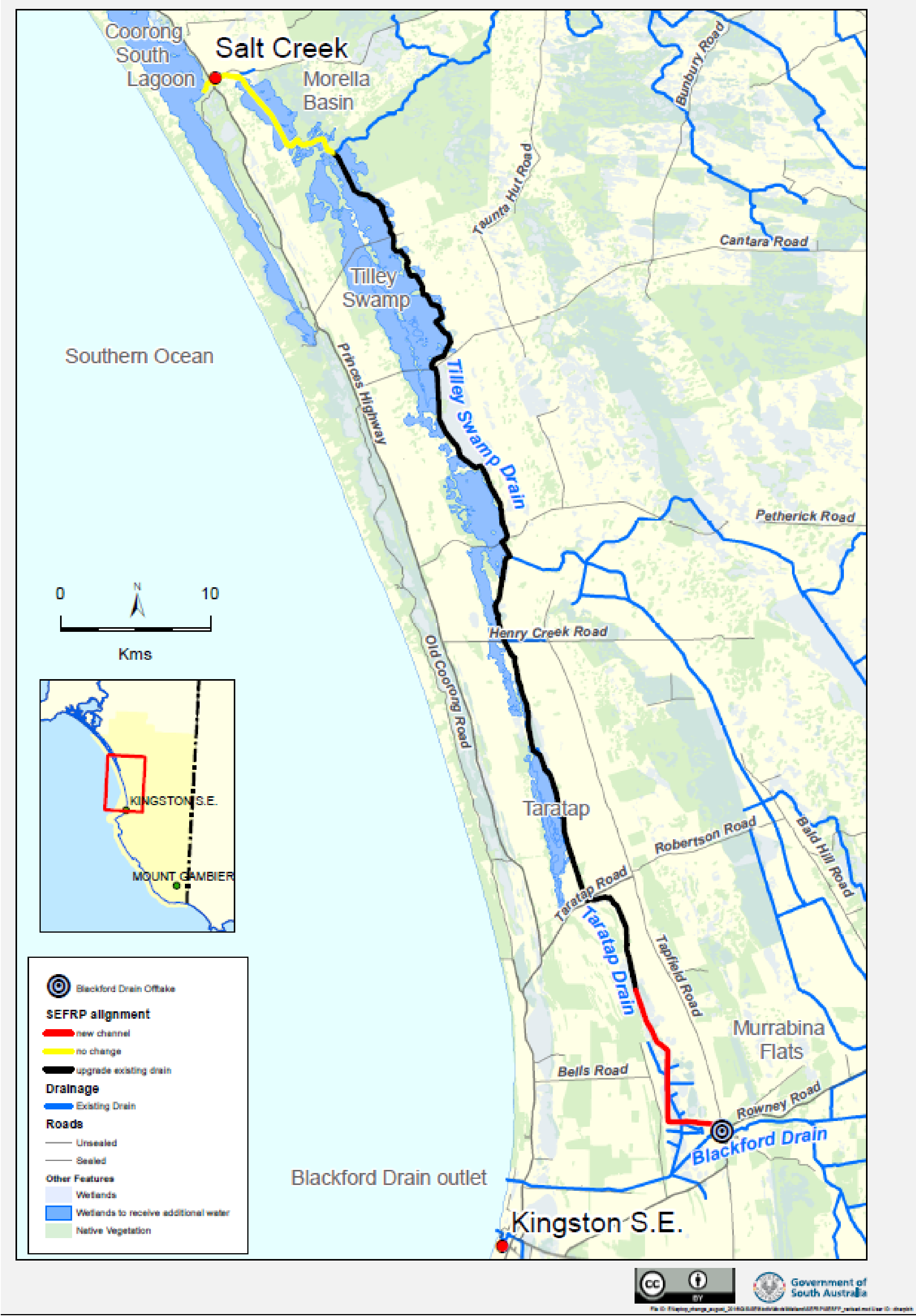

Figure 1.1. South East Flows Restoration Project Alignment (Department for Environment and Water).

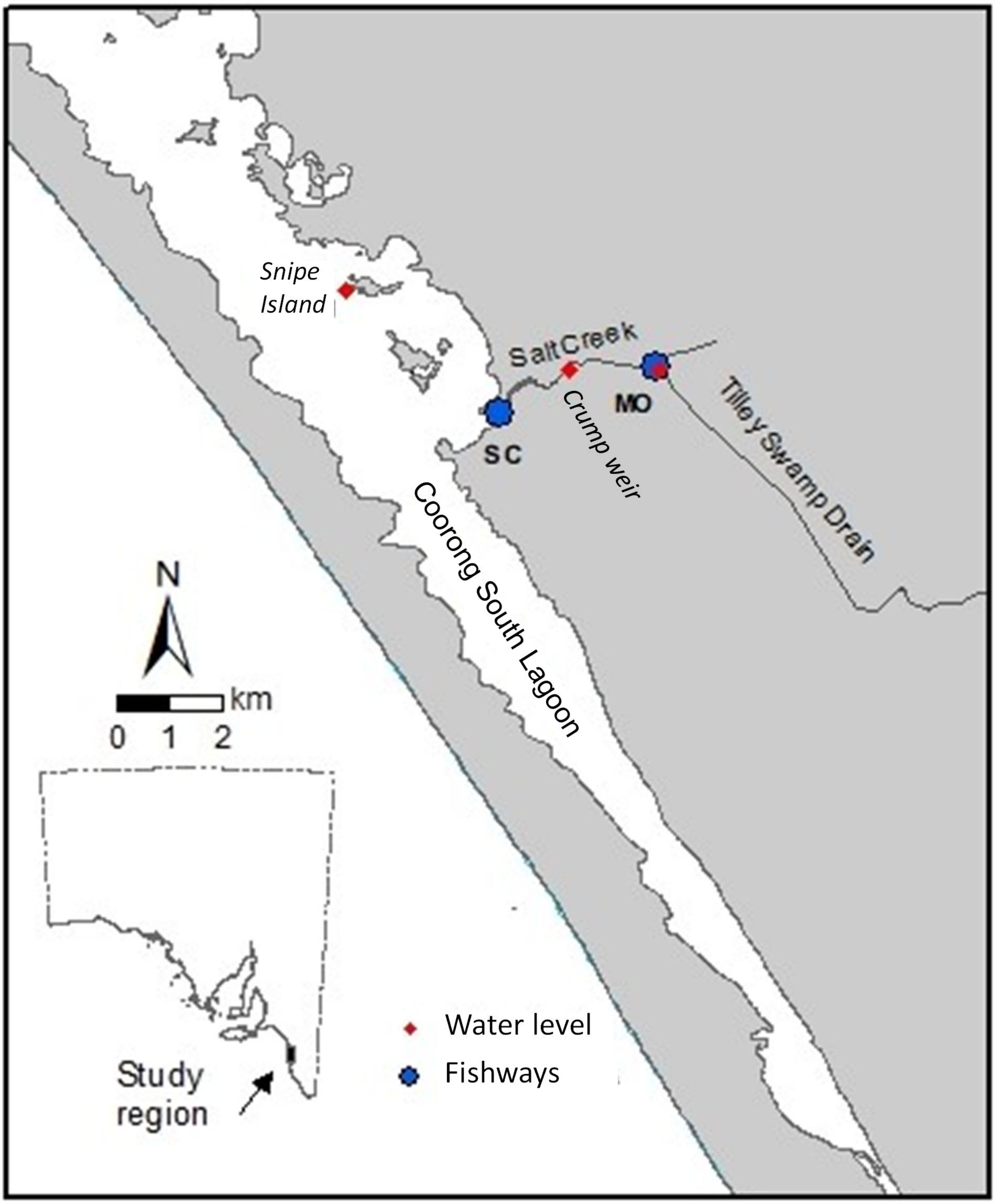

Figure 1.2. A map of the study sites including the location of the Salt Creek (SC) and Morella (MO) fishways and telemetered surface water level monitoring stations.

2. METHODS

2.1. Fishways, hydrology and sampling trap design

Fishways

The Salt Creek rock-ramp fishway bypasses the Salt Creek regulator and has a total length of ~60 m and base width of 3–4 m (Figure 2.1). It consists of a series of pools (n = 12) interspersed by rock ridges/riffles. The rock ridges comprise of large boulders (height ~0.5–0.7 m) with small gaps (width ~0.2–0.35 m) in-between. Lengths of pools range from 2–7 m with drops between the pools of ~100 mm, and overall fishway slope is 1:46. There are two box culverts incorporated in the fishway: Culvert 1 at the fishway exit (width 2.1 m; length 2.4 m), which incorporates a penstock gate at the upstream end, and Culvert 2 at mid-point of the fishway to allow vehicular traffic (width 2.1 m; length 4.8 m) (Figure 2.1). The penstock gate on Culvert 1 can be operated to shut and dewater the fishway (i.e. when Salt Creek water level exceeds the operating range of the fishway, or for fishway maintenance work).

Similarly, the Morella rock-ramp fishway bypasses the Morella regulator and has a total length of ~45 m and base width of 3.5–7 m (Figure 2.1). It consists of 14 pools interspersed by rock ridges/riffles. The rock ridges comprise of large boulders (height ~0.5–0.7 m) with small gaps (width ~0.2–0.35 m) in-between. Lengths of pools range from 2–3 m with drops between the pools of ~100 mm, and overall fishway slope is ~1:30. The last section of the fishway incorporates a box culvert (width ~2.1 m; length ~6 m) with a penstock gate before fish enter a small side exit channel (see Figure 2.1) which leads to the Morella Basin proper. The penstock gate on the culvert can be operated to shut and dewater the fishway when required (i.e. when Morella Basin water level exceeds the operating range of the fishway, or for fishway maintenance work).

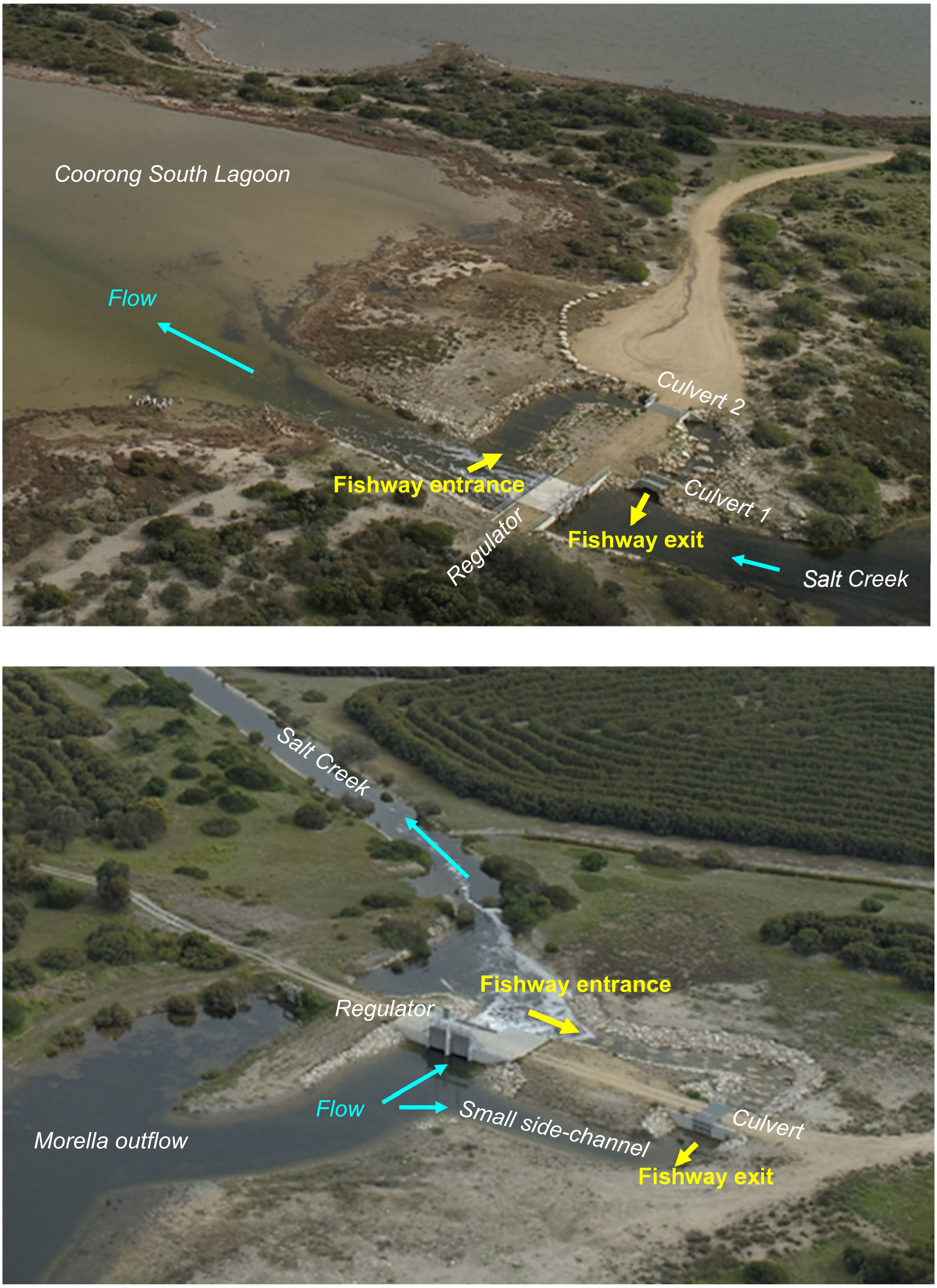

Figure 2.1. Drone photo of the Salt Creek rock-ramp fishway (top) and Morella rock-ramp fishway (bottom) (G. Bowman, South East Water Conservation and Drainage Board).

Hydrology

The two rock-ramp fishways were designed to operate under limited hydrological scenarios, including optimum fishway discharge rates from 0–40 ML.day^{-1}, water depth at the fishway exit of 0.1–0.4 m (i.e. 3.8–4.1 m AHD at Morella; 0.95–1.25 m AHD at Salt Creek) and head loss of ~1,300 mm. The upstream water levels and discharge are managed by operation of the Morella and Salt Creek regulators. At times, all flow can be delivered through the fishways or discharge can be shared by the fishways and regulator structures (i.e. through lay-flat gates). Operational scenarios have an influence on headwater and tailwater levels, and therefore, fishway hydraulics and function.

Over the past two decades from 2000/01–2020/21, annual discharge of Salt Creek was highly variable, ranging between 0–55 GL.year^{-1} (mean 14.2 GL.year^{-1}); daily discharge was generally <300 ML.day^{-1}, and salinity in Salt Creek varied from fresh to brackish (0–30.4 ppt) (Figure 2.2). Flows were highly seasonal, with peak discharges occurring between July to October (winter–spring). In 2021/22, annual flow discharge of Salt Creek was 24 GL. During winter–spring, high rainfall across the South East region enabled increased releases from Salt Creek to the Coorong. The newly upgraded Morella and Salt Creek regulators were tested and operated at higher discharges (>400 ML.day^{-1}) between late August and early September 2021. Both fishways were in operation from early August 2021 to early February 2022, during which regulators were operated to adjust the split of discharge through regulator gates and associated fishways, attempting to maintain optimal water depths at both fishway exits (0.1–0.4 m). The estimated percentages of the regulator-fishway flow split at Salt Creek and Morella are presented in Table 2.1.

Table 2.1. Estimates of the split of flow discharge through the regulator and associated fishway at Salt Creek and Morella from early August 2021 to early February 2022 (Richard Palmer 2022, personal comm.).

	Estimated split of flow discharge (%)		Mean discharge (ML.day^{-1})
Date	**Regulator**	**Fishway**	
11 Aug – 25 Aug 2021	75	25	230
26 Aug – 8 Sep 2021	90	10	557
9 Sep – 15 Dec 2021	50	50	93
16 Dec 2021 – 10 Feb 2022	0	100	14

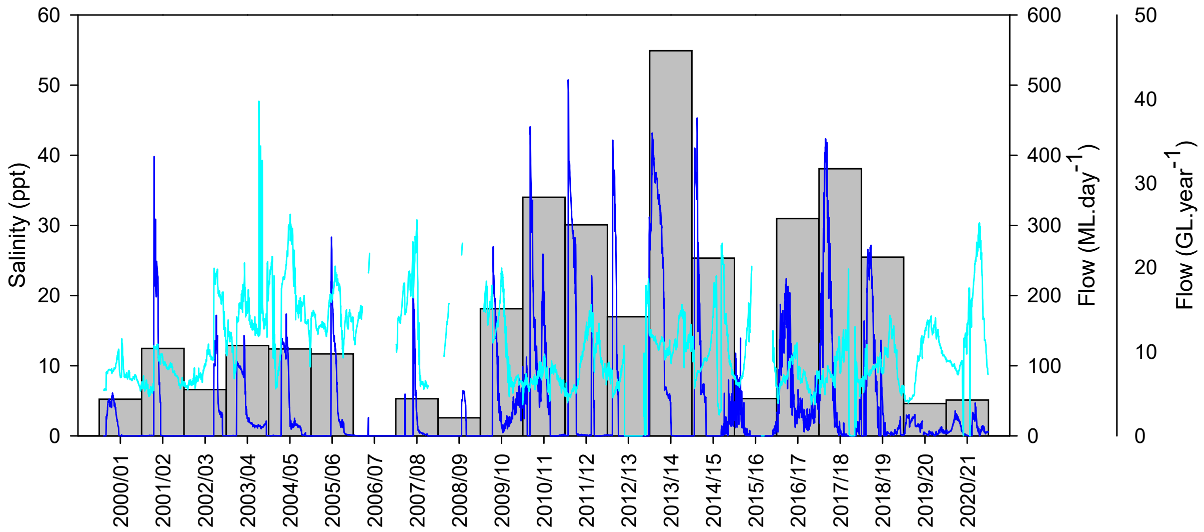

Figure 2.2. Annual (grey bar; GLyear^{-1}) and daily (blue line; MLday^{-1}) discharge through the Salt Creek outfall, with salinity levels (cyan line; ppt) from July 2000 to June 2021 (DEW 2021, Water Data SA, Station A2390568).

Fishway trap/net design

A field reconnaissance trip was conducted in August 2021 to inspect the Salt Creek and Morella fishways (Figure 2.1). *In situ* measurements and 'as constructed' design drawings allowed for detailed net/trap design for the two fishways (Figure 2.3). Because the individual fishways have different dimensions, specific traps were designed to sample the entrance and exit of each fishway.

For the Salt Creek fishway, two different fyke net designs were employed to sample the entrance and exit. To trap the fishway entrance, a double wing fyke was used, which had a 3.5 m long body with five hoops, two funnels and 6 m wings, and 4 mm mesh. The wings and entrance of the fyke net were 0.7 m high to sample the entire water column within the fishway. At the fishway exit, a wingless fyke net was used with the same dimensions as above. An aluminum frame was fitted to the mouth of the fyke net body, which was subsequently set abutting the exit of Culvert 1. This covered the entire fishway exit and replaced the need for the fyke wings.

For the Morella fishway, a double wing fyke net was designed and constructed to trap both the exit and entrance of the fishway. It had a 4 m long body with five hoops, two funnels and 6 m wings, and 4 mm mesh. The wings and entrance of the fyke net were 1.1 m high to sample the entire water column within the fishway.

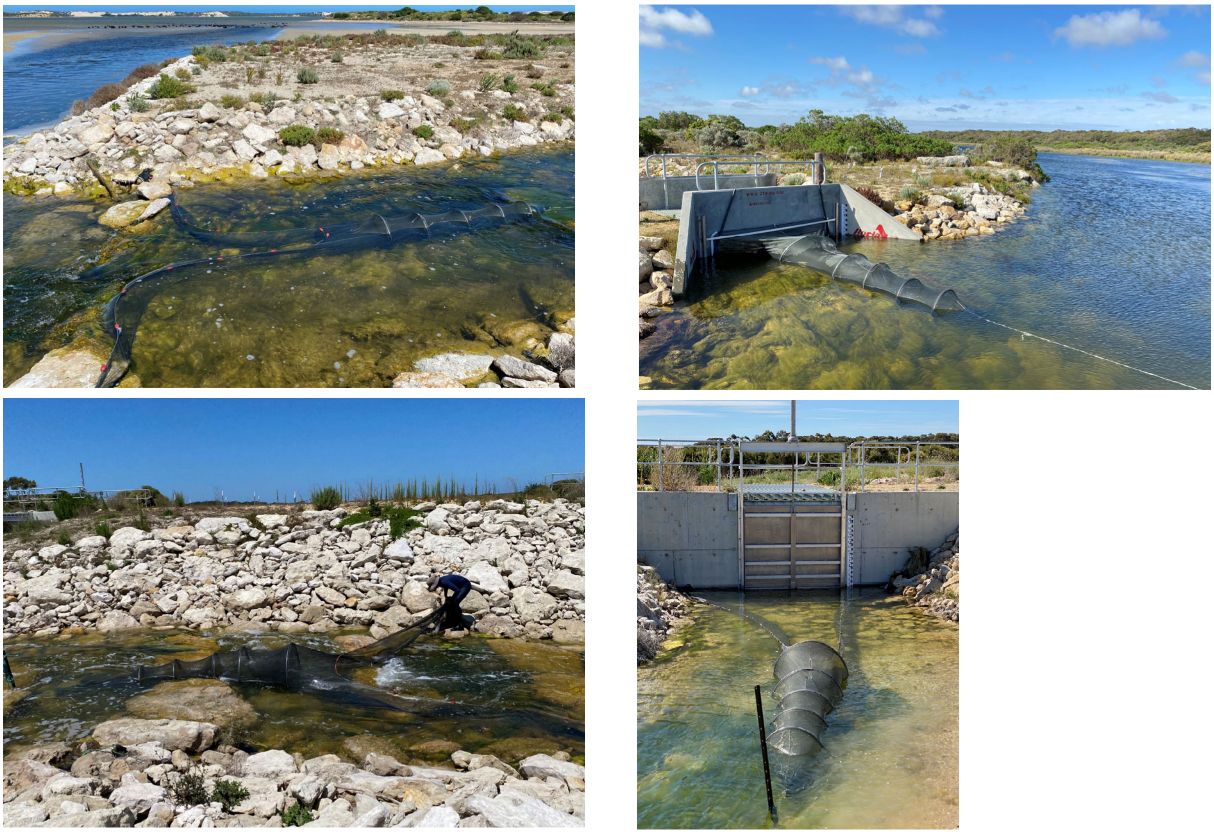

Figure 2.3. Fish trapping at the Salt Creek rock-ramp fishway entrance (top left) and exit (top right) and the Morella rock-ramp fishway entrance (bottom left) and exit (bottom right).

2.2. Fish sampling and fishway assessments

Trapping involved undertaking paired replicate samples of the fishway entrances and exits, each for an overnight period of ~18–24 hours (see Appendix A). Entrance and exit trapping allowed for a comparison between the species, abundance and size range of fish that entered the fishway (entrance trapping) with those that successfully ascended (exit trapping). Following a pilot sampling at the Morella fishway, formal fishway trapping was conducted over four weeks from 3 November to 26 November 2021. This resulted in a total of seven entrance and seven exit trapping events for the Salt Creek fishway and six entrance and six exit trapping events for the Morella fishway (Appendix A). Prior to undertaking trapping, SARDI staff consulted with the water managers and operators (Department for Environment and Water, South East Water Conservation and Drainage Board) of the structures to ensure the regulators were being operated in a way that maximised fish attraction to the fishways.

Upon retrieval, all trapped fish were removed from nets and placed in aerated holding tubs, before being identified to species and enumerated. A sub-sample of fish (up to 50 individuals per species per trapping event) were measured for length (mm, total length) to represent the size structure from the sampled population at the fishway entrance or exit.

During trap retrieval, water quality parameters (i.e. salinity, temperature, pH) were recorded using a TPS water quality meter and water transparency was measured with the aid of a Secchi disc. Measurements were taken at the entrance and exit of both fishways.

2.3. Data analysis

Fish passage efficiency at the Salt Creek and Morella fishways was assessed by comparing assemblage structure, species-specific abundance and length-frequency distributions between entrance and exit trapping events. Similarity in fish assemblages, with regards to species identity and abundance (fish.hour^{-1}.trap event^{-1}), among entrance and exit samples was assessed using multidimensional scaling (MDS) ordination and a single-factor (trap position) PERMANOVA (Permutational Multivariate Analysis of Variance) ($\alpha = 0.05$). These analyses were performed on Bray-Curtis similarity matrices in the software package PRIMER v. 6.12 and PERMANOVA+ (Anderson et al. 2008). When difference occurred, Similarity of Percentages (SIMPER) analysis was used to determine species contributing to differences in assemblages (a 70% cumulative contribution cut-off was applied). Species-specific passage efficiency was assessed for the most abundant species (> 20 individuals) at each fishway by comparing relative abundance (fish.hour^{-1}.trap event^{-1}) between entrance and exit samples using uni-variate PERMANOVA, performed on Euclidean Distance similarity matrices. Due to low numbers of permutations in some instances, *p* values were compared with the Monte Carlo *p* values (*p* MC), where the real data were compared against 5000 runs of randomised data (Dufrene and Legendre 1997). There were no differences in statistical results, and thus we presented *p* values. Fish relative abundance data were square-root transformed prior to all analyses.

The length-frequency distributions of the most common species (i.e. >25 individuals sampled at both the entrance and exit) were compared between entrance and exit trapping events to determine if any size-related obstruction of passage had occurred. A two-tailed Kolmogorov-Smirnov ‘goodness-of-fit’ test was used to determine statistical differences ($\alpha = 0.05$) in length-frequency distributions between entrance and exit samples (pooled over the study period).

3. RESULTS

3.1. Environmental conditions

In late winter–early spring 2021, Salt Creek discharge increased from ~10 ML.day^{-1} to a peak of 796 ML.day^{-1} on 26 August 2021 (Figure 3.1). Discharge reduced to ~220 ML.day^{-1} around mid-September 2021, then further reduced to ~110 ML.day^{-1} in early October 2021, and remained <100 ML.day^{-1} for the rest of the year. During the fishway trapping period (3–26 November 2021), discharge varied between 50–95 ML.day^{-1} (mean = 79 ML.day^{-1}), with releases through both regulators and fishways. The flow split between each regulator and associated fishway was estimated at approximately 50%:50% during this period (Table 2.1).

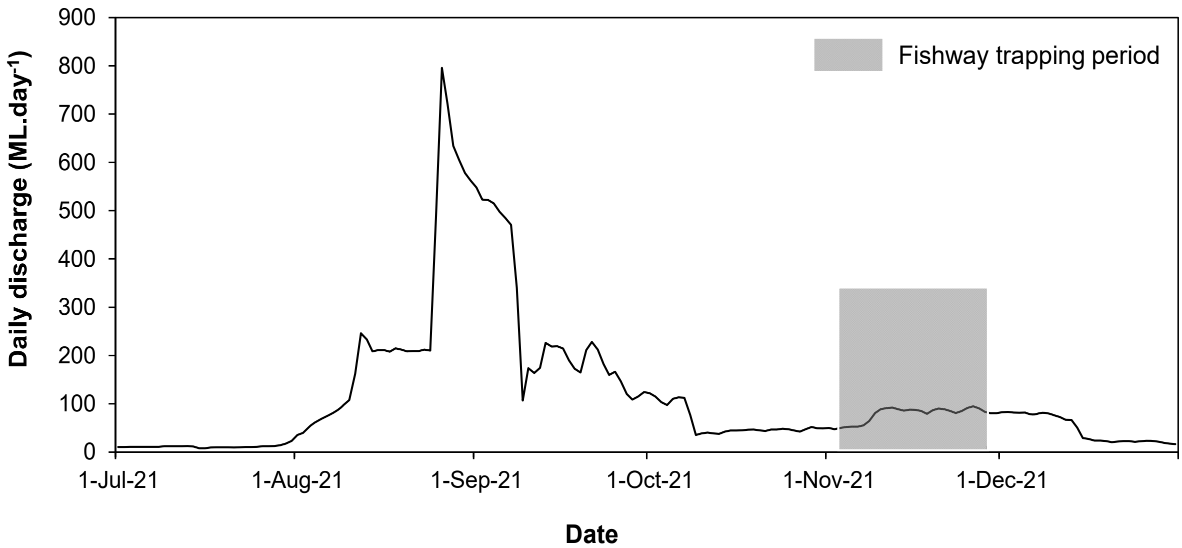

Figure 3.1. Daily flow discharge from Morella/Salt Creek (ML.day^{-1}) and the period for assessing the Salt Creek and Morella rock-ramp fishways (grey bar).

During fishway trapping, headwater levels ranged 4.13–4.23 m AHD above the Morella regulator (Figure 3.3), 2.44–2.58 m AHD at the Salt Creek crump weir (Figure 3.2), and 0.09–0.37 m AHD in the Coorong South Lagoon (Snipe Island) (Figures 1.2 and 3.3). Specifically, the water depth ranged 0.35–0.46 m (4.05–4.16 m AHD) at the exit of the Morella fishway and 0.30–0.38 m (1.15–1.23 m AHD) at the exit of the Salt Creek fishway (Figure 3.3). There were no gauge boards at the entrance of each fishway to measure tailwater levels.

Water quality parameters during fish sampling are presented in Table 3.1. Dissolved oxygen levels were higher at the Morella fishway (both entrance and exit) compared to the Salt Creek fishway, while the range of other parameters were similar.

Table 3.1. The ranges of water quality parameters during fishway trapping at the Salt Creek and Morella fishways from 4–26 November 2021.

	Salt Creek Fishway		Morella Fishway	
Water quality	**Entrance**	**Exit**	**Entrance**	**Exit**
Salinity (ppt)	8.2–8.5	8.2–8.5	8.1–8.4	8.1–8.3
Temperature (°C)	15.1–21.0	15.8–20.2	13.8–21.0	14.8–22.6
Dissolved oxygen (mg.L^{-1})	4.3–6.7	3.4–6.4	8.7–10.2	7.8–11.3
pH	8.4–10.2	9.6–9.9	7.9–10.1	8.2–10.1
Secchi disc depth (mm)	1,000	1,000	1,000	1,000

Figure 3.2. Crump weir gauging station for water levels within Salt Creek.

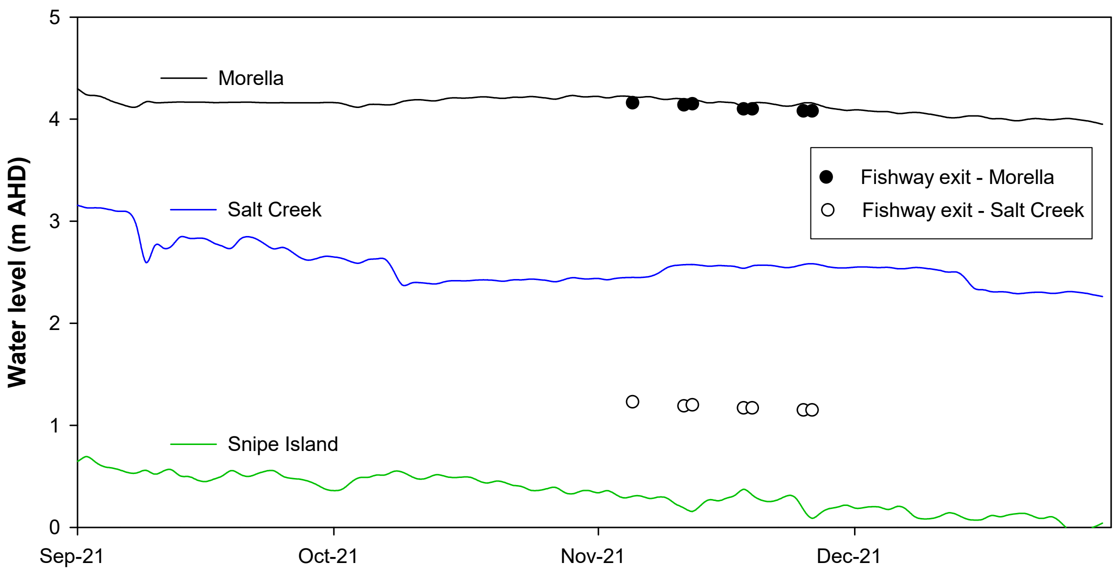

Figure 3.3. Daily average water levels (m AHD) just above the Morella regulator (A2391274), at Salt Creek crump weir (A2390568), and at Snipe Island (A4261165) in the Coorong South Lagoon between 1 September and 31 December 2021 (data Source: Department for Environment and Water (DEW)), and measurements by SARDI staff at the exits of the Salt Creek and Morella fishways during trapping.

3.2. Catch summary

A total of 61,361 fish from seven species were sampled collectively from the Salt Creek and Morella fishways (Table 3.2). The overall catch was numerically dominated by small-bodied estuarine smallmouth hardyhead (99.56% of total catch). The next most numerous species were the medium-bodied catadromous congolli (0.19%), the medium-bodied marine-estuarine opportunist yelloweye mullet (0.15%), and the small-bodied estuarine bluespot goby (0.09%). The above four species were present at both fishways. Three further species were sampled in low numbers ($n \leq 3$) from individual fishways, namely the large-bodied estuarine black bream and catadromous shortfin eel (*Anguilla australis*) at the Salt Creek fishway and the small-bodied freshwater-estuarine opportunist flatheaded gudgeon *(Philypnodon grandiceps)* at the Morella fishway (Table 3.2).

Table 3.2. Species, total numbers and total length (TL) range (mm) of fish sampled during the Salt Creek and Morella fishway monitoring in November 2021. FG = Functional group, E = Estuarine, C = Catadromous, FO = freshwater-estuarine opportunist, MO = Marine-estuarine opportunist.

				Salt Creek			Morella			Total
Common name	**Scientific name**	**FG**	**Body size**	**Entrance**	**Exit**	**TL range**	**Entrance**	**Exit**	**TL range**	
	Sampling events			7	7		6	6		
	No. of species			5	5		4	3		**7**
Smallmouth hardyhead	*Atherinosoma microstoma*	E	Small-bodied	25,990	753	24–105	31,840	2,511	15–107	**61,094**
Bluespot goby	*Pseudogobius olorum*	E	Small-bodied	43	4	33–69	7		45–67	**54**
Black bream	*Acanthopagrus butcheri*	E	Large-bodied	3		280–320				**3**
Congolli	*Pseudaphritis urvillii*	C	Medium-bodied	21	73	31–243	6	14	89–196	**114**
Shortfin eel	*Anguilla australis*	C	Large-bodied		1	1,070				**1**
Flatheaded gudgeon	*Philypnodon grandiceps*	FO	Small-bodied				1		67	**1**
Yelloweye mullet	*Aldrichetta forsteri*	MO	Medium-bodied	50	42	40–280		2	285–290	**94**
Total				**26,107**	**873**		**31,854**	**2,527**		**61,361**

3.3. Passage efficiency

3.3.1. Salt Creek fishway

At the Salt Creek fishway, a total of 26,107 fish from five species were sampled from entrance trapping, and 873 fish from five species from exit trapping (Table 3.2). Black bream was the only species sampled exclusively at the entrance (n = 3), and shortfin eel (n = 1) was the only species exclusively sampled at the exit, whilst the remaining four species were sampled at both the entrance and exit. PERMANOVA indicated that fish assemblages from the entrance and exit trap samples were significantly different (Pseudo-$F_{1, 12}$ = 8.189, p = 0.007, Table 3.2). This was supported by MDS ordinations of fish assemblage data, which exhibited a strong dispersion of samples from entrance and exit trapping (Figure 3.4). SIMPER suggested that the assemblages differed primarily (87%) due to greater abundances of smallmouth hardyhead sampled at the entrance (Figure 3.5; Appendix B).

Relative abundances were significantly higher at the fishway entrance than exit for smallmouth hardyhead (Pseudo-$F_{1, 12}$ = 8.97, p = 0.004) and bluespot goby (Pseudo-$F_{1, 12}$ = 9.11, p = 0.011), whereas the abundance of congolli was significantly higher at the exit than entrance (Pseudo-$F_{1, 12}$ = 8.61, p = 0.009) (Table 3.2; Figure 3.5). Yelloweye mullet abundances were not significantly different (Pseudo-$F_{1, 12}$ = 0.18, p = 0.718) between the entrance and exit.

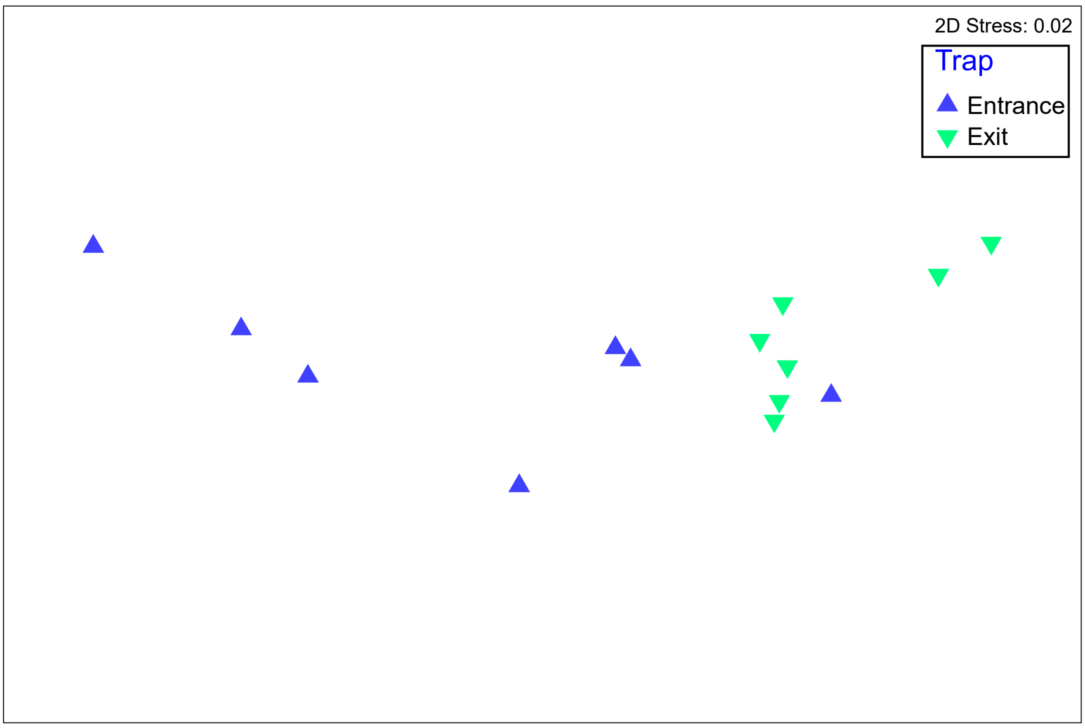

Figure 3.4. Non-metric multi-dimensional scaling (MDS) ordination of fish assemblages from each of the entrance and exit samples at the Salt Creek rock-ramp fishway.

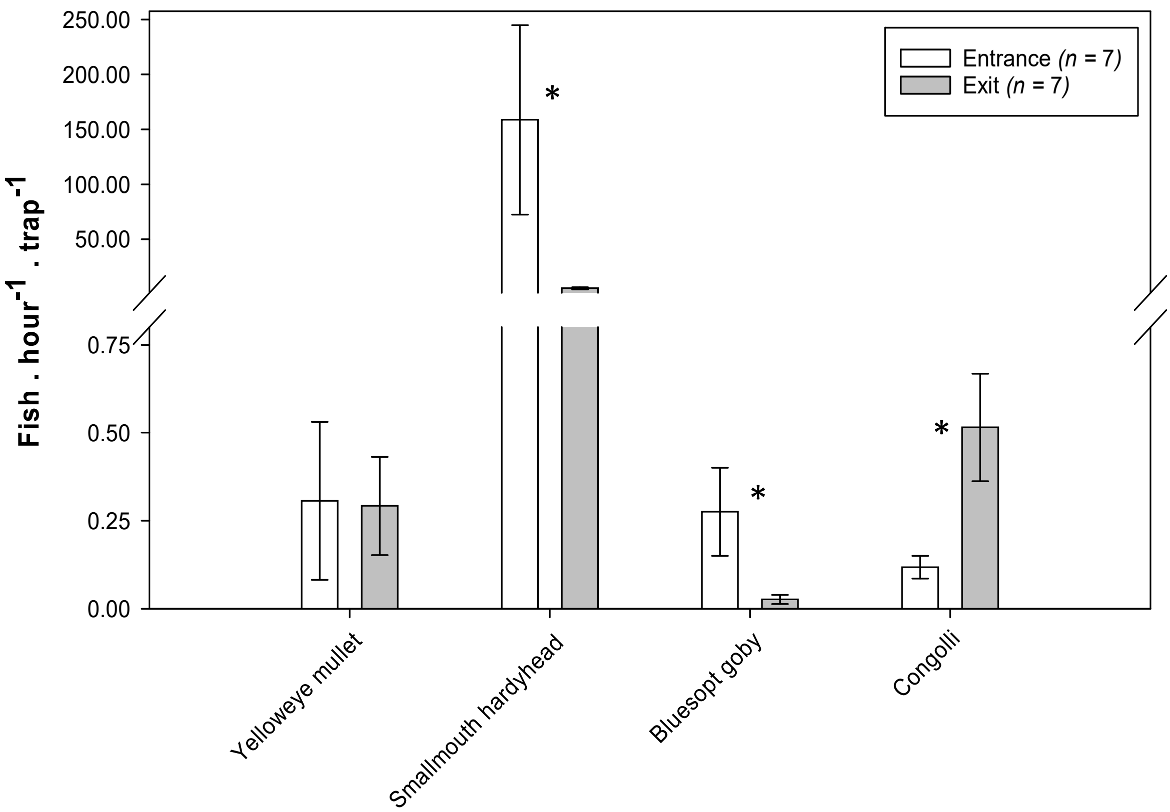

Figure 3.5. Comparison of mean relative abundance (number of fish.hour^{-1}.trap event^{-1} ± standard error) of the most abundant species sampled at the entrance (white bar) and exit (grey bar) of the Salt Creek rock-ramp fishway during November 2021. Significant differences between entrance and exit abundance are indicated by asterisks.

Fish sampled at the entrance of the Salt Creek fishway ranged from 24–320 mm in TL, whilst those sampled at the exit ranged from 28–240 mm in TL (Figure 3.6), except for the single shortfin eel of 1,070 mm TL collected at the exit (Table 3.2). The length-frequency distributions for smallmouth hardyhead ($D_{350, 309} = 0.342$, $p < 0.001$) were significantly different between the fishway entrance and exit; there was a greater proportion of individuals 20–39 mm TL sampled from the entrance (39%) than the exit (5%) (Figure 3.6b). For yelloweye mullet ($D_{50, 42} = 0.119$, $p = 1$), the length-frequency distributions were not significantly different between the entrance and exit (Figure 3.6a).

There were insufficient numbers of bluespot goby and congolli sampled to enable statistical comparison. Nonetheless, congolli sampled at the fishway exit appeared to be smaller than those at the entrance, for instance, congolli <40 mm TL represented 30% of the fish sampled at the exit compared to 10% at the entrance. For bluespot goby, the proportion of fish <60 mm TL seemed greater at the fishway entrance than the exit although the sample size was low at the exit ($n = 4$) (Figure 3.6).

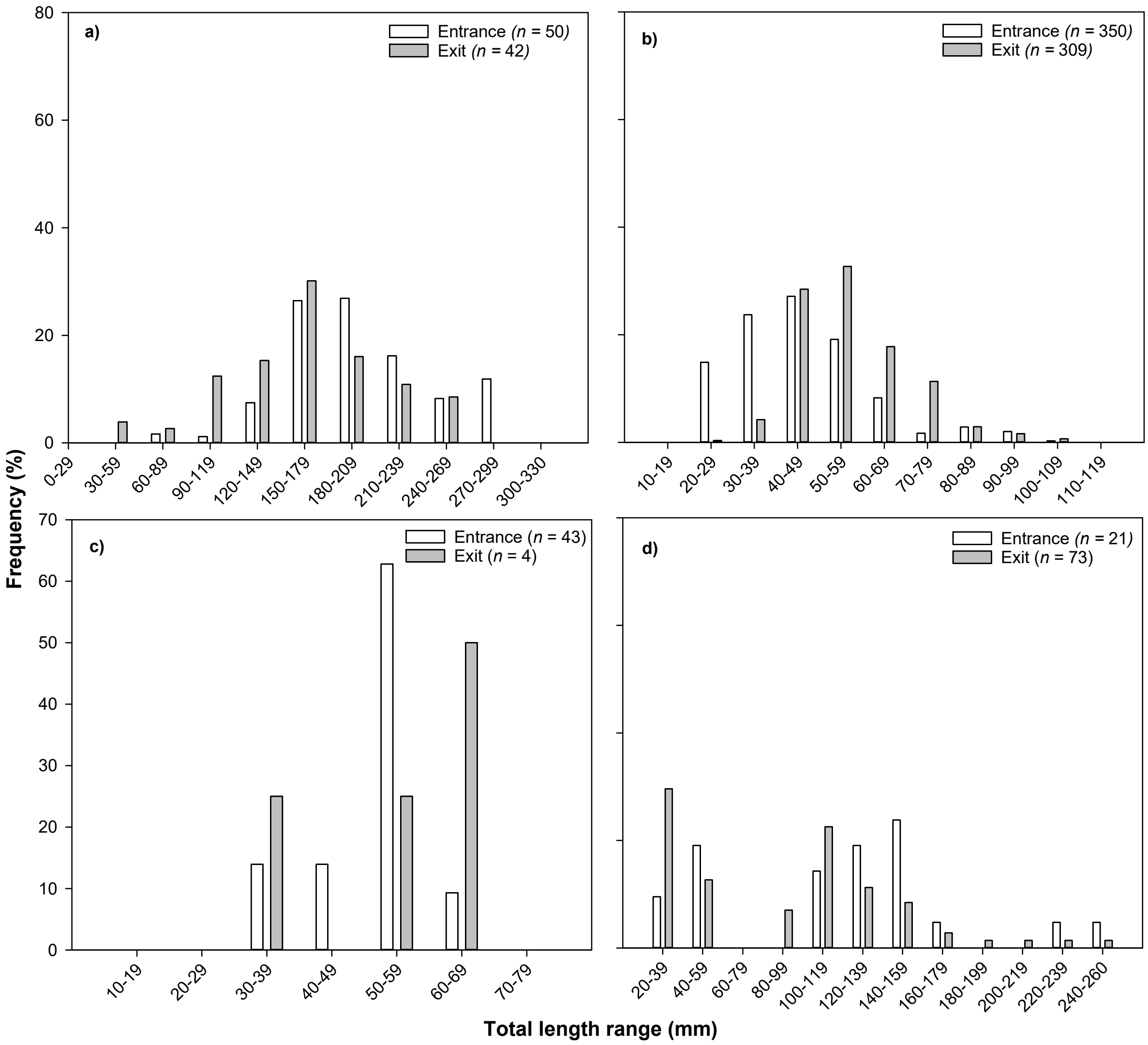

Figure 3.6. Length-frequency distributions of a) yelloweye mullet, b) smallmouth hardyhead, c) bluespot goby and d) congolli captured from the entrance (white) and exit (grey) of the Salt Creek rock-ramp fishway during November 2021. Sample sizes (*n*) represent the number of fish measured for length for each species. Note: plots have varying axis scaling.

3.3.2. Morella fishway

At the Morella fishway, a total of 31,854 fish from four species were sampled from entrance trapping, and 2,527 fish from three species from exit trapping (Table 3.2). Bluespot goby (*n* = 7) and flatheaded gudgeon (*n* = 1) were exclusively sampled at the entrance, whilst yelloweye mullet (*n* = 2) were only sampled at the exit, and the remaining two species, smallmouth hardyhead and congolli, were sampled at both the entrance and exit (Table 3.2). PERMANOVA indicated that fish assemblages from entrance and exit trap samples were significantly different (*Pseudo-*$F_{1,\ 10}$ =38.875, *p* = 0.006, Table 3.3). This was supported by MDS ordinations of fish assemblage data, which exhibited a complete separation of samples from entrance and exit trapping (Figure 3.7). SIMPER suggested that the assemblages differed primarily (95%) due to greater abundances of smallmouth hardyhead sampled at the entrance (Figure 3.8; Appendix B).

The relative abundance of smallmouth hardyhead was significantly higher at the fishway entrance than at the exit ($Pseudo\text{-}F_{1,\ 10}$ = 45.07, p = 0.003), whereas that of congolli was significantly higher at the exit than entrance ($Pseudo\text{-}F_{1,\ 10}$ = 38.88, p = 0.004). No significant difference in abundance was detected between the entrance and exit for yelloweye mullet ($Pseudo\text{-}F_{1,\ 10}$ = 2.49, p = 0.458) and bluespot goby ($Pseudo\text{-}F_{1,\ 10}$ = 8.86, p = 0.065) (Table 3.3; Figure 3.8).

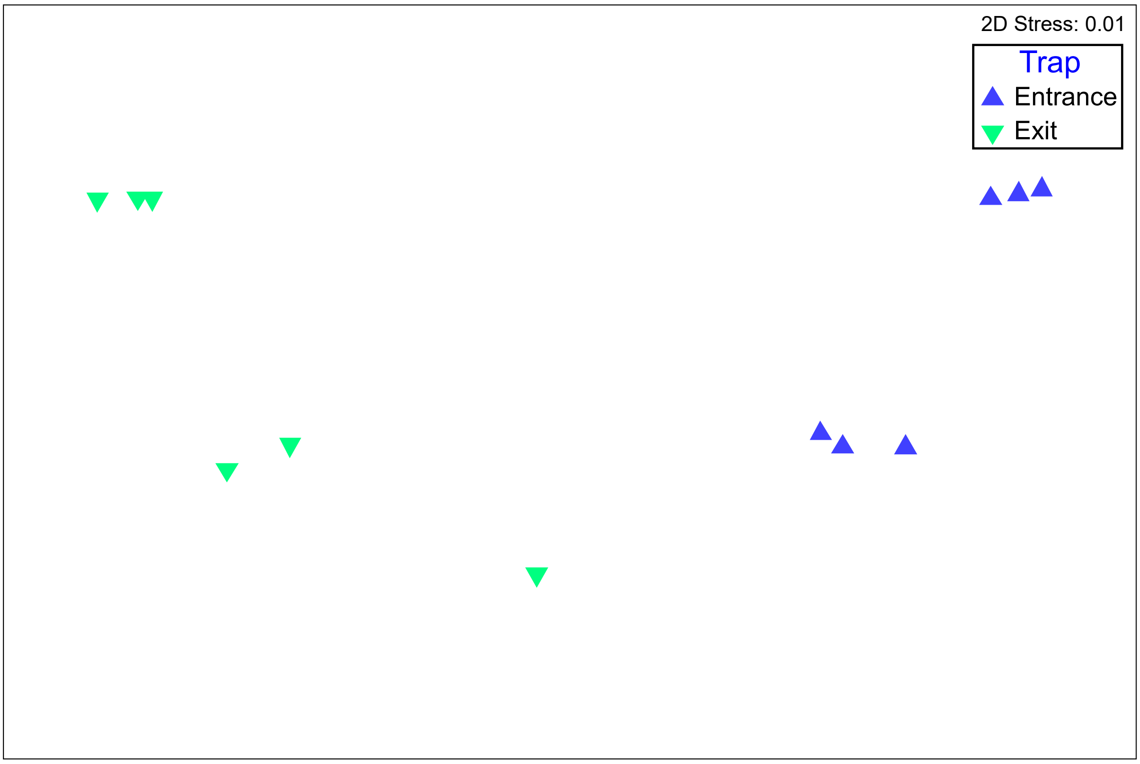

Figure 3.7. Non-metric multi-dimensional scaling (MDS) ordination of fish assemblages from each of the entrance and exit samples at the Morella Creek rock-ramp fishway.

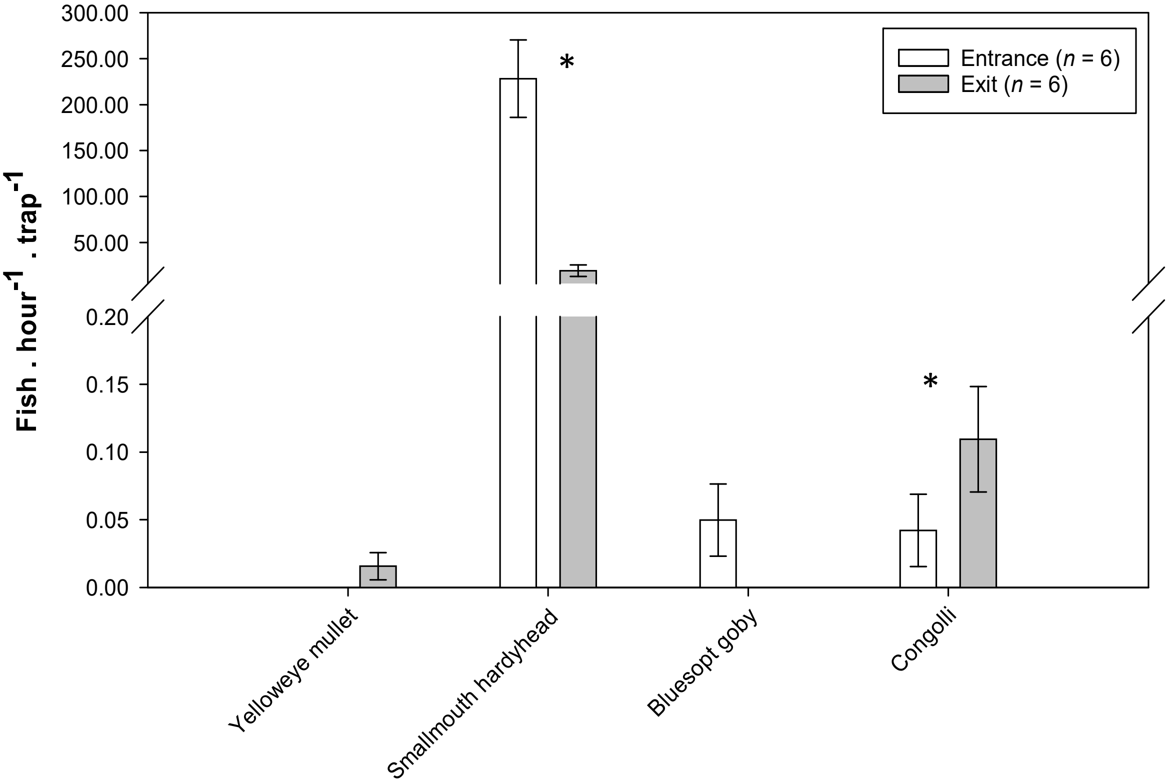

Figure 3.8. Comparison of mean relative abundance (number of fish.hour^{-1}.trap event^{-1} ± standard error) of the most abundant species sampled at the entrance (white bar) and exit (grey bar) of the Morella rock-ramp fishway during November 2021. Significant differences between entrance and exit abundance are indicated by asterisks.

Fish sampled at the entrance of the Morella fishway ranged from 15–285 mm in TL, whilst those sampled at the exit ranged from 67–290 mm in TL (Figure 3.9). The length-frequency distributions for smallmouth hardyhead ($D_{300, 300}$ = 0.177, p < 0.001) were significantly different between the fishway entrance and exit; there was a greater proportion of individuals <50 mm TL sampled from the entrance (85%) than the exit (68%) (Figure 3.9a). For congolli, there were insufficient numbers sampled to enable statistical comparison, although the size distributions indicated ~20% more individuals <100 mm TL at the fishway entrance than the exit (Figure 3.9). Notably, unlike the Salt Creek fishway, no congolli <80 mm TL were collected at either the entrance or exit.

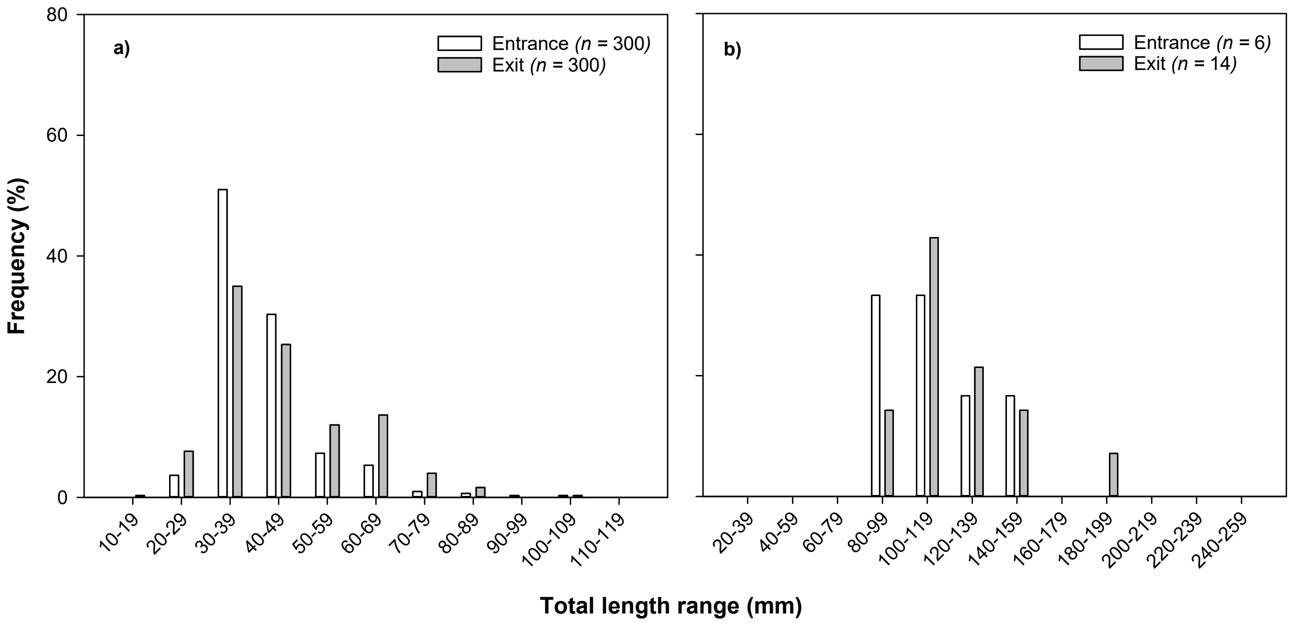

Figure 3.9. Length-frequency distributions of a) smallmouth hardyhead and b) congolli captured from the entrance (white) and exit (grey) of the Morella rock-ramp fishway during November 2021. Sample sizes (*n*) represent the number of fish measured for length for each species. Note: plots have varying x axis scaling.

4. DISCUSSION

As part of the SEFRP, the Salt Creek and Morella rock-ramp fishways were constructed in conjunction with regulator upgrades at these sites, with the objective of improving fish passage and biological connectivity between the Coorong and South East. Fundamental to fishway construction programs is the assessment of fish passage efficiency. The current study undertook the first monitoring of these fishways to provide an initial evaluation of passage efficiency with regards to the abundance, composition and size classes of species able to successfully ascend. Advice is provided on future operation of these regulators and associated fishways, potential structure improvements, and further investigations.

4.1. Fishway use

The seven fish species sampled from the Salt Creek and Morella fishways during November 2021 represent the species commonly found in the Coorong South Lagoon (Ye et al. 2020), Salt Creek (SARDI unpublished data), and/or expected to use these fishways. They comprised four different functional groups of small to large-bodied species (Table 3.2).

Two catadromous species, congolli and shortfin eel, were sampled in this study. These species migrate between freshwater and marine environments to complete their life cycle (Potter et al. 2015) and are therefore regularly encountered using fishways on coastal streams in southeastern Australia (e.g. Bice et al. 2018; Koster et al. 2020). At the nearby Murray Barrage fishways, juvenile congolli are commonly detected in high numbers migrating upstream during spring–early summer following winter spawning in the sea (Bice et al. 2020). In this study, congolli were the second most abundant species caught in both the Salt Creek and Morella fishways, and their sizes were similar to those caught in Murray Barrage fishways during spring (Bice et al. 2020; 2021). The other catadromous species encountered during this study was shortfin eel, with one individual (1,070 mm TL) caught at the exit of the Salt Creek fishway around mid-November 2021. Shortfin eels migrate from inland waters to the sea to spawn, with migrations of adult silver eels into the sea typically occurring from late summer to autumn (Crook et al 2014; Koster et al 2020). This is followed by extensive marine migration and spawning is believed to occur in the western South Pacific Ocean region (e.g., the regions around Solomon Islands, Vanuatu, New Caledonia, and Fiji) (Aoyama et al 1999; Arai et al 1999). The larval eels drift with ocean currents down the east Australian coast. The larvae then metamorphose and attain the typical eel shape (transparent 'glass eels') before entering inland waters around winter–spring (Gooley and Ingram 2002), followed by subsequent migrations upstream (Sloane 1984). Adults may remain in fresh waters for 20 years or more before migrating to the sea to breed and then die (Chisnall and Hayes 1991). The individual eel trapped at the Salt Creek fishway exit was an adult and may have been in the early phase of downstream spawning migration (Wayne Koster 2022, personal comm.) or was taking advantage of the food resources and foraging within the fishway.

Three solely estuarine species (i.e. fishes that can complete entire life cycle in estuaries) were caught during this study. Smallmouth hardyhead, a small-bodied estuarine species, was numerically dominant at both fishways. This Atherinidae species commonly occurs in estuaries, coastal embayment/wetlands, and hypersaline lagoons in high abundance throughout southern Australia (McDowall 1980) and can tolerate a broad range of salinities from 3–108 ppt (Lui 1969). It has been the most abundant species in the Coorong South Lagoon over at least the past two decades (Ye et al. 2020), and also occurs in high abundance within Salt Creek (Ye et al. 2015). Bluespot goby was the other small-bodied estuarine species detected in both fishways, although the numbers were orders of magnitude lower compared to smallmouth hardyhead. Bluespot goby commonly occur in the South Lagoon during high flow years (Ye et al. 2020). Black bream, a large-bodied estuarine species, was sampled in low numbers (only three individuals) at the entrance of the Salt Creek fishway during November 2021. The sizes (285–290 mm TL) suggest these fish were mature adults (Cheshire et al. 2013). Therefore, they might be attracted by Salt Creek flows to the salt wedge to spawn, given the sampling time overlapped with their reproductive season in this region (spring–summer) (Cheshire et al. 2013; Ye et al. 2019). Alternatively, black bream could be pursuing the abundant food resource (prey fish) concentrated in or below the rock-ramp fishway.

A marine-estuarine opportunist species (i.e. marine fishes that enter estuaries regularly, in substantial numbers, often as juveniles), yelloweye mullet, was sampled in both fishways during this study. They are also commonly found using fishways in low–moderate abundance in coastal streams of southeastern Australia (e.g. O'Connor et al. 2019; Bice et al. 2021). This species has a high tolerance for elevated salinity (LC_{50} 82 ppt at 23°C, McNeil et al. 2013) and is usually the most abundant medium-bodied fish, along with congolli (LC_{50} 94 ppt at 23°C, McNeil et al. 2013), in the Coorong South Lagoon under predominantly hypersaline conditions (salinities 60–100 ppt) (Ye et al. 2020). From September to November 2021, daily salinities in the South Lagoon (Snipe Island) varied between 57 and 59 ppt (Water Data SA, DEW).

Lastly, a small-bodied native freshwater fish, flatheaded gudgeon, was present at the entrance of the Morella fishway. As a freshwater-estuarine opportunist (i.e. freshwater species that commonly use estuarine habitats in substantial numbers), this species often enters the Coorong estuary (Bice et al. 2018), with high numbers found in the vicinity below the Murray barrages during high flow years (Ye et al. 2020; Dittmann et al. 2022). Flatheaded gudgeon prefer salinities <5 ppt (SARDI unpublished data), whilst at the time of fish sampling, the salinity in Salt Creek was ~8 ppt. This may explain the low abundance (one individual) sampled in the system.

4.2. Passage efficiency

4.2.1. Salt Creek fishway

At the Salt Creek rock-ramp fishway, smallmouth hardyhead overwhelmingly dominated the overall catch (99.1% by number). There was a significant difference in fish assemblages, and relative abundance of smallmouth hardyhead and bluespot goby between entrance and exit samples of the fishway, suggesting potential compromised passage efficiency for these species. Furthermore, comparison of length-frequency distributions indicated smallmouth hardyhead <40 mm TL and bluespot goby <60 mm TL formed a greater proportion of the sampled population at the entrance, suggesting these smaller individuals, in particular, may have been obstructed. Small juvenile fish have inherently weaker swimming abilities than their larger conspecifics (Beamish 1978), and therefore, tend to be the individuals with greatest potential for compromised fish passage.

In contrast, the relative abundance and length composition of yelloweye mullet was similar between the entrance and exit, suggesting efficient passage for this species. Furthermore, congolli was more abundant at the fishway exit than the entrance, and smaller individuals (<40 mm TL) formed a greater proportion at the exit, even though smaller fish tend to be weaker swimmers (Beamish 1978). This suggests high passage efficiency for this catadromous species, likely due to upstream movement of juveniles driven by life history process. However, the result may also reflect compromised sampling efficiency at the fishway entrance due to imperfect fit of fyke net trap on the rocky structure (e.g. potential escapees under the fyke net wings), whereas the fishway exit was most efficiently sampled by setting the wingless fyke net abutting the exit of Culvert 1 to cover the entire fishway exit (Figure 2.3). This is a common challenge in sampling the entrance of rock ramp fishways.

Overall, the Salt Creek rock-ramp fishway appears to be functioning to meet its primary biological design objective, effectively facilitating the passage of the catadromous congolli and marine-estuarine opportunist yelloweye mullet. At the time of monitoring, Salt Creek flow discharge was 50–95 ML.day^{-1} and the fishway exit water depth ranged 0.3–0.38 m, which was within the designed optimal range for fishway function (depths 0.1–0.4 m). Using water levels at Snipe Island as an indicative estimate of the water level at the Salt Creek fishway entrance, head loss across the fishway was 780–1,140 mm, which is within the specified operating range for this fishway (1,300 mm). The secondary objective of passing small-bodied estuarine species was not fully met, reflected by greater abundances and smaller individuals of smallmouth hardyhead and bluespot goby at the fishway entrance than exit. Nevertheless, movements of estuarine species from estuaries to freshwater systems are likely facultative, and their motive of upstream movement is not life history driven. As such, greater abundance at the entrance, may reflect use of the fishway as habitat, rather than driven attempts at upstream movement. Throughout monitoring, salinity below the Salt Creek fishway and in the vicinity below Salt Creek outfall was brackish (~8 ppt) and favorable for most estuarine species. Therefore, these species, may be attracted to the fishway outflows, but not necessarily driven to pass the fishway and move upstream. The upstream movement for these species, however, may become important when hypersaline conditions in the South Lagoon intensify and become unfavourable for residence (typically in summer/autumn during low flow years). As such, facilitating the upstream passage of all species is desired to allow access to low salinity refuge habitat.

4.2.2. Morella fishway

Smallmouth hardyhead also dominated the catch (99.9% by number) at Morella rock-ramp fishway. There was a significant difference in fish assemblages, and relative abundance of smallmouth hardyhead, between entrance and exit samples of the fishway, suggesting compromised passage efficiency for this species. In addition, smaller individuals (<40 mm TL) of this species appeared to form a greater proportion of the sampled population at the entrance, suggesting this size class was being obstructed. The other small-bodied estuarine species, bluespot goby, were only sampled at the entrance in low numbers (n = 7; 45–67 mm TL), suggesting their passage was potentially impeded.

In contrast, yelloweye mullet were only caught at the fishway exit (285–290 mm TL). This implied effective passage for some larger individuals of this species, although the sample size was very low (n = 2). For congolli, the abundance was higher at the fishway exit than the entrance, however, the proportion of smaller individuals (<100 mm TL) appeared greater at the entrance. This suggests partial effectiveness of the Morella fishway for congolli passage. Noticeably, the cohort of young-of-year (YOY) congolli present at the Salt Creek fishway (<60 mm TL) were absent at the Morella fishway (Figures 3.6d and 3.9b), even at the entrance. This result may be explained by YOY choosing to reside in Salt Creek downstream of Morella, being in transit within Salt Creek, or more likely, their upstream movement within Salt Creek may have been impeded by the crump weir (Figure 3.2). Crump weirs can form a complete barrier to passage during periods of no flow or velocity barriers during low flows when discharge is restricted to the centre of the structure. They are, however, passable when drowned out during high flow.

At the time of assessment, the Morella rock-ramp fishway appeared to be partially functional in meeting its biological design objectives. In particular, the passage of smaller congolli (<100 mm TL), and small-bodied estuarine species (smallmouth hardyhead <40 mm TL; bluespot goby) likely requires improvement. During the monitoring, water depth at the Morella fishway exit ranged 0.35–0.46 m, which was slightly above the designed optimal range for fishway function (depths 0.1–0.4 m). This at least partially explained the reduced passage efficiency due to greater velocity and turbulence when water depth at the fishway exit exceeded 0.4 m (i.e. Morella water level >4.1 m AHD). Unfortunately, at the time of monitoring, there were no gauge boards for water depth/level measurements at the entrance of the fishway, therefore, head loss could not be estimated.

4.3. Recommendations

Five out of the six targeted species that the Salt Creek and Morella rock-ramp fishways were designed for (KBR 2019) were present during the monitoring in November 2021. Common galaxias was the only target species not sampled, though has not been found in the South Lagoon since 2006 (Noell et al. 2009; Ye et al. 2020). The results of fishway assessments indicated varying passage efficiency between the two fishways.

The Salt Creek rock-ramp fishway was effective in facilitating the passage of congolli and yelloweye mullet, but passage efficiency appeared to be limited for the two small-bodied estuarine species, particularly for smaller individuals (<40 mm TL for smallmouth hardyhead; <60 mm TL for bluespot goby). This was likely due to a combination of poor swimming ability and a lack of drive for upstream movement. Future monitoring is recommended when the fishway exit water depth is 0.1–0.3 m and at reduced head loss (e.g. <800 mm), to better assess if the fishway performs at the full range of hydrological conditions. Additionally, monitoring during summer–autumn, particularly when salinities in the South Lagoon are elevated and approaching unfavourable levels, will help to understand if upstream passage improves when there is a stronger biological drive (i.e. to access low salinity refuge) for these species, and if the fishway effectively facilitates this movement. Nonetheless, a detailed fishway inspection is required to survey the drops between resting pools, assess the hydraulic conditions, and potentially modify the placement of ridges (boulders/gaps) if/where required to improve fishway function, considering that the Salt Creek fishway construction didn't fully align with the design specifications. Despite water level data being available at Snipe Island, installation of a gauge board is recommended to directly measure the water depth/level in the vicinity of the entrance of the Salt Creek fishway.

The Morella rock-ramp fishway was partially effective in facilitating the passage for congolli and potentially larger yelloweye mullet, but passage efficiency seemed compromised for congolli <100 mm TL. Furthermore, the passage of smallmouth hardyhead was limited particularly for individuals <40 mm TL, and bluespot goby also appeared to be obstructed. Given part of the monitoring period was under suboptimal hydrological conditions for fishway function (i.e. at fishway exit depths 0.35–0.46 m vs optimal depths 0.1–0.4 m), further monitoring is recommended under optimal design conditions to assess if passage efficiency improves. As per the Salt Creek fishway, a gauge board will be needed for water depth/level measurement near the fishway entrance. Such data will help to understand the influence of discharge through the Morella regulator and fishway on downstream water levels, particularly near the fishway entrance, and better assess the head loss (water level difference between fishway exit and entrance) of the Morella fishway to inform optimal flow management to improve fishway function. Furthermore, a detailed fishway inspection is required to survey the drops between resting pools, assess the hydraulic conditions, and potentially modify the placement of ridges (boulders/gaps) if/where required to improve fishway function, considering the design of this fishway was adapted from that of the Salt Creek fishway. In particular, the most upstream pool of the Morella fishway is a long (6 m) box culvert with little roughness, which may present an impediment to fish to successfully ascend the fishway. Hydraulic assessment of this pool at different flow rates and water levels will be required, and roughness elements could be introduced (e.g. rocks, which will increase the heterogeneity in water velocity by creating a continuous or discrete low velocity zone to improve fish passage (Magaju et al. 2020)). Also to note, when the Morella fishway is in operation, the penstock at the fishway exit should be fully open to avoid any hydraulic or physical impediment to fish movement. Moreover, investigations should be conducted into potential fish passage obstructions along the Salt Creek, specifically at the crump weir, as suggested by the absence of YOY congolli (<60 mm TL) at Morella and an order of magnitude lower abundance of other species than smallmouth hardhead at Morella compared to the Salt Creek fishway.

In addition to fish passage efficiency, fishway functionality also includes attraction efficiency, which is the ability of fish attempting to migrate to locate the fishway entrance (Cooke and Hinch 2013). Reliably assessing attraction efficiency typically involves mark-recapture or telemetry studies. This is often challenging when assessing small-bodied fishes and species that are not undertaking driven, obligate migrations, such as the smallmouth hardyhead in this study. Hence in the absence of empirical data on attraction efficiency, attentions should be made in regulator operations to manage flow discharge through regulator gates and associated fishways to create/maintain favourable entrance conditions at both fishways. This includes maintaining integrity of fishway entrance discharge.

Finally, improved understanding of the movement ecology of key species, particularly timing and direction of movement of various life stages, is required. Such knowledge, along with the results of fishway assessment across broad hydrological conditions, will inform the development of guidelines to optimise regulator/fishway operations and flow management to improve biological connectivity between the Coorong and South East region. Importantly, the broader ecological context needs to be considered and a holistic approach adopted when developing flow management plans given there are multiple ecological objectives in this region. These include managing water levels, hence the mudflat habitat and food resources for waterbird populations in the Morella Basin and the effects of Salt Creek flows (both benefits and potential risks) on the Coorong ecosystem.

5. CONCLUSION

Most of the fish species commonly occurring in the Coorong South Lagoon that are expected to undertake movements between the Coorong and South East were captured from the Salt Creek and Morella fishways during the monitoring in November 2021. Congolli and yelloweye mullet were most successful ascending both fishways, whilst smallmouth hardyhead and bluespot goby had limited passage efficiency. Although upstream movements for these estuarine species are not life history driven, like diadromous[b] species with obligate migrations, providing un-obstructed fish passage could become important for them to access upstream refuge habitats when environmental condition deteriorates (e.g. salinity increases to unfavourable levels for species in the South Lagoon).

At the time of fishway assessment, the Salt Creek fishway was generally performing to biological design objectives, whilst the Morella fishway was partially meeting objectives. Further monitoring and investigations for both fishways will be required to assess passage efficiency under different hydrological conditions (flow discharge and water levels) and seasons. The data, in conjunction with improved understanding of fish movement ecology (direction and timing for different species and life stages), will inform the regulator/fishway operations, potential structural modifications, and the development of flow management plans/guidelines to optimise fishway function, considering the broader context of ecological objectives for the Coorong and South East region.

[b]Diadromous: This category is defined as those species that must migrate between freshwater and marine environments to complete their life cycles (Potter et al. 2015)

REFERENCES

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

Aoyama, J. et al. Distribution and dispersal of *anguillid leptocephali* in the western Pacific Ocean revealed by molecular analysis. *Marine Ecology Progress Series* 188, 193–200 (1999).

Arai, T., Otake, T., Jellyman, D. J. and Tsukamoto, K. (1999). Differences in the early life history of the Australasian shortfinned eel *Anguilla australis* from Australia and New Zealand, as revealed by otolith microstructure and microchemistry. *Marine Biology* 135, 381-389.

Beamish, F. W. H. (1978). Swimming capacity. In 'Fish Physiology'. Eds. Hoar, W.S. and Randall, J. D. New York, Academic Press, Inc. Vol 7, 101–187.

Bice, C. M., Schmarr, D. W., Zampatti, B. and Fredberg, J. (2020). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2019/20. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-10. SARDI Research report Series No. 1081. 66pp.

Bice, C. M., Schmarr, D. W., Zampatti, B. P. and Fredberg, J. (2021). Fish assemblage structure, movement and recruitment in the Coorong and Lower Lakes in 2020/21. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000186-11. SARDI Research report Series No. 1117. 66pp.

Bice, C. M., Hammer, M. P., Wedderburn, S. D., Ye, Q. and Zampatti, B. P. (2018). Fishes of the Lower Lakes and Coorong: An Inventory and Summary of Life History, Population Dynamics and Management. In: Mosley, L., Ye, Q., Shepherd, S., Hemming, S., Fitzpatrick, R. (eds) Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe). Royal Society of South Australia, Adelaide. pp 371-399.

Cheshire, K. J. M., Ye, Q., Fredberg, J., Short, D. and Earl, J. (2013). Aspects of reproductive biology of five key fish species in the Murray Mouth and Coorong. South Australian Research and Development institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-3. SARDI Research Report Series No. 699.

Chisnall, B. L. and Hayes, J. W. (1991). Age and growth of shortfinned eels (*Anguilla australis*) in the lower Waikato basin, North Island, New Zealand, New Zealand. *Journal of Marine and Freshwater Research* 25:1, 71-80, DOI: 10.1080/00288330.1991.9516455

Cooke, S. J. and Hinch, S. G. (2013). Improving the reliability of fishway attraction and passage efficiency estimates to inform fishway engineering, science and practice. *Ecological Engineering* 58, 123–132.

Crook, D. A., McDonald, J. I., Morrongiello, J. R., Belcher, C. A., Lovett, D., Walker, A. and Nicol, S. J. (2014). Environmental cues and extended estuarine residence in seaward migrating eels (*Anguilla australis*). *Freshwater Biology* 59, 1710–1720.

Dittmann, S., Ye, Q., Furst, D., Newbery, A., Nitschke, J., Bucater, L., Pyke, W., Kent, J., Schroder, L., Henkens, J., Baring, R., Lam-Gordillo, O., Brookes, J. and Short, D. (2022). Food resource availability, energy content and nutritional value of major food sources for key fish and waterbird species under varying environmental conditions in the Coorong. Goyder Institute for Water Research Technical Report Series No. 22/12.

Gooley, G. J. and Ingram, B. A. (2002). Assessment of eastern Australian glass eel stocks and associated eel aquaculture. Final report of FRDC Project No 97/312 (and No. 99/330). Marine and Freshwater Resources Institute, Victoria, Australia.

Koster, W., Bannam, L., Church, B., Dawson, D., Lyon, J., O'Connor, J. and Stuart, I. (2020). Assessing eel movement through the Budj Bim landscape. Unpublished Client Report for Water and Catchments | Department of Environment, Land, Water and Planning. Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, Heidelberg, Victoria.

KBR (2019). Design Report - Morella Basin Outlet Structure and Salt Creek Outfall Structure & Fishway. South East Flows Restoration Project. A report prepared for the Department of Planning, Transport and Infrastructure. Adelaide, South Australia.

Lui, L. C. (1969). Salinity tolerance and osmoregulation in *Taenomembrus microstomus* (Gunther, 1861) (Pisces: Mugiliformes: Atherinidae) from Australian salt lakes. Australian *Journal of Marine and Freshwater Research* 20, 157–162.

Magaju, D., Montgomery, J., Franklin, P., Baker, C. and Friedrich, H. (2020). A new framework for assessing roughness elements in promoting fish passage at low-head instream structures. *Journal of Ecohydraulics* 5 (2), 152 –164.

McDowall, R. M. (1980). Freshwater fishes of South-eastern Australia (A H & A W Reed Pty Ltd, Sydney).

McNeil, D. G., Westergaard, S., Cheshire, K. J. M., Noell, C. J. and Ye, Q. (2013). Effects of hypersaline conditions upon six estuarine fish species from the Coorong and Murray Mouth. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2009/000014-4. SARDI Research Report Series No. 700. 27pp.

Noell, C. J., Ye, Q., Short, D. A., Bucater, L. B. and Wellman, N. R. (2009). Fish assemblages of the Murray Mouth and Coorong region, South Australia, during an extended drought period. CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

O'Connor, J., Pickworth, A., Fanson, B. and Lovric, D. (2019). Assessment of a vertical slot fishway in south-eastern Australia designed to pass numerous species and size classes of fish. *Ecological Management and Restoration* 20 (2), 151-155.

Potter, I. C., Tweedley, J. R., Elliott, M. and Whitfield, A. K. (2015). The ways in which fish use estuaries: A refinement and expansion of the guild approach. *Fish and Fisheries* 16, 230-239. https://doi.org/10.1111/faf.12050.

Sloane, R. (1984). Invasion and upstream migration by glass-eels of *Anguilla australis australis* Richardson and *A. reinhardtii Steindachner* in Tasmanian Freshwater Streams. *Marine and Freshwater Research* 35, 47-59.

Ye, Q., Bucater, L. and Short, D. (2015). Coorong fish condition monitoring 2008–2014: Black bream (*Acanthopagrus butcheri*), greenback flounder (*Rhombosolea tapirina*) and smallmouthed hardyhead (*Atherinosoma microstoma*) populations. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-4. SARDI Research Report Series No. 836. 105pp.

Ye, Q., Bucater, L., Lorenz, Z., Giatas, G. and Short, D. (2019). Monitoring salt wedge conditions and black bream (*Acanthopagrus butcheri*) recruitment in the Coorong during 2017-18. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2018/000425-1. SARDI Research Report Series No. 1012. 42pp.

Ye, Q., Giatas, G., Dittmann, S., Baring, R., Bucater, L., Deane, D., Furst, D., Brookes, J., Rogers, D. and Goldsworthy, S. (2020). A synthesis of current knowledge of the food web and food resources for waterbird and fish populations in the Coorong. Goyder Institute for Water Research Technical Report Series No. 20/11.

APPENDIX

Appendix A. Sampling regime for fishway entrance and exit trapping at the Salt Creek and Morella fishways during November 2021.

Fishway	Trap	Rep	Date Retrieved	Set Time	Retrieve Time	Hours Trapped	Sampling
Morella	Exit	1	4/11/21	3/11 17:30	4/11 12:15	18.8	Pilot
Salt Creek	Exit	1	4/11/21	3/11 16:30	4/11 10:20	17.8	Formal
Morella	Entrance	1	5/11/21	4/11 14:00	5/11 13:00	23.0	Pilot
Salt Creek	Entrance	1	5/11/21	4/11 11:20	5/11 10:35	23.3	Formal
Morella	Exit	2	9/11/21	8/11 14:30	9/11 10:00	19.5	Formal
Salt Creek	Exit	2	9/11/21	8/11 15:00	9/11 9:15	18.2	Formal
Morella	Exit	3	10/11/21	9/11 10:15	10/11 10:15	24.0	Formal
Salt Creek	Exit	3	10/11/21	9/11 10:15	10/11 9:00	22.7	Formal
Morella	Entrance	2	11/11/21	10/11 11:30	11/11 9:45	22.3	Formal
Salt Creek	Entrance	2	11/11/21	10/11 9:30	11/11 9:00	23.5	Formal
Morella	Entrance	3	12/11/21	11/11 10:30	12/11 9:45	23.3	Formal
Salt Creek	Entrance	3	12/11/21	11/11 9:30	12/11 9:00	23.5	Formal
Morella	Exit	4	16/11/21	15/11 14:00	16/11 9:00	19.0	Formal
Salt Creek	Exit	4	16/11/21	15/11 15:00	16/11 9:45	18.8	Formal
Morella	Exit	5	17/11/21	16/11 9:30	17/11 9:30	24.0	Formal
Salt Creek	Exit	5	17/11/21	16/11 10:00	17/11 9:00	23.0	Formal
Morella	Entrance	4	18/11/21	17/11 10:30	18/11 10:00	23.5	Formal
Salt Creek	Entrance	4	18/11/21	17/11 9:30	18/11 9:00	23.5	Formal
Morella	Entrance	5	19/11/21	18/11 10:30	19/11 10:30	24.0	Formal
Salt Creek	Entrance	5	19/11/21	18/11 9:30	19/11 9:00	23.5	Formal
Morella	Exit	6	23/11/21	22/11 15:30	23/11 10:00	18.5	Formal
Salt Creek	Exit	6	23/11/21	22/11 15:00	23/11 9:15	18.2	Formal
Morella	Exit	7	24/11/21	23/11 10:30	24/11 10:10	23.7	Formal
Salt Creek	Exit	7	24/11/21	23/11 9:45	24/11 9:15	23.5	Formal
Morella	Entrance	6	25/11/21	24/11 11:00	25/11 10:45	23.7	Formal
Salt Creek	Entrance	6	25/11/21	24/11 10:00	25/11 9:15	23.3	Formal
Morella	Entrance	7	26/11/21	25/11 10:15	26/11 9:45	23.5	Formal
Salt Creek	Entrance	7	26/11/21	25/11 11:45	26/11 9:00	21.2	Formal

Appendix B. SIMPER analysis for fish assemblage comparisons between entrance and exit traps placed at the Salt and Morella fishways. Mean abundance is number of fish trapped per hour. CR (consistency ratio) indicates the consistency of differences in abundance between the different traps, with larger values indicating greater consistency. The contribution (%) indicates the proportion of difference between traps attributable to individual species. A cumulative cut-off of 70% was applied. Mean dissimilarity is expressed as a percentage ranging between 0% (identical) and 100% (totally dissimilar).

	Mean abundance			Mean dissimilarity = 52.44	
Salt Creek fishway	**Entrance**	**Exit**	**CR**	**Contribution %**	**Cum.%**
Smallmouth hardyhead	11.46	3.89	1.94	87.12	87.12
	Mean abundance			**Mean dissimilarity = 56.47**	
Morella fishway	**Entrance**	**Exit**	**CR**	**Contribution %**	**Cum.%**
Smallmouth hardyhead	14.77	4.14	3.96	95.36	95.36