

Technical information supporting the South Australian Basin Plan Environmental Outcome Evaluation

South Australian River Murray: Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset

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Acknowledgement of Country

We acknowledge and respect the Traditional Custodians whose ancestral lands we live and work upon and we pay our respects to their Elders past and present.

We acknowledge and respect their deep spiritual connection and the relationship that Aboriginal and Torres Strait Islanders people have to Country.

We also pay our respects to the cultural authority of Aboriginal and Torres Strait Islander people and their nations in South Australia, as well as those across Australia.

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Contents

Acknowledgement of Country	ii
Acknowledgements	iii
Summary	18
1 Introduction	20
1.1 Basin Plan Schedule 12	20
1.2 South Australia's approach to 2025 Basin Plan Environmental Outcome Evaluation and Reporting (Matter 8)	20
1.2.1 South Australian River Murray expected outcomes	21
2 Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset	22
2.1 Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset	22
3 Hydrology	25
3.1 Flows to South Australia (QSA)	25
3.1.1 Water for the environment	26
3.2 River Murray inflow	26
3.3 Lakes	27
3.4 Barrage flows	29
3.5 Coorong	30
3.6 Coorong salinity	31
3.7 Murray Mouth	32
3.7.1 Tidal influence	32
4 Objectives, targets and expected environmental outcomes	33
4.1 Ecological objectives and targets	33
4.2 Methods	35
4.2.1 Assessment	35
4.2.2 Trend	36
4.2.3 Information reliability	37
4.2.4 Expert elicitation workshops	38
5 Murray Mouth openness: annual flow	41
5.1 Introduction	41
5.2 Ecological objective, target and environmental outcomes	42
5.3 Method	43
5.3.1 Barrage flow	43
5.3.2 Supplementary datasets	44
5.3.3 Trend assessment	44
5.3.4 Flow categories	44
5.3.5 Information reliability	45
5.3.6 Limitations and assumptions	45
5.4 Results	45
5.4.1 Environmental outcome assessment	45

5.4.2	Annual barrage flow	46
5.4.3	Trend	47
5.4.4	Dredging	48
5.4.5	Diurnal Tidal Ratio	48
5.4.6	Daily barrage flow	49
5.4.7	Information reliability	50
5.5	Evaluation	51
5.5.1	Key factors contributing to outcomes	52
5.5.2	Unanticipated outcomes	56
5.5.3	Actions to achieve environmental outcomes	56
5.6	Conclusion	57
6	Aquatic and littoral vegetation	58
6.1	Introduction	58
6.2	Ecological objective, target and environmental outcomes	59
6.3	Method	61
6.3.1	Data source	61
6.3.2	Data collection	61
6.3.3	Trend assessment	61
6.3.4	Information reliability	62
6.4	Results	62
6.4.1	Environmental outcome assessment	62
6.4.2	Trend	64
6.4.3	Information reliability	66
6.5	Evaluation	67
6.5.1	Key factors contributing to environmental outcomes	68
6.5.2	Complementary actions contributing to environmental outcomes	70
6.5.3	Unanticipated outcomes	71
6.5.4	Actions to achieve environmental outcomes	71
6.6	Conclusion	72
7	<i>Ruppia tuberosa</i>	73
7.1	Introduction	73
7.2	Ecological objective, targets and environmental outcomes	75
7.3	Method	77
7.3.1	Data collection	77
7.3.2	Summer monitoring	78
7.3.3	Winter monitoring	78
7.3.4	Assessment of environmental outcomes	78
7.3.5	Trend	78
7.3.6	Information reliability	79
7.4	Results	79
7.4.1	Outcome assessment: Area of occupation (AOO)	79
7.4.2	Trend: Area of occupation (AOO)	80
7.4.3	Extent of occurrence (EOO)	81
7.4.4	Trend: extent of occurrence (EOO)	83
7.4.5	Outcome assessment: Long-term resilience (seed bank)	83

7.4.6	Trend: Long-term resilience (seed bank)	85
7.5	Information reliability	85
7.6	Contextual and Supporting Information	86
7.6.1	<i>Ruppia tuberosa</i> abundance and reproduction	86
7.7	Evaluation	88
7.7.1	Factors and summary of influence	89
7.7.2	Complementary actions	92
7.7.3	Unanticipated outcomes	94
7.8	Actions to achieve environmental outcomes	95
7.9	Conclusion	95
8	Case study: Nutrient dynamics and problematic algal blooms in the southern Coorong	96
8.1	Sources of nutrients	97
8.2	Effects of the 2022–23 River Murray flood on water quality in the Coorong	98
9	Black bream and greenback flounder	99
9.1	Introduction	99
9.1.1	Black bream	99
9.1.2	Greenback flounder	100
9.2	Ecological objective, target and environmental outcomes	101
9.3	Method	103
9.3.1	Trend assessment	104
9.3.2	Information reliability	104
9.4	Limitations and assumptions	104
9.4.1	Black bream	104
9.4.2	Greenback flounder	104
9.5	Results	104
9.5.1	Environmental outcome assessment: black bream population condition	104
9.5.2	Environmental outcome assessment: greenback flounder population condition	105
9.5.3	Trend	109
9.5.4	Information reliability	110
9.6	Evaluation	111
9.6.1	Black bream	111
9.6.2	Greenback flounder	113
9.6.3	Unanticipated outcomes	114
9.6.4	Actions to achieve environmental outcomes	115
9.7	Conclusion	116
10	Diadromous fish	117
10.1	Introduction	117
10.2	Ecological objective, targets and environmental outcomes	119
10.3	Method	120
10.3.1	Recruitment Index (RI) calculation	121
10.3.2	Trend assessment	122
10.3.3	Information reliability	122
10.3.4	Limitations	122
10.4	Results	122

10.4.1	Recruitment index (RI)	122
10.4.2	Environmental outcome assessment	123
10.4.3	Trend	124
10.4.4	Information reliability	125
10.5	Evaluation	127
10.5.1	System connectivity	127
10.5.2	Open Murray Mouth	129
10.5.3	Unanticipated outcomes	129
10.5.4	Actions to achieve environmental outcomes	132
10.6	Conclusion	132
11	Small-mouthed hardyhead	133
11.1	Introduction	133
11.2	Ecological objective, target and environmental outcomes	134
11.3	Method	136
11.3.1	Data sources	136
11.3.2	Trend assessment	136
11.3.3	Information reliability	136
11.4	Limitations and assumptions	136
11.5	Results	137
11.5.1	Environmental outcome assessment	137
11.5.2	Trend	137
11.5.3	Information reliability	138
11.6	Evaluation	139
11.6.1	Barrage flows	139
11.6.2	Unanticipated outcomes	141
11.6.3	Actions to achieve environmental outcomes	141
11.7	Conclusion	141
12	Waterbirds	142
12.1	Introduction	143
12.2	Ecological objective, target and environmental outcomes	144
12.3	Method	147
12.3.1	Lakes	147
12.3.2	Coorong	147
12.3.3	Trend assessment	147
12.3.4	Information reliability	147
12.3.5	Limitations and assumptions	147
12.4	Results	148
12.4.1	Lakes outcome assessment: Abundance	148
12.4.2	Trend: Abundance	150
12.4.3	Lakes Outcome Assessment: Area of Occupation (AOO)	151
12.4.4	Lakes Outcome Assessment: Extent of Occupation (EOO)	154
12.4.5	Coorong Outcome Assessment: Abundance	156
12.4.6	Trend: Abundance	158
12.4.7	Coorong Outcome Assessment: Area of Occupation (AOO)	159
12.4.8	Coorong Outcome Assessment: Extent of Occurrence (EOO)	162

12.4.9	Information reliability	164
12.5	Evaluation	165
12.5.1	Lakes	165
12.5.2	Coorong	169
13	Abbreviations and Glossary	176
13.1	Abbreviations	176
13.2	Glossary	177
14	References	181
	Introduction	181
	Murray Mouth openness: annual flow	184
	Aquatic and littoral vegetation	185
	Ruppia tuberosa	187
	Case Study: Nutrient dynamics and problematic algal blooms in the Southern Coorong	191
	Black bream and greenback flounder	192
	Diadromous fish	195
	Small-mouthed hardyhead	196
	Waterbirds	199
15	Appendices	204
	Appendix A: Ecological objective, target and indices for aquatic and littoral vegetation condition in the Lakes (Nicol 2017).	204

List of figures

Figure 2-1.	Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environmental Asset (PEA) and Coorong, and Lakes Alexandrina and Albert Wetland Ramsar Site.	24
Figure 3-1.	Flows to South Australia (QSA) between 2000–01 and 2022–23. The left axis and black area correspond to daily QSA (ML day ⁻¹), while the right axis and grey bars correspond to annual QSA (GL year ⁻¹) for each water year (1 July to 30 June).	25
Figure 3-2.	Contribution of unregulated flow, water for the environment (E-water), additional dilution flow (ADF) and SA entitlement flow, to flow (GL month ⁻¹) to the South Australian border (QSA) from June 2012 (Basin Plan adoption) to June 2023.	26
Figure 3-3.	Average monthly water level (m AHD) in Lake Alexandrina (monitoring stations: A4260524, A4260527, A4260574, A4261133, A4261156) and Lake Albert (monitoring stations: A4260630, A4261153, A4261155) between 2001 and 2023. Data source: Water Data SA.	28
Figure 3-4.	Monthly salinity concentrations (µS cm ⁻¹) in Lake Alexandrina (monitoring stations: A4261156, A4260524, A4260574, A4261133) and Lake Albert (monitoring stations: A4260630, A4261153, A4261155) between 2004 and 2023. Data source: Water Data SA.	29
Figure 3-5.	The total monthly barrage flow (black left axis; GL month ⁻¹) and total annual (July–June) barrage flow (grey right axis; GL year ⁻¹) between July 2000 and June 2023. Data sources: MSM-BIGMOD calculated barrage flow (July 2000–January 2011) and DEW barrage calculator (January 2011–June 2023).	30
Figure 3-6.	The average monthly water levels (m AHD) in the Murray estuary (monitoring stations: A4261036, A4261039, A4261043, A4261128), North Lagoon (monitoring stations: A4260572, A4261134, A4261135) and South Lagoon (monitoring stations: A4261165, A4261209) between 2003 and 2023. Data source: Water Data SA.	31
Figure 3-7.	Salinity concentrations (TDS GL ⁻¹) in the Coorong between 2007 and 2023, in the Murray Estuary (monitoring stations: A4261036, A4261039, A4261043, A4261128), North Lagoon (monitoring stations: A4261134, A4261135, A426057) and South Lagoon (monitoring stations: A4261209, A4261165). Data source: Water Data SA.	32
Figure 4-1.	Schematic diagram showing how data driven and expert elicitation processes underpin the assessment and evaluation of environmental outcomes and enable South Australia's four evaluation questions to be addressed. The progress to the target will be considered through the assessment of expected outcomes.	39
Figure 5-1.	The expected environmental outcomes for the percentage of years since Basin Plan adoption (2012) that the annual flow is expected to be ≥730 GL year ⁻¹ (i.e. annual flow requirement (730 GL year ⁻¹) in 2019, 2029 and 2042 under modelled water recovery conditions.	43
Figure 5-2.	The cumulative percentage of years since Basin Plan adoption (2012) where there was a calculated annual barrage flow of ≥ 730 GL, with expected outcome included for reference.	46
Figure 5-3.	Barrage flow (GL year ⁻¹) for each water year from 2000–01 to 2022–23. The grey horizontal shaded area represents the LTWP target range of 730–1,090 GL year ⁻¹ . Shaded columns are the flow categories from the Lower Lakes, Coorong and Murray Mouth (LLCMM) Scientific Advisory Group. Data sources: MSM-BIGMOD barrage flow data (July 2000–December 2010) and DEW (A4261002) barrage flow data (January 2011–June 2023). The blue dashed line represents the adoption of the Basin Plan (2012).	47
Figure 5-4.	Estimated values for the slope generated from Bayesian modelling for the frequency of years that annual barrage flow was ≥ 730 GL between 2000 and 2023. Data used in trend assessment was from both MSM-BIGMOD (July 2000–December 2010) and DEW (January 2011–June 2023). Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	47
Figure 5-5.	The total monthly barrage flow (GL month ⁻¹) from 2000–01 to 2022–23. Data sources: MDBA's MSM-BIGMOD (July 2000–January 2011), DEW barrage calculator (February 2011–June 2023). Also shown are periods of dredging operations (shaded rectangles).	48
Figure 5-6.	The Diurnal Tide Ratio (DTR) recorded in the Murray Estuary (Goolwa Barrage), between August 2002–03 to June 2022–23. Also shown are periods of dredging operations (shaded rectangles). Data sources: MDBA's MSM-BIGMOD (July 2000–January 2011), DEW barrage calculator (February 2011–June 2023), and SA Water (DTR and dredging).	49
Figure 5-7.	The percentage of days per water year with barrage flow at least 2,000 ML between 2011–12 and 2022–23. Show below each column is the total annual barrage flow. Data sources: DEW barrage calculator (July 2011–June 2023).	50

Figure 5-8.	Murray-Darling Basin (MDB) rainfall deciles between 1 of July and the 30 of June each year since 2006–07. Data source: BOM 2023.	53
Figure 5-9.	Bathymetry (illustrating difference in elevation) of the Murray Mouth in October 2022 and February, May, and June 2023. Lower elevation areas are shown in purple and higher elevation areas are shown in red. Scouring flows commenced in early December 2022 and continued until late February 2023.	55
Figure 6-1.	Expected environmental outcomes for Lakes aquatic and littoral vegetation in 2019, 2029, and 2042, based on the whole of icon site score. Expected outcomes were estimated by experts and were informed by modelled water recovery conditions.	60
Figure 6-2.	The whole of icon site score for aquatic and littoral vegetation in the Lakes from spring 2008 to autumn 2023. The grey dots and associated 80% confidence intervals represent the 2019 and 2029 expected outcomes. Data source: SARDI.	63
Figure 6-3.	Habitat scores for each wetland type: Goolwa Channel, Lake Albert, Lake Alexandrina, permanent wetlands and temporary wetlands from spring 2008 to autumn 2023. Habitat scores are averaged to calculate the whole of icon site score. The adoption of the Basin Plan is marked by a vertical dashed blue line. Data Source: SARDI.	64
Figure 6-4.	Estimated values for the slope generated from Bayesian modelling for the icon site score from spring 2008 to autumn 2023. Posterior slope values >0 infer a positive trend (improvement) and values <0 infer a negative trend (decline).	65
Figure 6-5.	Estimated values for the slope generated from Bayesian modelling for habitat scores from spring 2008 to autumn 2023. Posterior slope values >0 infer a positive trend (improvement) and values <0 infer a negative trend (decline).	66
Figure 6-6.	Mean monthly lake levels (m AHD) at Lake Albert (A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2001 to 2023 with respect to Basin Plan (BP) adoption as shown by the dashed blue line. Data source: Water Data SA.	68
Figure 6-7.	Mean monthly electrical conductivity ($\mu\text{S cm}^{-1}$) in Lake Albert (A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2004-2023. Basin Plan (BP) adoption in November 2012 is shown by the dashed blue line. Data source: Water Data SA.	70
Figure 7-1.	Summary schematic of the lifecycles for <i>Althenia cylindrocarpa</i> and <i>Ruppia tuberosa</i> depicting seasonal changes in the stages of growth, reproduction and senescence and broad timing of each life stage. Attribution: Michelle Waycott, CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0/ , via Wikimedia Commons.	74
Figure 7-2.	Expected environmental outcomes for <i>R. tuberosa</i> . Area of occupation (AOO) is the expected proportion of sites with live plants within the 43 km sampling distribution. Seed bank measures reflect the mean seed density across the 43 km sampling distribution to assess the long-term resilience in the Coorong.	77
Figure 7-3.	The area of occupation (percentage of sites within the 43 km EOO where live shoots are present) for <i>R. tuberosa</i> during January (summer) and July (winter) monitoring periods from 2012 to 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars. Data source: (Paton & Bailey 2014; Paton & Paton 2023b; Paton et al. 2016a; 2020; Paton et al. 2016c).	80
Figure 7-4.	Estimated values for the slope from Bayesian modelling for the frequency of sites containing live <i>R. tuberosa</i> shoots over the 43 km EOO for both winter and summer between 2009 and 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	81
Figure 7-5.	The extent of occurrence (EOO) of the <i>R. tuberosa</i> in the southern Coorong during summer (January) and winter (July) monitoring periods between 2012 and 2023. Data source: (Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016b; 2018b; 2020; Paton et al. 2016c).	82
Figure 7-6.	Estimated slope values from Bayesian modelling indicating the probability of <i>R. tuberosa</i> achieving the 43 km historic distribution in the southern Coorong between 2009 and 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	83
Figure 7-7.	The estimated mean and standard error for summer seed density (seeds.m ⁻²) of <i>R. tuberosa</i> in the Coorong between 2007 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.	84
Figure 7-8.	Estimated slope values from Bayesian modelling indicating the probability of trend in seed-bank density for <i>R. tuberosa</i> between summer (January) 2007 and 2023 in the southern Coorong. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	85

Figure 7-9.	Mean shoot density $\text{m}^{-2} \pm$ standard error for summer (January sampling) aggregated across all monitoring sites. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.	87
Figure 7-10.	Mean Shoot density $\text{m}^{-2} \pm$ standard error for winter (July sampling) aggregated across all monitoring sites sampled in a given year. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.	87
Figure 7-11.	Seed density $\text{m}^{-2} \pm$ standard error for summer sampling aggregated across all monitoring sites. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.	88
Figure 7-12.	The proportion of sites with the <i>Ruppia</i> Community present across elevation gradient in the 2021 growth season (during HCHB Trials & Investigations Project) measured in m AHD calculated from Hobbs et al. (2019); figure derived from Waycott et al. (2022).	89
Figure 7-13.	Summary of optimal (darker shades) and sub-optimal (lighter shades) salinity ranges for different stages of the <i>R. tuberosa</i> life cycle, with conditions separated for sexual reproduction shown in blue, asexual reproduction shown in orange and vegetative growth in green. Unsuitable conditions are not included in this figure (Coorong Dynamics Model, <i>Ruppia</i> Habitat Suitability Index, Gen 2, Hipsey et al. 2022a).	91
Figure 7-14.	<i>Ruppia</i> Community total biomass across salinities derived from Lewis et al. (2022).	91
Figure 7-15.	Mean growth rate of algal biomass extracted from the southern Coorong under laboratory condition vs salinity derived from Waycott et al. (2022).	92
Figure 7-16.	<i>Ruppia</i> Community biomass at; a) non-translocated 'control' vs translocated sites in the southern Coorong and, b) donor vs non-donor 'control' sites in Lake Cantara (Waycott & Lewis 2022).	93
Figure 7-17.	Overall Rapid Assessment Protocol Sediment Condition Scores from 2021 <i>Healthy Coorong, Healthy Basin</i> (HCHB) Phase 1 Trials and Investigations Project <i>Ruppia</i> Community sampling.	94
Figure 8-1.	Typical seasonal water conditions, aquatic plant growth and filamentous algae lifecycle in the southern Coorong.	96
Figure 8-2.	Nutrient sources and cycling in the southern Coorong.	97
Figure 9-1.	Expected population condition scores ($\pm 80\%$ confidence interval) for black bream and greenback flounder in 2019, 2029 and 2042.	103
Figure 9-2.	Black bream population condition assessment scores from 2008–09 to 2022–23. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.	105
Figure 9-3.	Greenback flounder population condition assessment scores from 2008–09 to 2022–23. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.	106
Figure 9-4.	Estimated values for the slope generated from Bayesian modelling for the population condition scores of black bream. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	109
Figure 9-5.	Estimated values for the slope generated from Bayesian modelling for the population condition scores of greenback flounder. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	109
Figure 10-1.	Life history of congolli in the Coorong, Lower Lakes and Murray Mouth (CLLMM).	118
Figure 10-2.	Life history of common galaxias in the Coorong, Lower Lakes and Murray Mouth (CLLMM).	119
Figure 10-3.	Percentage of years ($\pm 80\%$ confidence interval) since adoption of the Basin Plan that annual Recruitment Index target values for congolli and common galaxias were expected to be met in 2019, 2029 and 2042.	120
Figure 10-4.	Annual recruitment index (RI) value, measuring the number of upstream migrating YOY hr^{-1} congolli and common galaxias from 2006–07 to 2022–23. Basin Plan adoption (2012) is shown as a vertical dashed blue line and the Long-term Watering Plan (LTWP) target is shown as a horizontal dashed red line. NB: no monitoring was conducted in 2012–13. Data source: SARDI.	123
Figure 10-5.	The cumulative percentage of years that the annual RI target value has been met through time since adoption of the Basin Plan for a) congolli and b) common galaxias. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars. Data source: SARDI.	124
Figure 10-6.	a) A hundred randomly drawn estimated slopes from the interaction model, based on expected posterior predictions representing the conditional effect (based on species) of the time step. b) Estimated values for	

	the slope generated from Bayesian modelling for recruitment index values for congolli and common galaxias from 2006–07 to 2022–23. Posterior slope values >1 infer a positive trend (improved) and values <1 infer a negative trend (declined).	125
Figure 10-7.	The proportion of downstream migration days (May to August) per year with at least one gate open on any barrage (grey bars), and the daily mean number barrages open during those same months (red line). Note: this graph does not include operational fishway data (see Figure 10-8 for fishway data).	128
Figure 10-8.	The number of constructed, and open (blue shaded) or closed (black shaded) status, of fishways through time.	128
Figure 10-9.	Dredging operations at the Murray Mouth from 2000 to 2023, with respect monthly barrage discharge (ML month ⁻¹) and adoption of the Basin Plan (blue dashed line). White = no dredges, light grey = 1 dredge in operation and dark grey = 2 dredges in operation.	129
Figure 10-10.	Boxplot of head loss differential between the Lakes and the Murray Estuary from 2010–11 to 2022–23 using hourly data. Solid black dots are outliers (>1.5xIQR).	130
Figure 10-11.	Catch per unit effort (CPUE) of common galaxias and congolli from sampling in the Murray Estuary, Coorong North Lagoon and South Lagoon from 2009–10 and 2022–23. Data source: Qifeng Ye, SARDI.	131
Figure 10-12.	Mean annual catch per unit effort (CPUE) of common galaxias and congolli in the Lakes from 2009 to 2023. Data source: Scotte Wedderburn, The University of Adelaide.	131
Figure 11-1.	Expected percentage of monitoring sites with >60% juvenile small-mouthed hardyhead (± 80% confidence limits) in 2019, 2029 and 2042.	135
Figure 11-2.	Percentage of monitoring sites with significant recruitment (>60% juvenile fish) of small-mouthed hardyhead from 2008-09 to 2022-23. The 2019 and 2029 expected outcomes (±80% confidence interval) are referenced by the grey point and associated error bars. Data source: SARDI.	137
Figure 11-3.	Estimated values for the slope generated from Bayesian modelling for the percentage of monitoring sites with proportional abundance of juvenile small-mouthed hardyhead >60%. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).	138
Figure 12-1.	The expected environmental outcomes for waterbirds in the Lakes and Coorong based on the expected proportion of selected species in each guild that exceed their target values. If the target value is met for all species in the subset of the waterbird community, then the proportion of species exceeding their respective targets would be 1. Expected outcomes were derived through expert elicitation and informed by the Basin Plan water recovery scenarios and best available data and information.	146
Figure 12-2.	The proportion of selected species within each Lakes waterbird guild that exceeded their abundance target value in two of the last three years between 2011 and 2023. The 2019 and 2029 expected outcomes (±80% confidence interval) are referenced by the black point and associated error bars. Note: only data from 2011 is presented due to insufficient data to assess interval expected outcomes before this period.	148
Figure 12-3.	The abundances of selected waterbird species during annual late January/early February censuses for the Lakes from 2009 to 2023. Each species is referenced to their (2013–2015) median abundance (horizontal red dashed line) that needs to be exceeded in two of the last three years to meet their abundance target. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).	149
Figure 12-4.	Estimated values for the slope from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species in the Lakes from 2009 to 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	150
Figure 12-5.	Estimated values for the slope from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species from the piscivore, generalist and herbivore guilds in the Lakes from 2009 to 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	151
Figure 12-6.	The proportion of selected species within each Lakes waterbird guild that achieved their AOO target values between 2009 and 2023. The 2019 and 2029 expected outcomes (±80% confidence interval) are referenced by the black point and associated error bars.	152
Figure 12-7.	Area of occupation (AOO) of selected waterbird species during the late January/early February censuses over the Lakes from 2009 to 2023. Each species is referenced to its target value (75% of the mean AOO between 2013 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).	153

Figure 12-8. The proportion of selected species within each Lakes waterbird guild that achieved their EOO target value between 2009 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.	154
Figure 12-9. Extent of occupation (EOO) of selected waterbird species during the late January/early February censuses for the Lakes from 2009 to 2023. Each species is referenced to its target value (75% of the mean EOO between 2013 and 2015) by the horizontal red dashed line. Data source: University of Adelaide/BioR (Assoc. Prof. David Paton).	155
Figure 12-10. The proportion of selected species within each Coorong waterbird guild that exceeded their abundance expected outcome in two of the last three years between 2002 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars. Note: only data from 2002 is presented due to insufficient data to assess interval expected outcome before this period.	156
Figure 12-11. Abundances of selected waterbird species during annual January censuses over the Coorong from 2000 to 2023. Each species is referenced to their (2000–2015) median abundance (horizontal red dashed line) that needs to be exceeded in two of the last three years to meet their abundance target. Note different y-axis ranges across panels. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).	157
Figure 12-12. Estimated values for the slope from Bayesian modelling for the annual January census of selected waterbird species in the Coorong from 2000 to 2023. Posterior values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	158
Figure 12-13. Estimated values for the slope from Bayesian modelling for the annual January census of selected waterbird species from the generalist, herbivore, migratory shorebird, piscivore and resident shorebird guilds in the Coorong from 2000 to 2023. Posterior values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).	159
Figure 12-14. The proportion of selected species within each Coorong waterbird guild that achieved their AOO target values between 2000 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.	160
Figure 12-15. Area of occupation (AOO) of selected waterbird species during the January census over the Coorong from 2000 to 2023. Each species is referenced to its target value (75% of the mean AOO between 2000 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).	161
Figure 12-16. The proportion of selected species within each Coorong waterbird guild that achieved their EOO target values between 2000 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.	162
Figure 12-17. Extent of occupation (EOO) of selected waterbird species during the January census over the Coorong from 2000 to 2023. Each species is referenced to its target value (75% of the mean EOO between 2000 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).	163
Figure 12-18. Mean monthly lake levels (m AHD) at Lake Albert (DEW water quality stations: A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (DEW water quality stations: A4260574, A4260524, A4261156, A4261133) from 2001 to 2023 with respect to Basin Plan adoption (2012) as shown by the dashed blue line.	166
Figure 12-19. Mean monthly electrical conductivity ($\mu\text{S cm}^{-1}$) in Lake Albert (DEW water quality stations: A4261155, A4260630, A4261153) and Lake Alexandrina (DEW water quality stations: A4260574, A4260524, A4261156, A4261133) from 2004 to 2023 with respect to Basin Plan adoption (2012) as shown by the dashed blue line.	167
Figure 12-20. Changes in wetland area index during the Eastern Australian Waterbird Aerial Survey from 1983–2022. The black horizontal line shows the long-term average. Source: Porter et al. (2022), see Eastern Australian waterbird survey Centre for Ecosystem Science - UNSW Sydney for further information.	168
Figure 12-21. Water levels (m AHD) in the Coorong between 2003 and 2023. Data are from the Murray Estuary (DEW water quality station A4261036, A4261039, A4261043, A4261128), North Lagoon (DEW water quality stations: A4261134, A4261135, A426057) and South Lagoon (DEW water quality stations: A4261209, A4261165).	171

Figure 12-22. Salinity (TDS GL⁻¹) in the Coorong between 2008 and 2023. Data are from the Murray Estuary (A4261036, A4261039, A4261128, A4261043), North Lagoon (DEW water quality stations: A4261134, A4261135, A426057) and South Lagoon (DEW water quality stations: A4261209, A4261165).

172

List of tables

Table 4–1.	Ecological objectives and targets for the CLLMM PEA selected for this assessment (DEW 2020).	33
Table 4–2.	Ecological indices for black bream and greenback flounder (DEWNR 2017).	34
Table 4–3.	Ecological objectives (DEW 2020) and CMP targets (DEWNR 2017) for waterbirds in the Lakes and Coorong.	35
Table 4–4.	South Australia’s Matter 8 key evaluation questions and methodology.	36
Table 4–5.	Alignment of trend outcomes based upon the probability of an increase or decrease (modified from Mastrandrea et al. 2010; as per McBride 2019) with the icons used for the evaluation.	37
Table 4–6.	Scoring system for the reliability of data used to assess and analyse trend, condition and LTWP targets and expected outcomes for Matter 8 reporting.	37
Table 4–7.	Conversion of the final score (0-12) of information reliability to an information reliability rating that ranges from poor to excellent for Matter 8 reporting.	38
Table 4–8.	Evaluation questions as part of the expert elicitation process.	39
Table 5–1.	Ecological objective and targets for Murray Mouth openness.	42
Table 5–2.	The expected environmental outcomes, based on the LTWP target (730 GL year ⁻¹), for Murray Mouth Openness in 2019, 2029 and 2042.	43
Table 5–3.	Annual (water year) barrage flow categories. Source: Lower Lakes, Coorong and Murray Mouth (LLCMM) Scientific Advisory Group.	44
Table 5–4.	Reliability of data to assess the trend and condition of Murray Mouth openness. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.	50
Table 6–1.	Ecological objective and targets set for aquatic and littoral vegetation in the Lakes (Nicol 2017, DEW 2020b).	60
Table 6–2.	Expected environmental outcomes for Lakes aquatic and littoral vegetation in 2019, 2029 and 2042. Expected outcomes were estimated by experts and were informed by Basin Plan hydrological modelling scenarios.	60
Table 6–3.	Outcomes from the Bayesian modelling assessment of trend for the icon site and each habitat. The probability of trend direction in the icon site score and habitat scores are presented and allocated to a trend category.	65
Table 6–4.	Reliability of aquatic and littoral vegetation data to assess the trend and condition of Lakes vegetation. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.	67
Table 7–1.	Ecological objective and targets for <i>Ruppia tuberosa</i> in the southern Coorong. Note that the 43 km historical extent ranges from N02E (Magrath Flat) to S41E/W (Tea Tree Crossing).	75
Table 7–2.	Expected environmental outcomes for <i>R. tuberosa</i> distribution (area of occupation) and long-term resilience (seed bank) across the 43 km sampling distribution in the Coorong in 2019, 2029 and 2042.	76
Table 7–3.	The area of occupation (percentage of sites within the 43 km EOO where live shoots are present) for <i>R. tuberosa</i> during January (summer) and July (winter) monitoring periods between 2012 and 2023. Data source: Paton and Bailey (2014); (Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c).	80
Table 7–4.	The extent of occurrence (EOO) for <i>R. tuberosa</i> in the southern Coorong during summer (January) and winter (July) monitoring periods between 2012 and 2023. Data source: (Paton & Bailey 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c).	81
Table 7–5.	Mean summer <i>R. tuberosa</i> seed bank densities (m ²) at sites (within the EOO) on the eastern and western shorelines of the Coorong between 2007 and 2023. Letter prefixes in site names denote site location in the either the North or South lagoons, numbers indicate distance (km) from Parnka point (the division between the North and South lagoons), and letter suffixes describe orientation in the Coorong. Overall mean and standard error are given below the individual site data. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.	84

Table 7-6.	Reliability of TLM <i>Ruppia</i> data to assess outcomes for <i>R. tuberosa</i> . The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.	85
Table 9-1.	Ecological objective, target and indices for black bream and greenback flounder.	101
Table 9-2.	Expected environmental outcomes for black bream and greenback flounder in 2019, 2029 and 2042.	102
Table 9-3.	Condition assessment for black bream population in the Coorong from 2008–09 to 2022–23. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of these indices meets the ecological target; (2) Distribution – meets the ecological target; (3) Age structure – a minimum of 2 indices must meet their ecological targets and (4) Recruitment – both indices must meet their ecological targets. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2023a).	107
Table 9-4.	Condition assessment for greenback flounder population in the Coorong from 2008–09 to 2022–23. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of these indices meets the ecological target; (2) Distribution – meets the ecological target; (3) Age structure – a minimum of 2 indices must meet their ecological targets and (4) Recruitment – both indices must meet their ecological targets. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2023a)	108
Table 9-5.	Reliability of data to assess outcomes of black bream and greenback flounder. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.	110
Table 10-1.	Ecological objective and targets for diadromous fish recruitment in the CLLMM PEA.	119
Table 10-2.	Expected environmental outcomes for annual congolli and common galaxias fish Recruitment Index (RI) values. All expected outcome values are years since Basin Plan adoption (i.e. since 2012).	120
Table 10-3.	Sampling period and young-of-year (YOY) size thresholds for congolli and common galaxias.	121
Table 10-4.	Reliability of diadromous fish recruitment index data to assess the expected environmental outcomes for diadromous fish (congolli and common galaxias). The methods used in data collection as well as the representativeness and repetition of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data collected were scored 2 points – Yes, 1 point – Partially and 0 points – No.	126
Table 11-1.	Ecological objective and target for small-mouthed hardyhead.	135
Table 11-2.	Expected outcomes for small-mouthed hardyhead in 2019, 2029 and 2042.	135
Table 11-3.	Reliability of data to assess outcomes of small-mouthed hardyhead. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.	138
Table 12-1.	Ecological objectives (DEW 2020) and CMP targets (DEWNR 2017) for waterbirds in the Lakes and Coorong.	144
Table 12-2.	Selected species grouped by guild that were used to assess outcomes in the Lakes waterbird community.	145
Table 12-3.	Selected species grouped by guild that were used to assess outcomes in the Coorong waterbird community.	145
Table 12-4.	Outcomes from Bayesian modelling assessing trends in the abundance of all selected species and selected species within the generalist, herbivore, and piscivore guilds in the Lakes between 2009 and 2023.	150
Table 12-5.	Outcomes from Bayesian modelling of trend for all selected species and selected species within the generalist, herbivore, migratory shorebird, piscivore and resident shorebird guilds in the Coorong between 2000 and 2023.	158
Table 12-6.	Reliability of data from the waterbird censuses of the Lakes and Coorong to assess expected environmental outcomes and trend in the abundance of selected species. The methods used in data	

collection as well as the representativeness and repetition of data were scored based on the answered to questions regarding each facet of data collection. Answers to questions on the method, representativeness and repetition of data collected were scored 2 points – Yes, 1 point – Partially and 0 points – No.

164

Summary

South Australia has assessed the achievement of environmental outcomes relating to a subset of the South Australian River Murray Long-term Watering Plan (LTWP) targets for the Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environmental Asset (PEA). By achieving these outcomes, the aim is to maintain or improve the health of vegetation, fish and bird communities, while also maintaining a permanently open Murray Mouth. The assessment of environmental outcomes presents the trend for each indicator along with an evaluation of the contribution of the Basin Plan and other influences on the achievement of these outcomes. A summary of the assessment is shown below.

Theme	Indicator	Trend	Information reliability	Key findings
Flow & Ecosystem Function	Murray Mouth openness	 Trend Improved	 Reliability Good	An open Murray Mouth has been possible at times by barrage flows supported by water for the environment but is still heavily reliant on dredging.
	Aquatic and littoral vegetation	 Trend Improved	 Reliability Very good	Vegetation condition in the Lakes has continued to improve, largely due to the management of seasonally variable water levels, supported by the delivery of water for the environment.
	<i>Ruppia tuberosa</i>	 Trend Improved	 Reliability Very good	The health of <i>Ruppia</i> has improved, but the community is still not considered resilient and is at risk to future perturbations.
Fish	Black bream and greenback flounder	 Trend Improved	 Reliability Excellent	Black bream and greenback flounder population condition have improved, reflecting more resilient populations.
	Diadromous fish	 Trend Improved	 Reliability Good	Improved connectivity between freshwater, estuarine and marine habitats has supported increased recruitment of diadromous fish.
	Small-mouthed hardyhead	 Trend Improved	 Reliability Very good	Small-mouthed hardyhead populations have improved, reflecting improved resilience with an increased abundance of juvenile fish.
Birds	Lakes waterbirds	 Trend Improved	 Reliability Very good	Abundances of Lakes waterbirds have improved, but with variability across the different waterbird guilds.
	Coorong waterbirds	 Trend Declined	 Reliability Very good	The abundance of Coorong waterbirds has continued to decline, particularly for resident and migratory shorebirds.

Implementation of the Basin Plan and the delivery of water for the environment is providing significant benefits and has supported improved environmental conditions in the Coorong, Lower Lakes and Murray Mouth:

- Additional water has helped maintain optimal lake levels and increased barrage flows across the year to improve salinity levels in Lake Alexandrina and Lake Albert.
- Lake level management and seasonal water level cycling has supported aquatic plant recruitment, improving the condition of aquatic and littoral vegetation. This has improved habitat condition and food resources, supporting the abundance, distribution and breeding of waterbird communities across the Lakes.
- Increased freshwater flows through the barrages have maintained and improved the extent of optimal salinity conditions, provided critical pathways for the movement and recruitment of key diadromous fish species and improved black bream and greenback flounder populations in the Murray Estuary and Coorong, as well as small-mouthed hardyhead in the Coorong.
- Maintenance of southern Coorong water levels through spring and summer have improved the abundance and distribution of aquatic plants, including *Ruppia tuberosa*.

Despite these improvements, challenges remain, including:

- The southern Coorong is considered degraded due to prolonged hyper-saline and hyper-eutrophic conditions, risking its ability to support key biota such as waterbirds, fish, plants and invertebrates if additional action is not taken.
- Recovery of waterbird populations, particularly shorebirds, requiring improved quality and availability of local, national and international wetland habitats.
- Improving the recovery and resilience of aquatic plants (including *Ruppia tuberosa*) in the southern Coorong
- Maintaining an open Murray Mouth, without ongoing dredging.

The following key messages have come from South Australia's assessment and evaluation of the achievement of environmental outcomes in the SA River Murray CLLMM PEA:

- Water for the environment and high (unregulated) flows are critical for maintaining the ecological health and function of the Coorong, Lower Lakes and Murray Mouth.
- Implementation of the Basin Plan to date has supported improved connectivity, increased barrage flows and maintained lake levels and salinities within optimal ranges.
- The delivery of water for the environment during recent dry years has likely prevented further disconnections of Lake Alexandrina from the Murray Estuary and Coorong and the resultant ecological outcomes similar to those experienced during the Millennium Drought.
- The 2022–23 River Murray flood event, along with recent high flow conditions, has provided short-term benefits to the Coorong ecosystem but further action is needed to secure its long-term health.

1 Introduction

1.1 Basin Plan Schedule 12

The reporting requirements outlined in Schedule 12 of the Basin Plan provide the Murray–Darling Basin Authority (MDBA) with the information necessary to evaluate the effectiveness of the Basin Plan against its objectives and outcomes (Chapter 4).

Matter 8 (achievement of environmental outcomes at an asset scale) is a state-based reporting obligation that is central to communicating the environmental outcomes achieved through the implementation of the Basin Plan. Basin states are required to report on Matter 8 on a 5-yearly basis, with the first round of reporting submitted in October 2020. The next round of reporting (of which this report contributes to) is to be submitted in October 2024. Basin States 5-yearly matter reports support the MDBA's Basin-scale evaluation in 2025. The MDBA is required to undertake an evaluation of the Basin Plan against its objectives in 2025, which will draw on the reporting undertaken by the MDBA, and reporting submitted by the Basin states under Schedule 12.

1.2 South Australia's approach to 2025 Basin Plan Environmental Outcome Evaluation and Reporting (Matter 8)

South Australia has identified the following objectives for Matter 8 environmental outcome reporting:

- To meet Basin Plan reporting obligations (Schedule 12, Basin Plan)
- To communicate Basin Plan outcomes to key stakeholders (including the community)
- To inform South Australia's, the Australian Government's, and other States' environmental water delivery decision making and adaptive management capacity
- To make a meaningful contribution to MDBA's evaluation of the effectiveness of the Basin Plan (at the Basin-scale) and our own evaluation of the effectiveness of the Basin Plan at a state-scale.

The South Australian Department for Environment and Water (DEW) has developed an approach to reporting on the achievement of environmental outcomes required for the Matter 8 reporting (Imgraben 2023). This approach recognises the linkages between the Basin Plan environmental objectives, environmental watering plans and strategies (state and Basin-wide) and asset-scale environmental outcome reporting (Matter 8). Four key evaluation questions guide South Australia's evaluation of environmental outcomes at an asset scale:

1. To what extent have outcomes been achieved?
2. If outcomes were not achieved, why not?
3. To what extent did the Basin Plan contribute to achieving outcomes?
4. Have there been any unanticipated outcomes?

Reporting for Matter 8 in South Australia is required for three Water Resource Plan Areas (WRPA):

- South Australian River Murray
- Eastern Mount Lofty Ranges
- South Australian Murray Region

In line with the Basin Plan, South Australia has developed a LTWP for each of the South Australian WRPA. These plans identify Priority Environmental Assets (PEAs) together with environmental objectives, targets, and

environmental water requirements (EWRs). The asset scale reporting of Matter 8 is therefore directly linked to the assets identified in the LTWPs and the objectives, targets, and EWRs for those assets.

The achievement of environmental outcomes across PEAs in the South Australian River Murray is assessed in relation to prioritised LTWP targets through the development of expected outcomes (see section 1.2.1). Prioritisation of LTWP targets was undertaken against the following criteria:

- Capability to track environmental trends at a range of spatial scales
- Environmental value
- Response to flow
- Consistency with the Basin-wide Environmental Watering Strategy
- Scientific credibility and reproducibility

1.2.1 South Australian River Murray expected outcomes

Targets in the South Australian River Murray LTWP are long-term and represent what is needed to support the PEAs in a 'healthy, functioning state'. The development of targets was not restricted to what is achievable under the Basin Plan, and the timeframes over which achievable targets are expected to be met vary based upon their response to water for the environment delivery and other management actions over time. To provide a more nuanced approach to the evaluation and reporting, quantitative expected environmental outcomes (expected outcomes) were developed that allows us to track the progression towards outcomes, targets and objectives.

Expected outcomes quantify the extent to which LTWP targets are met over three time points post-Basin Plan adoption in 2012 (i.e. 2019, 2029 and 2042). These time points were chosen to align with key Basin Plan implementation activities and reporting. Expected outcomes were developed using a best-practice expert elicitation approach (Speirs-Bridge et al. 2010) and informed by Basin Plan hydrological modelling scenarios and best available data and information. The achievement of the short-term (2019) expected outcomes was assessed for 2020 Matter 8 reporting. For this round of reporting, progress towards intermediate outcomes (2029) will be assessed.

2 Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset

2.1 Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset

The Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environment Asset (PEA) (Figure 2-1) is located approximately 75 km southeast of Adelaide. The CLLMM PEA is situated at the end of the River Murray and is the terminus of the Murray–Darling Basin (MDB), with the river system reaching the Southern Ocean at the Murray Mouth. The CLLMM PEA covers 142,530 ha of diverse freshwater, estuarine and marine habitats that are of regional, national and international significance (DEW 2020). These habitats support extensive and diverse waterbird, fish and plant assemblages as well as threatened ecological communities and species (DEW 2020).

The CLLMM PEA covers areas listed as a Ramsar wetland of international importance (Coorong, and Lakes Alexandrina and Albert Wetland) and Icon site (Lower Lakes, Coorong and Murray Mouth) in the MDB under *The Living Murray* (TLM) Program. The wetland complex was recognised as a Ramsar site in 1985 for its physical and biological diversity and waterbird populations, particularly migratory species (Phillips & Muller 2006). High ecological values, as well as the sites cultural and heritage significance to Traditional Owners, led to its selection as an Icon site.

The CLLMM PEA is comprised of the following units within the wetland complex; the Lakes, Murray Estuary, Murray Mouth and the Coorong. The Lakes are two large, shallow freshwater lakes, and include Lake Alexandrina and Lake Albert. Lake Alexandrina is the largest of the lakes and has direct connection with the River Murray channel near Wellington (Figure 2-1). Lake Albert is situated to the east of Lake Alexandrina, and is a terminal lake connected by a narrow flow path at Narrung, referred to as the Narrows. These freshwater lakes and adjoining fringing wetlands are characterised by wetland margins with shallow to steep shorelines and reed beds (Paton et al. 2015).

The freshwaters of the Lakes are separated from the saline waters of the Murray Estuary and Coorong through a series of five barrages, which were constructed between 1935 and 1940 across barrier islands near the Murray Mouth (Sim & Muller 2004). The barrages prevent seawater entering the Lakes to maintain freshwater conditions during times of low flows (Blackmore 2002), ensuring water supplies for agricultural productivity in the surrounding areas. During times of adequate flow, water can flow from the barrages through open barrage gates into the Murray Estuary and Coorong.

The lagoons of the Murray Estuary and Coorong are connected to the Southern Ocean via the Murray Mouth, which is the only connection to the sea in the MDB. The Murray Estuary is directly influenced by freshwater flows from the barrages, and with the mixing of seawater entering through the Murray Mouth, creates the only estuarine conditions within the MDB. The estuarine waters adjoin the Coorong, which is comprised of two lagoons, referred to as the North Lagoon and South Lagoon. The Coorong typically has a salinity gradient (Brookes et al. 2022) that increases with distance from the Murray Mouth, with salinities in the North Lagoon varying between estuarine and hypersaline, and those in the South Lagoon considered to be extremely hypersaline (Brookes et al. 2022). Salinities in the Coorong are primarily influenced by volumes of barrage flow and tidal influence, while flows from the upper south-east of South Australia via Salt Creek also have localised effects in the South Lagoon (Mosley et al. 2020). The habitats of the Murray Estuary and Coorong are characterised by vast areas of shallow, gently sloping shorelines where emergent vegetation is absent (Paton et al. 2015).

The Murray Mouth is a tidal inlet that is restricted by the accumulation of dune material on the flanking spits of Sir Richard Peninsula and Younghusband Peninsula. The location, size and shape of the Murray Mouth is dictated by barrage flow, tides and wave dynamics in Encounter Bay. The Murray Mouth is particularly important to the hydrodynamics of the Murray Estuary and Coorong, and it controls water exchanges between the Southern Ocean and the Coorong.

The CLLMM PEA includes the terrestrial coastal environments that surround the Lakes and Coorong lagoons, which include woodlands, shrublands and swamps. The entire Coorong National Park is covered by the CLLMM PEA, and therefore includes the Younghusband Peninsula, a peninsula of dunes and beach front that protects the Coorong from the Southern Ocean.



Legend

- Coorong, Lower Lakes & Murray Mouth PEA
- Coorong, and Lakes Alexandrina and Albert Wetland Ramsar Site

0 5 10 20 30 40
Kilometers



Government of South Australia
Department for Environment
and Water

Figure 2-1. Coorong, Lower Lakes and Murray Mouth (CLMM) Priority Environmental Asset (PEA).

3 Hydrology

3.1 Flows to South Australia (QSA)

Flows to South Australia (QSA) quantifies the volume of water in the River Murray arriving at the South Australian border. Flow volumes (Figure 3-1) vary markedly with climatic conditions (e.g., rainfall, drought, temperature) and the diversion of water resources, leading to annual and seasonal variability. Intra-annual patterns are relatively unpredictable; however, seasonal discharge patterns typically are at their peak in spring and at their lowest in late summer and early autumn (Maheshwari et al. 1995).

QSA has been highly variable over the last 22 years. The Millennium Drought occurred from 1996–2010 and included a period of prolonged low flow from 2001–02 to 2009–10 (average 1,717 GL year⁻¹), including a continuous period of three years (or more) with no barrage flow from the Lakes. Widespread flooding occurred over the MDB in 2010–11, with QSA peaking at ~93,508 ML day⁻¹ and an annual QSA totalling 15,137 GL. High flows continued in 2011–12 and 2012–13 with 10,248 GL and 6,970 GL of annual QSA, respectively. More moderate flows (3,570 GL) were recorded over 2013–14, before low flow conditions occurred over 2014–15 and 2015–16 (average 2,685 GL). In 2016–17, high flows were recorded with QSA peaking at ~94,381 ML day⁻¹. As there was a rapid recession in this high flow event, the annual volume (9,238 GL) was lower than 2010–11. Extreme dry conditions in the MDB between 2017–18 and 2019–20 greatly reduced QSA (average 2,508 GL year⁻¹) over this period. Three consecutive years of above-average rainfall in the Basin increased QSA between 2020–21 and 2022–23. Moderate flows were recorded in 2020–21 (3,078 GL year⁻¹), which were followed by high flows in 2021–22 (9,097 GL year⁻¹) and the third largest flooding event in the SA River Murray in 2022–23 (23,000 GL year⁻¹). The highest flow peaks in the last two water years were 42,976 ML day⁻¹ (30/06/2022) and 185,746 ML day⁻¹ (22/12/2022).

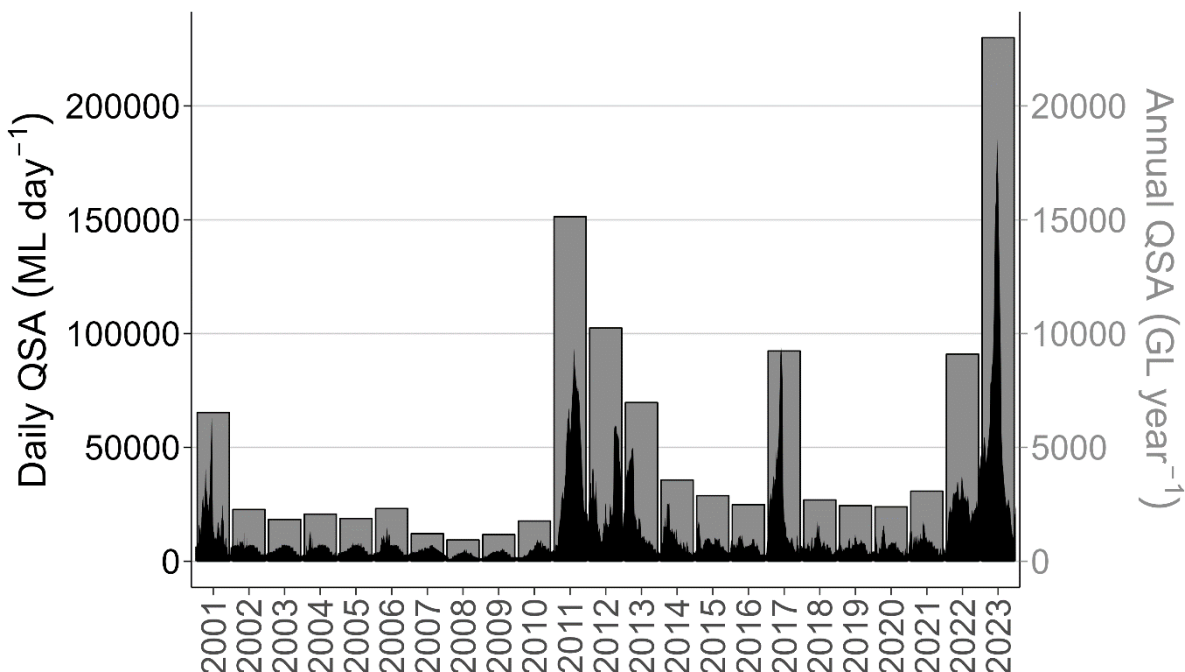


Figure 3-1. Flows to South Australia (QSA) between 2000–01 and 2022–23. The left axis and black area correspond to daily QSA (ML day⁻¹), while the right axis and grey bars correspond to annual QSA (GL year⁻¹) for each water year (1 July to 30 June).

3.1.1 Water for the environment

The Basin Plan provisions flow components to South Australia within the total QSA (shown in Figure 3-2). Sources of QSA include (but are not limited to) SA entitlement flow, additional dilution flow (ADF), water for the environment and unregulated flows. In years with low QSA, the relative contribution of water for the environment to QSA is higher, while the total volume SA receives is lower. For example, in 2022 water for the environment comprised 4% of annual QSA, while in lower flow years such as 2019 it was 33% of annual QSA. The total volume of water for the environment between these two years also differed. Annual volumes of water for the environment provided to South Australia has ranged from 421 GL (2016) to 1,306 GL (2017) since the adoption of the Basin Plan.

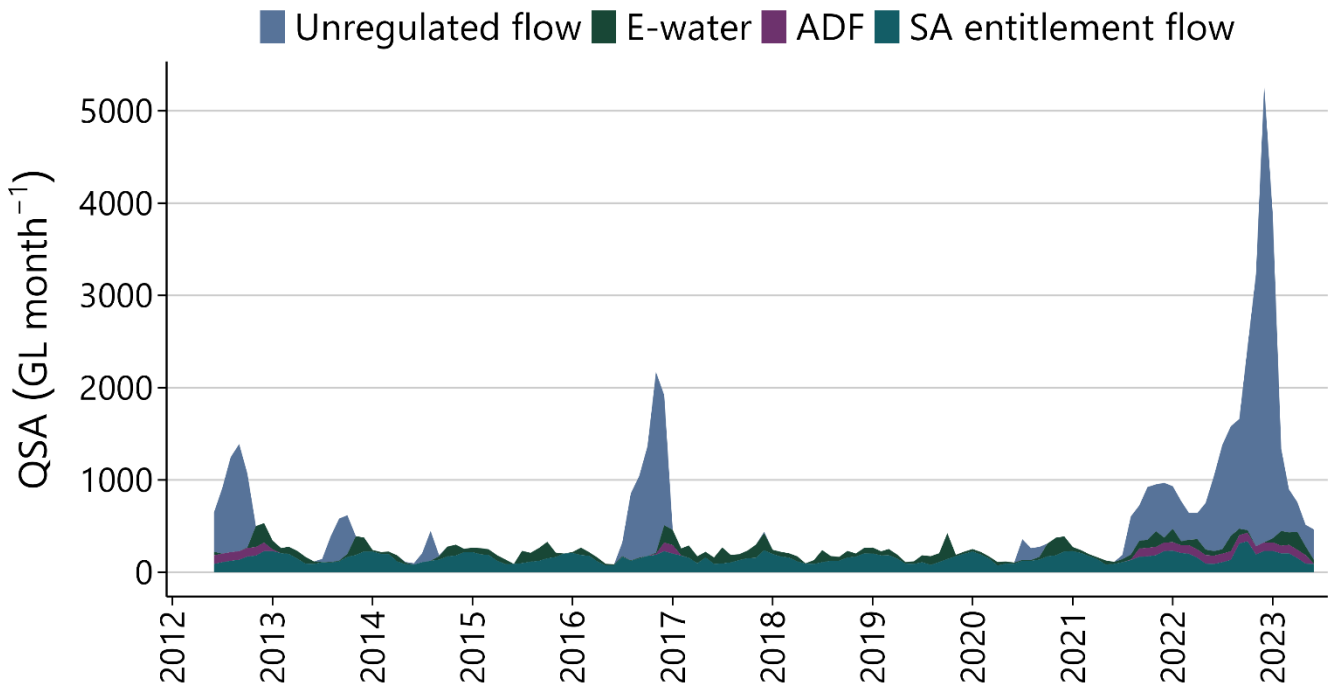


Figure 3-2. Contribution of unregulated flow, water for the environment (E-water), additional dilution flow (ADF) and SA entitlement flow, to flow (GL month⁻¹) to the South Australian border (QSA) from June 2012 (Basin Plan adoption) to June 2023.

3.2 River Murray inflow

Inflows from the River Murray provide the primary source of freshwater inflows into the CLLMM PEA, with a median annual inflow of 4,077 GL (Lock 1) (Gibbs et al. 2018). These inflows are generally highest over spring (September–November) and lowest in late summer and early autumn (February–April). Tributaries that drain the Eastern Mount Lofty Ranges (i.e. Currency Creek and Finniss, Angus and Bremer Rivers) contribute a median annual flow of 73 GL into the Lakes, which constitutes less than 2% of the overall inflows into the Lakes (Gibbs et al. 2018). Fresh–brackish water from the drainage networks in the upper south east of SA flows directly into the Coorong South Lagoon via Salt Creek, with a median annual inflow of 11 GL (15 GL average) (Gibbs et al. 2018). Localised rainfall and groundwater inputs at the site are minor when compared to River Murray inputs. Rather than rainfall, a major driver of the hydrology of the CLLMM PEA is the amount that evaporation exceeds rainfall, referred to as net evaporation. Inflows of marine water through the Murray Mouth into the Murray Estuary and Coorong significantly contribute to the system's water balance and vary seasonally in response to wind, sea level and tides (DEW 2022; Gibbs et al. 2018; Webster 2010), impacting the “openness” of the Murray Mouth.

Since European settlement, River Murray inflows have been significantly altered by water extraction and river regulation. Modelling by the MDBA during development of the Basin Plan has shown that under 'without development' conditions (a near-natural scenario approximating river flows without dams, weirs or extraction), an average of 12,500 GL year⁻¹ would flow out of the Basin through the Murray Mouth (MDBA 2010). Under current diversion limits (including all water that is recognised under water resource plans as pumped, diverted or intercepted for consumptive purposes including irrigation, urban supplies, stock water, domestic supplies and industry) this reduces to 5,100 GL year⁻¹, which is around 41% of 'without development' outflows. These levels of water extraction and development were modelled by CSIRO (2008) to cause the cessation of flow through the Murray Mouth 40% of the time, compared to 1% under natural flow conditions.

3.3 Lakes

The Lakes was a predominately freshwater ecosystem prior to post-European river regulation (Fluin et al. 2007; Tibby et al. 2022). The hydrology of the Lakes is primarily influenced by inflows from the River Murray, with small contributions from Eastern Mount Lofty Ranges tributaries and surrounding groundwater (Gibbs et al. 2018). Levels of Lake Alexandrina fluctuate seasonally and are dependent upon inflows from the River Murray, water extraction rates, releases from the barrages, and climatic factors, such as wind, tides and evaporation (Gibbs et al. 2018). Over an annual cycle, Lake Alexandrina levels usually fluctuate between +0.5 m AHD and +0.85 m AHD (DEW 2019), and generally rise in winter and fall in summer/autumn (Heneker 2010). Given that Lake Albert is a terminal wetland, with a narrow connection with Lake Alexandrina, its water level regime changes in association with that of Lake Alexandrina. Exchange between the Lakes can be driven by local wind conditions (direction and speed) as well as River Murray flows and barrage releases.

The Millennium Drought had severe consequences on the Lakes between 2007 and 2010, with water levels in Lake Alexandrina dropping to -1.0 m AHD in 2009 and -0.55 m AHD in Lake Albert in 2010 (Figure 3-3). Current water management objectives for the Lakes are focused on supporting the seasonal fluctuations in water levels (+0.5 m AHD and +0.85 m AHD) and maintaining salinities in Lake Alexandrina below ~1,000 $\mu\text{S cm}^{-1}$ to achieve ecological benefits (Lester et al. 2011). Winter-spring filling of the Lakes supports the growth and recruitment of aquatic and lakeshore vegetation (Nicol et al. 2023), and increases habitat, food availability and protection from alien fishes (Wedderburn et al. 2019). This provides conditions important for native wetland fauna to breed, including the regionally important and endangered southern pygmy perch (Wedderburn et al. 2019). Draw-downs during late summer and early autumn are also important to the ecology of the Lakes, with the exposure of wetland margins supporting opportunities for the recruitment of littoral vegetation and foraging by waterbirds, in particular waterhens and rails (Lester et al. 2011).

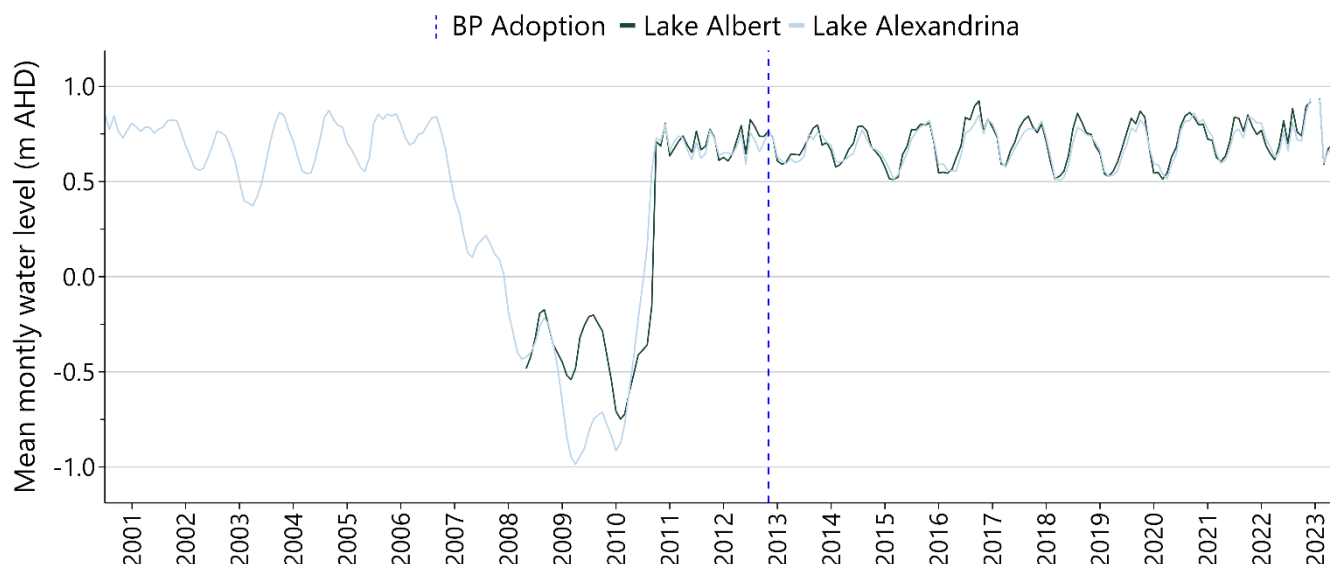


Figure 3-3. Average monthly water level (m AHD) in Lake Alexandrina (monitoring stations: A4260524, A4260527, A4260574, A4261133, A4261156) and Lake Albert (monitoring stations: A4260630, A4261153, A4261155) between 2001 and 2023. Data source: Water Data SA.

Between 2003 and 2006, water levels in the Lakes fluctuated seasonally between +0.4 and +0.8 m AHD, and freshwater inputs from the River Murray maintained salinity levels in Lake Alexandrina below $2,000 \mu\text{S cm}^{-1}$ (Kingsford et al. 2011). The Millennium Drought and upstream extraction rates caused water levels to begin to decline in 2007, receding below sea level (0 m AHD) in 2008. The combination of reduced flow and water exchange between the Lakes and Coorong (over the barrages) resulted in a lack of salt export from the MDB, causing Lake Alexandrina to exceed $5,000 \mu\text{S cm}^{-1}$, and Lake Albert $15,000 \mu\text{S cm}^{-1}$. High flow commencing in 2010–11 caused water levels in the Lakes to return to above +0.5 m AHD, resulting in decreased salinity concentrations due to flushing of the Lakes. Between 2012 and 2022, water level cycling retained a natural, seasonal fluctuation between +0.4 and +0.9 m AHD. Salinity concentrations in Lake Albert have steadily decreased between 2012–13 (mean $3,381 \mu\text{S cm}^{-1}$) and 2022–23 (mean $1,060 \mu\text{S cm}^{-1}$), while Lake Alexandrina has remained more stable (2012–13, mean $501 \mu\text{S cm}^{-1}$; 2022–23, mean $411 \mu\text{S cm}^{-1}$) (Figure 3-4). Lake levels increased above +1 m AHD in 2023 for the first time in over 20 years, due to the flood in 2022–23. Receding flood water by mid-2023 had resulted in water levels returning to the normal managed range. Electrical conductivities during and following the 2022–23 flood were maintained at pre-flood levels.

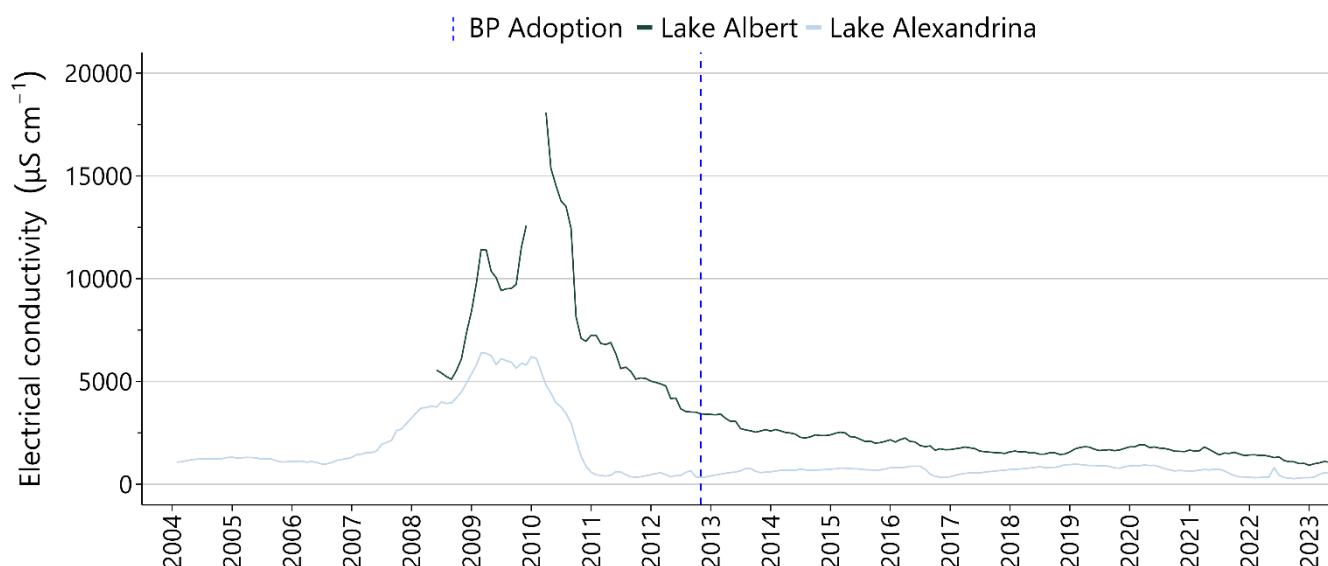


Figure 3-4. Monthly salinity concentrations ($\mu\text{S cm}^{-1}$) in Lake Alexandrina (monitoring stations: A4261156, A4260524, A4260574, A4261133) and Lake Albert (monitoring stations: A4260630, A4261153, A4261155) between 2004 and 2023. Data source: Water Data SA.

3.4 Barrage flows

Barrage flows are required to maintain hydrological and ecological connectivity between the River Murray, the Coorong and the Southern Ocean. Timed barrage releases influence water levels and salinity concentrations in both the Lakes and Coorong (Mosley 2016), while sufficient flow is required to scour marine sediment in the Murray Mouth and maintain connectivity between the MDB and the Southern Ocean. Sufficient barrage outflow is pivotal in mediating salt export from the MDB each year, for which water for the environment contributes a substantial portion, especially during dry years in the Basin (Brookes et al. 2022).

Mechanisms influencing barrage outflow include lake levels, tide and wind conditions, net evaporation losses, and River Murray flow into Lake Alexandrina. Tidal influence becomes greater in the Coorong lagoons in the absence of barrage outflow, contributing to salt accumulation and reducing the natural flushing that occurs with freshwater inflow (Mosley et al. 2020).

The Millennium Drought resulted in a low barrage outflow from the MDB (Figure 3-5). High flows were recorded over 2000–01, with a total barrage flow of 5,095 GL, but following this the mean flow between 2001–02 and 2009–10 was 288 GL, while zero flow was recorded between 2007–08 and 2009–10. Dredging of the Murray Mouth was essential during this period to prevent closure from marine sediment deposited from the Southern Ocean (Higham 2012). Flood conditions across the MDB in 2010–11 resulted in improved barrage flow, reaching a maximum monthly flow of 1,688 GL and an annual flow of 10,464 GL. High flows continued into 2011–12 (6,544 GL) and 2012–13 (4,901 GL). After the adoption of the Basin Plan in 2012, annual barrage flow returned to levels expected between flood periods until 2015–16 (1,211 GL). Prevailing flood conditions in 2016–17 resulted in increased annual barrage flow (7,663 GL). Dry conditions in the MDB led to low flows again during 2018–19 (586 GL) and 2019–20 (705 GL).

During wetter conditions in the MDB, unregulated QSA represent the majority of barrage outflow (Ye et al. 2023). During dry years, held water for the environment has a much higher relative contribution to barrage flows due to limited River Murray flows (Stewardson & Guarino 2019).

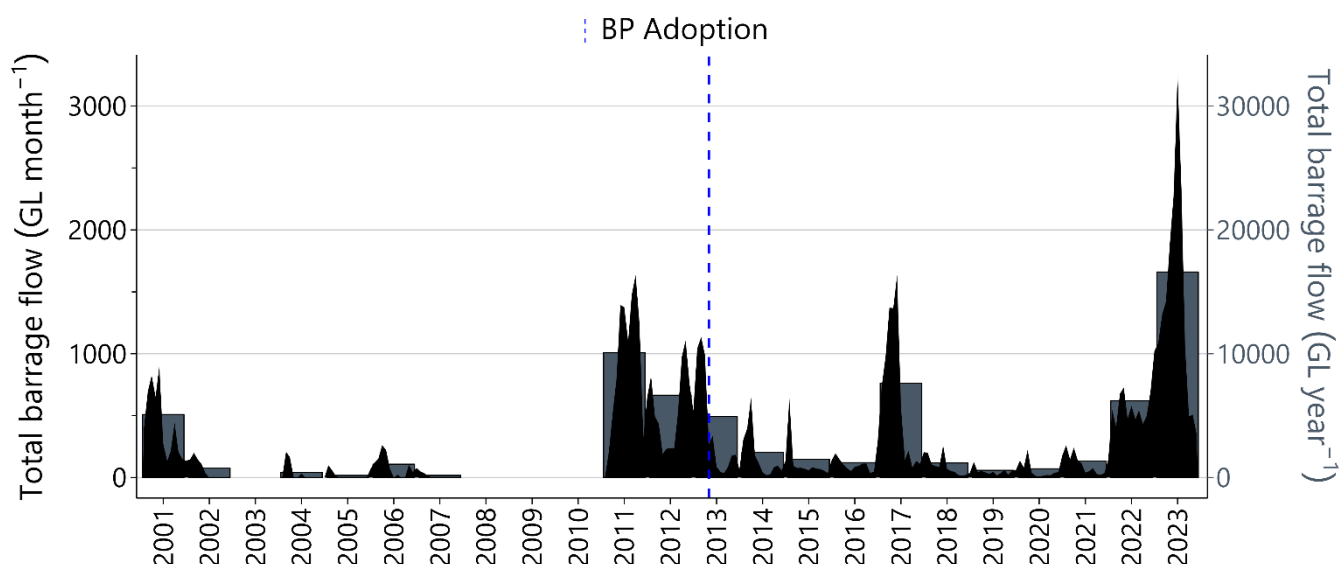


Figure 3-5. The total monthly barrage flow (black left axis; GL month⁻¹) and total annual (July–June) barrage flow (grey right axis; GL year⁻¹) between July 2000 and June 2023. Data sources: MSM-BIGMOD calculated barrage flow (July 2000–January 2011) and DEW barrage calculator (January 2011–June 2023).

3.5 Coorong

Hydrology in the Coorong is influenced by barrage flow, tidal influx through the Murray Mouth, evapotranspiration and wind conditions (Gibbs et al. 2018; Higham 2012; Webster 2005). A small portion of inflows are contributed through Salt Creek (Brookes et al. 2022). Reduced freshwater inflows from Lake Alexandrina and a lower frequency of high flow events have increased salinity and sedimentation in the Coorong (Gibbs et al. 2018).

The estuarine nature of the Murray Estuary and North Lagoon in the Coorong creates a unique and dynamic environment influenced by a combination of freshwater inflows, tidal movements, and evapo-concentration that contributes to the salinity gradient of the Coorong (Brookes et al. 2022). This balance is essential for maintaining the diverse habitats that support various aquatic plants, fish, and bird species (Paton et al. 2009; Ye et al. 2015). Fluctuations in water levels and salinity directly affect ecological variability and habitat availability, which are critical for the survival and reproduction of many species (Paton et al. 2009; Ye et al. 2015). Effective management of water flows and maintaining optimal conditions are crucial for preserving the health and biodiversity of the Coorong ecosystem (Lester et al. 2011).

The South Lagoon experiences long average water residence times due to the constriction between the two lagoons and limited freshwater inflows (Brookes et al. 2022). This prolonged residence time contributes to hypersaline conditions, particularly in the absence of substantial inflows to periodically freshen the waters (Brookes et al. 2018). As a result, the South Lagoon's ecological health can be vulnerable to extreme hyper-salinity, which impacts the diversity and availability of habitat and food resources for estuarine fish populations and other aquatic organisms (Paton et al. 2009; Ye et al. 2015). Strategic management of inflows, including those from drainage networks in the upper south-east of South Australia, is vital to periodically reduce salinity levels and support the ecological function of the South Lagoon (Brookes et al. 2018). Similar to the Lakes, water levels and salinity in the Coorong have a strong influence on habitat quality for aquatic plants, fish and birds (Paton et al. 2009; Ye et al. 2015).

Water levels influence particle resuspension and turbidity generated by wind and wave action in the shallow lagoons, thereby reducing the light conditions necessary for plankton and aquatic plants. Variation in water levels in the Murray Estuary and Coorong exposes and inundates extensive areas of mudflats for invertebrates. Water levels in the Coorong vary over timescales of seasons down to hours. A combination of wind, sea level, evaporation and

barrage releases all influence water levels in the Coorong, which undergo a seasonal cycle of up to approximately +0.7m AHD in range; higher water levels tend to occur in late winter-early spring, with lower water levels in late summer-early autumn (Figure 3-6) (Webster 2005).

Water levels in the North and South lagoons between 2003 and 2023 have been highly variable, compared with the Lakes (Figure 3-3 and Figure 3-6). Water levels in the South Lagoon have regularly fluctuated below sea level, notably during the Millennium Drought and during dry periods in the MDB last decade. Recently, wet conditions between January 2021 and June 2023 have resulted in an increasing trend in water levels in both lagoons (Figure 3-6).

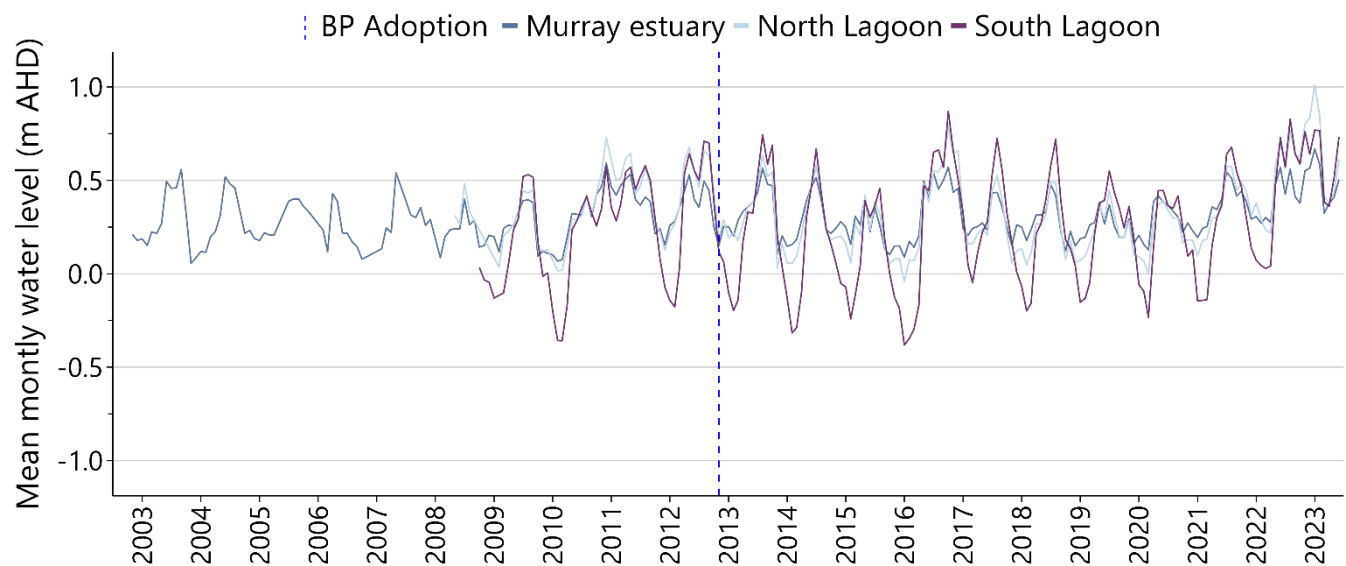


Figure 3-6. The average monthly water levels (m AHD) in the Murray estuary (monitoring stations: A4261036, A4261039, A4261043, A4261128), North Lagoon (monitoring stations: A4260572, A4261134, A4261135) and South Lagoon (monitoring stations: A4261165, A4261209) between 2003 and 2023. Data source: Water Data SA.

3.6 Coorong salinity

The connected Murray Estuary and Coorong exhibit a natural salinity gradient, transitioning from estuarine to marine conditions (up to 36 g L^{-1}) in the Murray Estuary to hypersaline conditions in the Coorong South Lagoon at the system's terminal end (Brookes et al. 2023). This salinity gradient influences the diversity of habitats and biota across the system (Paton et al. 2009).

Salinity concentrations in the North and South lagoons were at the highest level on record during and toward the end of the Millennium Drought (Figure 3-7). During this period, greater volumes of seawater entering the Coorong led to salinities in the southern Coorong reaching 150 g L^{-1} (Brookes et al. 2009; Gibbs et al. 2018). Increased saline conditions in the Coorong between 2007 and 2010 coincided with zero barrage flow from Lake Alexandrina. After 2012, the South Lagoon saw a gradual and sustained increase in average salinity over time, with a small decrease noted in 2017 post high flows. Late 2022 and early 2023 saw a notable decrease in salinity within the South Lagoon as a result of the 2022–23 flood event, illustrating the importance of maintaining freshwater inputs from the River Murray for the Coorong.

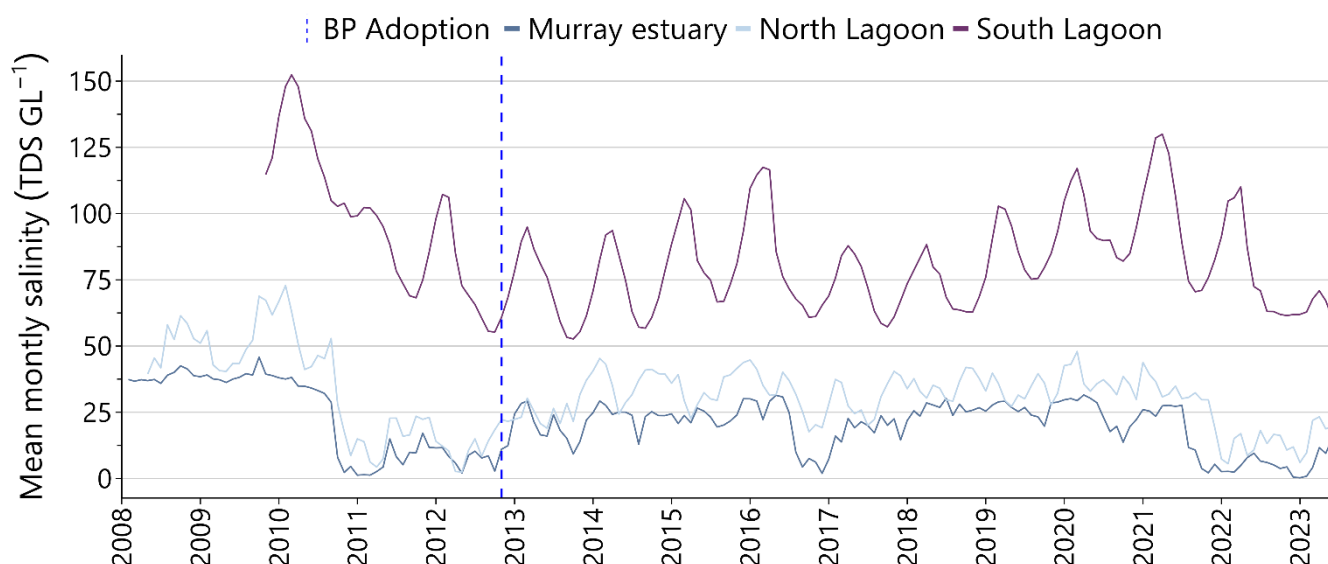


Figure 3-7. Salinity concentrations (TDS GL⁻¹) in the Coorong between 2007 and 2023, in the Murray Estuary (monitoring stations: A4261036, A4261039, A4261043, A4261128), North Lagoon (monitoring stations: A4261134, A4261135, A426057) and South Lagoon (monitoring stations: A4261209, A4261165). Data source: Water Data SA.

3.7 Murray Mouth

The Murray Mouth is located at the terminus of the MDB, where the Murray Estuary connects to the Southern Ocean. This dynamic interface is critical to the hydrological exchange between the marine and estuarine environments of Southern Ocean and Coorong, and facilitates the export of salt, nutrients and sediment from the MDB (Brookes et al. 2023; Thom et al. 2020). As the only connection between freshwater, estuarine and marine environments in the MDB, an open and functioning Murray Mouth is essential for diadromous and estuarine fishes successfully completing their life cycles (Bice et al. 2018).

3.7.1 Tidal influence

The coastline near the Murray Mouth is a high energy marine environment with a strong tidal force and influence of marine sediment influx into the Murray Mouth (Brookes et al. 2002). Ingression of seawater into the Murray Estuary mixes with freshwater barrage flow from Lake Alexandrina, creating the estuarine environment. As such, tides in the Southern Ocean have a strong influence on the width and depth (openness) of the Murray Mouth (Bourman et al. 2018; Harvey 1988; Webster 2005), which in turn affects the connectivity and water quality conditions in the Coorong. As a constant tidal force, seawater ingression into the Coorong increases salinities, in conjunction with evapotranspiration, when low or no barrage flows occur. Tidal signal is measured by the Diurnal tidal ratio (DTR), which is the ratio of tidal energy between the Goolwa Barrage in the Murray Estuary and Victor Harbor in the Southern Ocean (DEW 2018).

4 Objectives, targets and expected environmental outcomes

4.1 Ecological objectives and targets

The ecological objectives and targets outlined in the [South Australian River Murray Long-term Watering Plan](#) (LTWP) represent what is required to support each of the PEA in a healthy, functioning state (DEW 2020). As such, the objectives and targets within the LTWP were not constrained to those considered to be achievable under the Basin Plan. The ecological targets provide a means to assess and report on changes in condition over time, tracking progress towards ecological objectives.

A total of 14 ecological targets across five ecological objectives (Table 4–1; Table 4–2; Table 4–3) were prioritised and used as the basis for this assessment and evaluation of expected environmental outcomes for the CLLMM PEA. These were a subset of the total number of objectives and targets outlined in the LTWP (DEW 2020), selected for this assessment due to their relevance to delivery of water for the environment and availability of data. It is important to note that these targets have been refined since the LTWP was published, with a review of the [Lower Lakes Coorong and Murray Mouth Icon Site Condition Monitoring Plan](#) (DEWNR 2017), including the targets undertaken. The refined *LLCMM Icon Site Condition Monitoring Plan* targets have been used for the basis of the development of expected environmental outcomes. In addition to the assessment and evaluation of expected outcomes, a case study of Coorong nutrient dynamics is also provided.

Table 4–1. Ecological objectives and targets for the CLLMM PEA selected for this assessment (DEW 2020).

Indicator	Ecological objective	Ecological targets
Flow	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the sea	Maintain a minimum annual flow required to keep the Murray Mouth open (730–1,090 GL year ⁻¹).
		Maintain an open Murray Mouth, as indicated when the Diurnal Tidal Ratio (DTR) at Goolwa exceeds 0.3, with minimum DTR values of 0.05 and 0.2 at Tauwitchere and Goolwa, respectively.
Vegetation	Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes	Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the LLCMM vegetation indices.
	Restore <i>Ruppia tuberosa</i> colonisation and reproduction in the Coorong at a regional and local scale	Extent of occurrence (EOO) along the Coorong of 43 km, excluding outliers.
		Area of occupation (AOO) – within the sampled distribution, 80% of sites have plants present in both winter and summer.
		Long-term resilience: i. By 2019: 2,000.m² at 50% of sites (≥ 8 seeds per 75 mm diam. × 40 mm deep core)

Indicator	Ecological objective	Ecological targets
		ii. By 2029: 10,000.m ² at 50% of sites (≥ 40 seeds per 75 mm diam. × 40 mm deep core)
Fish	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lower Lakes and Coorong	Annual detection of juvenile catadromous fish at abundances ≥ that of defined 'Recruitment Index' values (44.5 for congolli; 6.1 for common galaxias). Maintain or improve abundances, distribution and recruitment of black bream and greenback flounder with a population condition score ≥ 3. Maintain the proportional abundance of small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM.

Table 4–2. Ecological indices for black bream and greenback flounder (DEWNR 2017).

Characteristic	Description
Ecological indices for black bream	1. Relative abundance (based on commercial fishery catch, t year ⁻¹) – Annual catch ≥8 t or positive trend over previous 4 years (linear regression).
	2. Distribution – >50% of the catch from southern part of the Coorong (south of Mark Point).
	3. Age structures – Need to meet at least 2 of the following 3 targets: >20% fish above 10 years; at least one strong cohort over the last 5 years; ≥2 strong cohorts in the population. Note: strong cohort is defined as a cohort representing ≥ 15% of the population.
	4. Recruitment – Catch per unit effort (CPUE) of young-of-year (YOY) >0.77 fish.net night ⁻¹ by fyke net and > 50% sites with black bream YOY present. (Note this metric has been updated in future reporting to >0.35 YOY net night ⁻¹).
Ecological indices for greenback flounder	1. Relative abundance (based on commercial fishery catch, t year ⁻¹) – Annual catch ≥ 24 t or positive trend over previous 4 years (linear regression).
	2. Distribution – >70% of the catch from southern part of the Coorong (south of Mark Point).
	3. Age structure – Presence of a very strong cohort (>60%) or at least a strong cohort (>40%) in year 0–2 and >20% of fish >2 years old.
	4. Recruitment – CPUE of YOY >1.04 fish seine net ⁻¹ – YOY distribution in the Coorong: > 50% sites with YOY present.

Table 4–3. Ecological objectives (DEW 2020) and CMP targets (DEWNR 2017) for waterbirds in the Lakes and Coorong.

Ecological objective	Area	CMP targets
Maintain or improve waterbird populations in the Coorong and Lakes	Lakes	Exceed the recent (2013–2015) median value for abundance of each of 25 selected waterbird species in the Lower Lakes in two of the last three years.
		Exceed the 75% threshold for the recent (2013–2015) AOO (km ²) for each of 25 selected waterbird species in the Lower Lakes.
		Exceed the 75% threshold for the recent (2013–2015) EOO for each of 25 selected waterbird species in the Lower Lakes.
	Coorong	Exceed the long-term (2000–2015) median value for abundance of each of 40 selected waterbird species in the Coorong in two of the last three years.
		Exceed the 75% threshold for the long-term (2000–2015) AOO for each of 40 selected waterbird species in the Coorong.
		Exceed the 75% threshold for the long-term (2000–2015) EOO for each of 40 selected waterbird species in the Coorong.

The expected environmental outcomes (based on the ecological targets shown above) assessed for the CLLMM PEA as part of the SA River Murray are presented in each of the relevant sections within this report.

4.2 Methods

South Australia’s key evaluation questions were designed to align with the MDBA’s evaluation questions and their reporting guidelines. Answers to SA’s key evaluation questions are intended to contribute to the MDBA’s Basin-scale evaluation of the Basin Plan against its objectives.

4.2.1 Assessment

An evaluation methodology was developed to address each of SA’s key evaluation questions, and is underpinned by the following assessments and evaluative processes:

- achievement of expected environmental outcomes
- trend (as described in section 4.2.2)
- information reliability (as described in section 4.2.3)
- evaluation of environmental outcomes using expert elicitation supported by available data and information including the identification of actions to achieve environmental outcomes in the future.

An overview of the method followed to address SA’s key evaluation questions is shown in Table 4–4.

Table 4–4. South Australia’s Matter 8 key evaluation questions and methodology.

SA key evaluation questions	Evaluation method
To what extent have outcomes been achieved at the asset scale?	Progress towards intermediate (2029) expected outcomes were quantitatively assessed and reported for each indicator at the asset scale. The data cut-off point for this assessment for all indicators was 30 June 2023. Trend and change will be assessed where possible. • All available data will be presented to provide a baseline for assessing and reporting trend. • Change since the 2020 evaluation will be assessed using data collected between July 2019 and June 2023.
If outcomes were not achieved, why not?	Qualitative evaluation of achievement of outcomes were undertaken using: • Contextual datasets and supplementary information • Expert judgement through a structured elicitation process • Assessment of documented assumptions, limitations and contributing factors for expected outcomes • Outcomes for 2020 Matter 8 reporting.
To what extent did the Basin Plan contribute to achieving outcomes?	Qualitative evaluation of achievement of outcomes were undertaken using: • Contextual datasets and supplementary information • Expert judgement through a structured elicitation process • Assessment of documented assumptions, limitations and contributing factors for expected outcomes • Outcomes for 2020 Matter 8 reporting. The evaluation will comment on the contribution of Basin Plan and will not attempt to provide an attribution of impact.
Have there been any unanticipated outcomes?	Qualitative evaluation of unanticipated outcomes at the asset scale will be undertaken using a structured expert elicitation process.

The cut-off date for data included in this evaluation was 30 June 2023. Any data collected after this date will be included in the next Basin Plan environmental outcome evaluation. This will take into consideration any environmental changes which have occurred since 30 June 2023.

4.2.2 Trend

A Bayesian modelling approach was used to assess trend in the time series data. Bayesian modelling calculates a probability distribution of coefficient values which estimate some relationship between a predictor (time step) and an outcome. The median coefficient summarises the slope (trend) describing the relationship, whilst the distribution around this estimate provides uncertainty about the true relationship that exists in the population. Bayesian trend analysis was performed in R Studio (R Core Team 2023), using generalised linear models and (if necessary) mixed models using the `stan_glm` and `stan_glmer` functions provided by the “rstanarm” package (Goodrich et al. 2020). All models used 4,000 iterations, four sampling chains, and the default (weakly-informative) priors. Specific details on

variable specification are provided in the methods for each indicator. Trend direction (sign of median slope) was assessed using calculated probability (modified from Mastrandrea et al. 2010; as per McBride 2019) using a graduated scale to present results, and to align with trend categories used for the South Australian Trend and Condition Report Cards, presented in Table 4–5.

This trend outcome is summarised as the following:

- Improved: The indicator is improving over the period of assessment
- Stable: The indicator is neither improving nor declining over the period of assessment
- Declined: The indicator is declining over the period of assessment
- Unknown: Data are not sufficient to determine any trend in the status of this indicator.

Table 4–5. Alignment of trend outcomes based upon the probability of an increase or decrease (modified from Mastrandrea et al. 2010; as per McBride 2019) with the icons used for the evaluation.

Outcome	Probability (%)	Trend category
Virtually certain increase	> +99 to +100	Improved
Extremely likely increase	> +95 to +99	
Very likely increase	> +90 to +95	
Likely increase	> +66 to +90	
About as likely as not	-66 to +66	Stable
Likely decrease	< -66 to -90	Declined
Very likely decrease	< -90 to -95	
Extremely likely decrease	< -95 to -99	
Virtually certain decrease	< -99 to -100	

4.2.3 Information reliability

The reliability of data to assess the achievement of environmental outcomes and the progression towards the LTWP targets were scored based upon the method devised by Battisti et al. (2014) with modifications to improve its applicability to Matter 8 reporting. This scoring system assesses questions relating to the method used for data collection, representativeness and repetition. A scoring system as shown in Table 4–6 was used to determine a final score for information reliability that ranges between 0 and 12. Final scores are then converted into an information reliability rating that ranges between poor and excellent using the matrix in Table 4–7.

Table 4–6. Scoring system for the reliability of data used to assess and analyse trend, condition and LTWP targets and expected outcomes for Matter 8 reporting.

Methods	Question	Scoring system		
		Yes	Partially	No
Methods used	Are the methods used appropriate to gather the information required for evaluation?	2	1	0
Standard methods	Has the same method been used over the sampling program?	2	1	0
Representativeness				

Methods	Question	Scoring system		
		Yes	Partially	No
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	2	1	0
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	2	1	0
Repetition				
Space	Has sampling been conducted at the same sites over the assessment period?	2	1	0
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	2	1	0

Table 4–7. Conversion of the final score (0-12) of information reliability to an information reliability rating that ranges from poor to excellent for Matter 8 reporting.

Final score	Information reliability
12	Excellent
11	Very good
10	Good
9	Fair
≤8	Poor

4.2.4 Expert elicitation workshops

Relevant subject matter experts attended a half-day workshop for each respective indicator to evaluate and review the preliminary data and findings of the assessments as presented in a workshop paper. The process follows that outlined in Figure 4-1 to discuss and answer the questions described in Table 4–8.

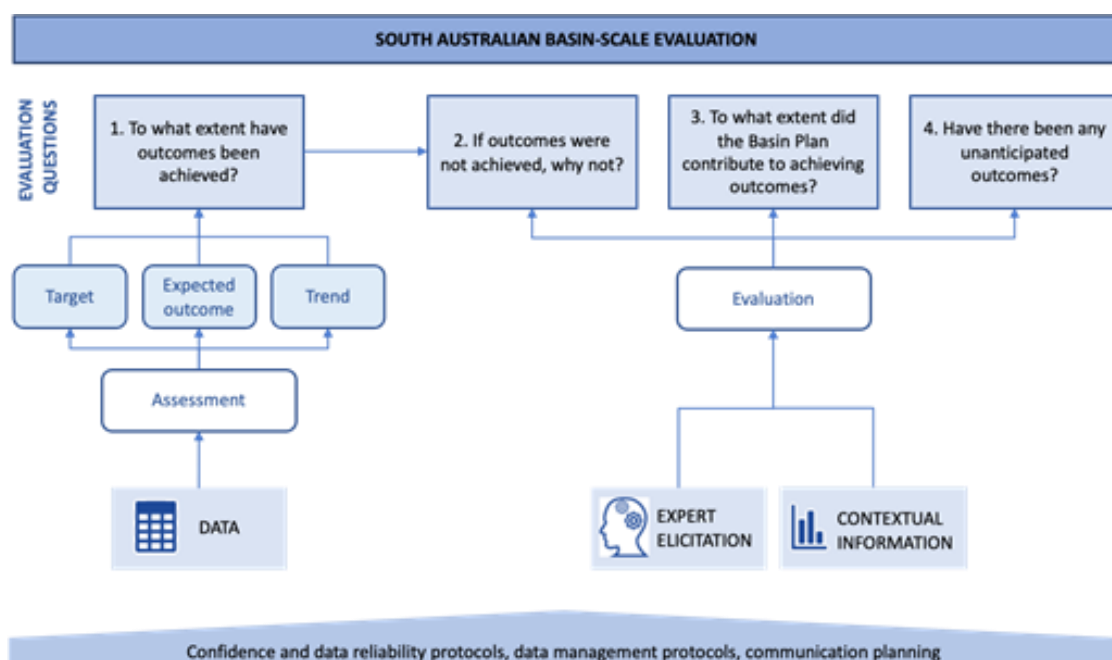


Figure 4-1. Schematic diagram showing how data driven and expert elicitation processes underpin the assessment and evaluation of environmental outcomes and enable South Australia’s four evaluation questions to be addressed. The progress to the target will be considered through the assessment of expected outcomes.

Table 4–8. Evaluation questions as part of the expert elicitation process.

Matter 8 evaluation questions	Questions or information needed from experts for each indicator
To what extent have environmental outcomes been achieved at the asset scale?	- Is the data sourced for the analysis appropriate and have funding bodies been acknowledged? - Has information reliability been accurately assessed and justified? - Has the data been analysed and presented effectively? - Has the trend been represented correctly across the available dataset? - Has change between reporting periods been assessed adequately? *note: the information reliability-related questions above support discussion on each of the criteria within the information reliability scoring assessment
If environmental outcomes were not achieved, why not?	- What are the contributing factors influencing the observed outcome and do any factors have a stronger influence than others? - How have these factors influenced trend? - What evidence supports this (data, published information, observations, opinion)?
To what extent did the Basin Plan contribute to achieving environmental outcomes?	- Which Basin Plan activities or projects may have contributed to outcomes? - How have these Basin Plan activities contributed to the observed trend?

Matter 8 evaluation questions	Questions or information needed from experts for each indicator
	• Are there any outcomes that may be expected but are yet to be observed due to a time lag in environmental response? • Are there any aspects of Basin Plan implementation that are expected to influence outcomes in the future? • What evidence supports this (data, published information, observations, opinion)?
Have there been any unanticipated environmental outcomes?	• Have there been any unanticipated environmental outcomes (positive or negative) as a result of management actions or other Basin Plan implementation activities? • What evidence supports this (data, published information, observations, opinion)?

The feedback gathered within the expert elicitation workshops was then used to inform the evaluation for each expected environmental outcome.

5 Murray Mouth openness: annual flow



Trend
Improved



Reliability
Good

Key findings and messages:

- Water for the environment delivered through the Basin Plan has significantly improved barrage flows compared to pre-2010 conditions, however barrage flows alone were largely insufficient to maintain an open Murray Mouth, with dredging required.
- In 82% of years, the minimum flow volume of 730 GL required to maintain an open Murray Mouth has been exceeded.
- Barrage flow, supported by water for the environment has helped limit sand ingress into the Murray Mouth.
- Current water recovery volumes and physical and operational delivery constraints mean barrage flows alone are unlikely maintain an open Murray Mouth without dredging.
- In future years, it is unlikely that the percentage of years with annual barrage flows exceeding 730 GL will be maintained without the recovery and delivery of additional water for the environment.
- Full implementation of the Basin Plan, including increased recovery and delivery of water for the environment and addressing current water delivery constraints, will contribute to an increase in days with barrage flows above 2,000 ML day⁻¹ required to prevent sand ingress.

5.1 Introduction

The Murray Mouth is located at the terminus of the MDB, where the Murray Estuary connects to the Southern Ocean. Freshwater flows from the River Murray enter Lake Alexandrina where it is discharged through a series of tidal barrages to the Murray Estuary and Coorong, and subsequently the Southern Ocean through an open Murray Mouth (Mosley et al. 2023). Therefore, hydrological exchange between fresh, estuarine, and marine ecosystems relies on the openness of the Murray Mouth. This connection of aquatic habitats plays important roles in water quality, ecosystem functioning and the life histories of biota (Bice et al. 2018; Lester et al. 2009).

The environment at the Murray Mouth is dynamic, with freshwater flow from the River Murray and waves, tide and storm conditions of the Southern Ocean changing the location of the Mouth as well as its width and depth ('openness') (Bourman et al. 2018; Harvey 1988; Webster 2005). When barrage flows are low, sand is deposited at the Murray Mouth from the Southern Ocean, leading to its constriction (Harvey 1988; Higham 2012; Webster 2005). Sand deposition during periods of low flow led to the complete closure of the Mouth in 1981 and dredging of the Mouth has occurred during low flow periods since 2002 to prevent closure (DEW 2018). To naturally prevent net sand deposition in the Mouth, a minimum daily barrage flow of ~2,000 ML day⁻¹ is required from Tauwichee barrage (BMT WBM 2009), whilst a high flow event where barrage flows exceed ~60,000 ML day⁻¹ is required to clear a constriction of the Mouth (DEW 2018).

An open Murray Mouth is critical to the CLLMM region and for the MDB. As the terminus of the MDB, an open Murray Mouth enables the export of salt, nutrients and sediment from the system (Brookes et al. 2023; Thom et al.

2020). A target of 2 million tonnes salt export was set under the Basin Plan and ensures that water is suitable for drinking, agriculture and the environment (Hart et al. 2020), with the structure and function of freshwater ecosystems adversely affected by increased salinity (Nielsen et al. 2003). As the only point of connection between freshwater, estuarine and marine environments in the MDB, maintaining an open Murray Mouth is also essential to diadromous and estuarine fishes successfully completing their life cycles (Bice et al. 2018).

The water quality and ecosystem health of the Coorong is also dependent upon an open Murray Mouth. The influence of tides, swell and water exchange between the Southern Ocean, Murray Estuary and North Lagoon is controlled by the condition of the Murray Mouth. This in turn affects water levels and salinity in the Coorong (Higham 2012; Kingsford et al. 2009; Webster 2005). The contribution of seawater defines the estuarine conditions in the Coorong and is a critical source of water during periods of low barrage flow (Kingsford et al. 2009). The connection between the Coorong and Southern Ocean is important for the exchange of salt and nutrients (Higham 2012; Webster 2005). As water levels, salinity and nutrient concentrations are the key drivers of Coorong ecosystem health and determinants of habitat quality for aquatic plants, invertebrates, fish and waterbirds, an open Murray Mouth is critical to the ecosystem’s function and species populations.

The productivity of marine environments near the Murray Mouth is influenced by the volumes of freshwater outflow from an open Murray Mouth (Auricht et al. 2017). Chlorophyll-*a* and particulate organic carbon concentrations in coastal oceans adjacent to the Murray Mouth are strongly associated with River Murray flow through the barrages (Auricht et al. 2017).

5.2 Ecological objective, target and environmental outcomes

The [South Australian River Murray Long-term Watering Plan](#) (LTWP) sets ecological objectives and targets for Murray Mouth openness are presented in Table 5–1 (DEW 2020).

Table 5–1. Ecological objective and targets for Murray Mouth openness.

Ecological objective	Ecological target
Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the sea.	Maintain a minimum annual flow required to keep the Murray Mouth open (730–1,090 GL year ⁻¹). Maintain an open Murray Mouth, as indicated when the Diurnal Tidal Ratio (DTR) at Goolwa exceeds 0.3, with minimum DTR values of 0.05 and 0.2 at Tauwitchere and Goolwa, respectively.

The expected environmental outcome for Murray Mouth openness is based on the proportion (%) of years that a group of experts expect barrage flow to meet the minimum annual flow required to keep the Murray Mouth open (730 GL year⁻¹) (Table 5–2). Over time, it is expected that the percentage of years that the minimum annual flow volume is met will remain stable (Table 5–2; Figure 5-1). However, the confidence in predictions attenuates with time.

Table 5–2. The expected environmental outcomes, based on the LTWP target (730 GL year⁻¹), for Murray Mouth Openness in 2019, 2029 and 2042.

Year	Expected environmental outcome
2019	The minimum outflow (730 GL year ⁻¹) is met for 6 of 7 (86%) years of monitoring since the adoption of the Basin Plan (80% confidence range of 72–92%)
2029	The minimum outflow (730 GL year ⁻¹) is met for 14 of 17 (82%) years of monitoring since the adoption of the Basin Plan (80% confidence range of 61–93%)
2042	The minimum outflow (730 GL year ⁻¹) is met for 25 of 30 (83%) years of monitoring since the adoption of the Basin Plan (80% confidence range of 50–95%)

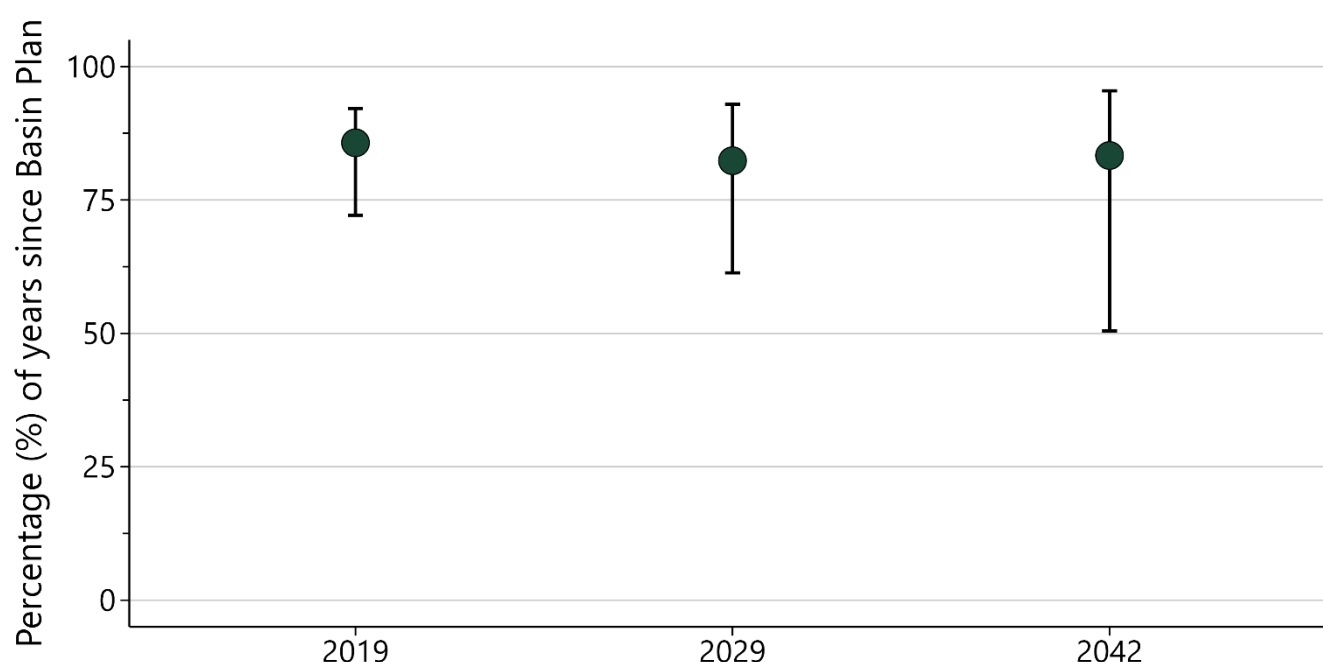


Figure 5-1. The expected environmental outcomes for the percentage of years since Basin Plan adoption (2012) that the annual flow is expected to be ≥ 730 GL year⁻¹ (i.e. annual flow requirement (730 GL year⁻¹) in 2019, 2029 and 2042 under modelled water recovery conditions.

5.3 Method

5.3.1 Barrage flow

Direct measures of outflow through the Murray Mouth are not possible due its shifting and dynamic nature. Therefore, the accepted method for estimating outflow through the Murray Mouth is based on modelled and calculated barrage flow. Modelled and calculated estimates of barrage flow for each water year (1 of July to 30 of June) were sourced from both the DEW and MDBA. Barrage flow data between July 2000 and December 2010 was sourced from the MDBA's MSM-BIGMOD model, which calculates barrage flow from a water balance below Lock 1 (MDBA 2014). Equivalent data from January 2011 to June 2023 was sourced from the DEW's barrage calculator that uses weir equations to calculate flow through barrage bays based on their type, dimensions, location, open

configurations, and upstream and downstream water levels (DEW 2021). This data is available at [Water Data SA](#) (station: A4261002).

5.3.2 Supplementary datasets

The following supplementary datasets were used to support the assessment of environmental outcomes for Murray Mouth openness and to inform the evaluation:

- **Dredging operations:** Dredging involves the mechanical removal of marine sediment to ensure that the Murray Mouth remains open during periods of limited barrage flow (Bourman et al. 2018). Dredging data (provided by SA DEW Water Infrastructure and Operations) included the date range over which one or two dredges were in operation at the Murray Mouth.
- **Diurnal Tide Ratio (DTR):** DTR is a ratio of the tidal energy between the Goolwa Barrage in the Murray Estuary and Victor Harbor in the Southern Ocean (DEW 2018). Data were provided by SA Water. The ratio of tidal energy in the Murray Estuary provides an index for Murray Mouth openness, with a ratio of 0.3 indicative of an open Mouth and 0.2 indicative of a constricted Mouth that requires dredging (DEW 2018).
- **Daily barrage flow:** A minimum daily barrage flow of 2,000 ML day⁻¹ from Tauwichee barrage is required to prevent sand ingress in the Murray Mouth (BMT WBM 2009). Therefore, the percentage of days in each water year with an estimated barrage flow of $\geq 2,000$ ML day⁻¹ is presented, using DEW's barrage calculator data.

5.3.3 Trend assessment

The analysis was undertaken as per section 4.2.2 using a Bayesian Generalised Linear Model. The trend analysis for Murray Mouth openness used a logistic Bayesian generalised linear model. Trend was assessed based upon whether the annual minimum barrage flow was ≥ 730 GL or below 730 GL, using a binomial response distribution with corresponding water years given a 1, and 0 respectively. Both MSM-BIGMOD (July 2000–December 2010) and DEW (January 2011–June 2023) barrage data were used in this trend analysis, to include all available data. Time step (years since the commencement of the assessment period; 2000–01) was included as a fixed effect.

5.3.4 Flow categories

In assessing the expected outcome and to inform the evaluation outcomes for Murray Mouth openness, the following annual barrage flow volume categories were used (Table 5–3).

Table 5–3. Annual (water year) barrage flow categories. Source: Lower Lakes, Coorong and Murray Mouth (LLCMM) Scientific Advisory Group.

Category	Annual barrage flow (GL)	Descriptor for range used
No flow	0	
Very low	>0 to ≤ 115	>0 to 10 th percentile
Low	> 115 to ≤ 600	> 10 th to $\leq 25^{\text{th}}$ percentile
Low-moderate	> 600 to $\leq 2,500$	> 25 th to $\leq 50^{\text{th}}$ percentile
Moderate	> 2,500 to $\leq 7,000$	> 50 th to $\leq 75^{\text{th}}$ percentile
High	> 7,000 to $\leq 12,000$	> 75 th to $\leq 90^{\text{th}}$ percentile
Very high	> 12,000	$\geq 90^{\text{th}}$ percentile

5.3.5 Information reliability

The information reliability assessment for Murray Mouth openness was conducted as per section 4.2.3.

5.3.6 Limitations and assumptions

The expected outcome is based on the target minimum annual flow (730–1,090 GL year⁻¹) required to maintain an open Murray Mouth (as described in the LTWP; DEW 2020). These annual volumes are based on daily barrage flow volumes of at least 2 GL day⁻¹ from Tauwitschere barrage required to limit sand deposition inside the Murray Mouth. As barrage flow is not consistent over the year, there will be periods where barrage flow is less than 2 GL day⁻¹, likely leading to the accumulation of sand inside the Murray Mouth and its constriction. As such, the ecological objective of maintaining a permanent Murray Mouth opening through freshwater outflows may not be achieved despite the minimum annual barrage flow volume being met.

To more appropriately assess environmental outcomes associated with an open Murray Mouth following the adoption of the Basin Plan in 2012, dredging and DTR data were used in conjunction with barrage flow data. The congruent use of these datasets helped to determine whether dredging was initiated due to constriction of the Murray Mouth in association with insufficient barrage flow. Therefore, multiple lines of evidence were used to ensure a robust assessment of Murray Mouth openness.

5.4 Results

5.4.1 Environmental outcome assessment

The assessment in 2019 found that the proportion of years at or exceeding the minimum annual barrage flow requirement was as expected, with six of seven years (86%) since adoption of the Basin Plan having flows greater than 730 GL (Figure 5-2).

Since 2019, three of four years had annual barrage flow greater than 730 GL, with only 2019–20 having annual barrage flows of less than 730 GL (Figure 5-3). The River Murray flood event of 2022–23 resulted in the highest annual barrage flow volume for the assessment period, of 16,597 GL (peaking at 120 GL day⁻¹ on 30/01/2023). In 2029, we expect that there will have been barrage flows of at least 730 GL (i.e. the minimum annual flow requirement) in 14 of 17 years (82%) (80% confidence range of 61–93%). As nine of the eleven years since adoption of the Basin Plan have had annual barrage flows greater than 730 GL, we are considered likely on-track to meet the 2029 expected Murray Mouth openness outcome of, 14 out of 17 years (82%) to exceed 730 GL. However, it is expected that barrage flows alone will remain insufficient to keep the Mouth open without dredging in low to moderate flow conditions.

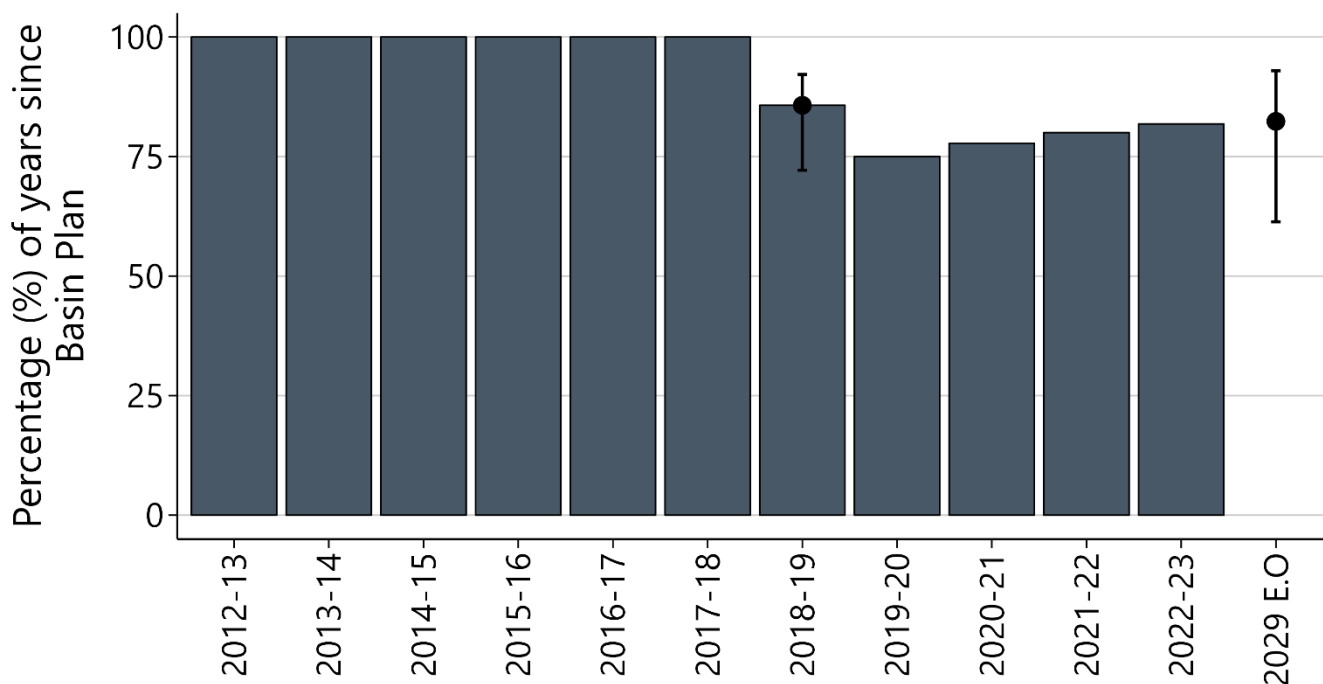


Figure 5-2. The cumulative percentage of years since Basin Plan adoption (2012) where there was a calculated annual barrage flow of ≥ 730 GL, with expected outcome included for reference.

5.4.2 Annual barrage flow

Annual barrage flow varied greatly between 2000–01 and 2022–23 (Figure 5-3) and ranged between no flow and very high flow conditions (in line with categories shown in Table 5–3). During the Millennium Drought (1996–2010) there were nine consecutive years (2001–02 to 2009–10) of low-moderate to zero barrage flows. Annual barrage flows were high to very high in both 2010–11 (10,081 GL) and 2011–12 (6,650 GL) and were followed by more moderate barrage flows in 2012–13 (4,930 GL) and 2013–14 (2,033 GL). Following this, low-moderate barrage flows were recorded in 2014–15 (1,476 GL) and 2015–16 (1,208 GL) until high barrage flows returned in 2016–17 (7,629 GL). Barrage flows over the next four years (2017–18 to 2020–21) were low to low-moderate, not exceeding 1,500 GL year⁻¹. Moderate barrage flows (6,198 GL) were recorded in 2021–22 and this was followed by a flood event in 2022–23 (16,597 GL) that was the largest in the River Murray since 1956.

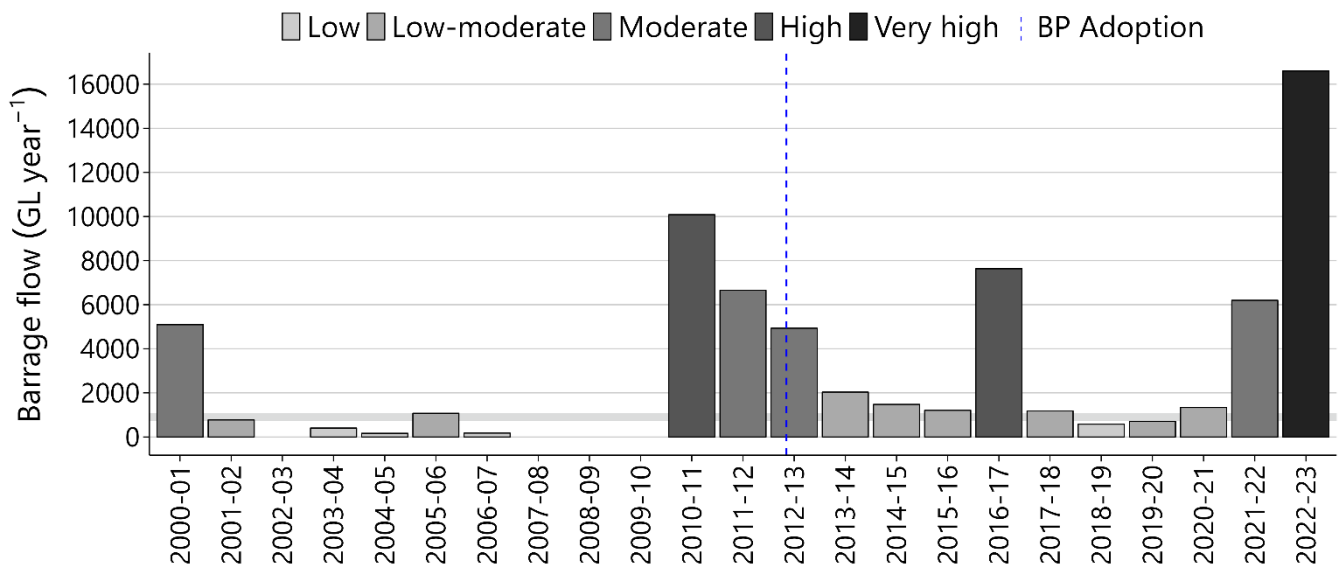


Figure 5-3. Barrage flow (GL year⁻¹) for each water year from 2000-01 to 2022-23. The grey horizontal shaded area represents the LTWP target range of 730–1,090 GL year⁻¹. Shaded columns are the flow categories from the Lower Lakes, Coorong and Murray Mouth (LLCMM) Scientific Advisory Group. Data sources: MSM-BIGMOD barrage flow data (July 2000–December 2010) and DEW (A4261002) barrage flow data (January 2011–June 2023). The blue dashed line represents the adoption of the Basin Plan (2012).

5.4.3 Trend

The frequency of years that barrage flow has been equal to or greater than 730 GL from 2000-01 to 2022-23 is very likely (94% probability) to have **improved** (Figure 5-4).

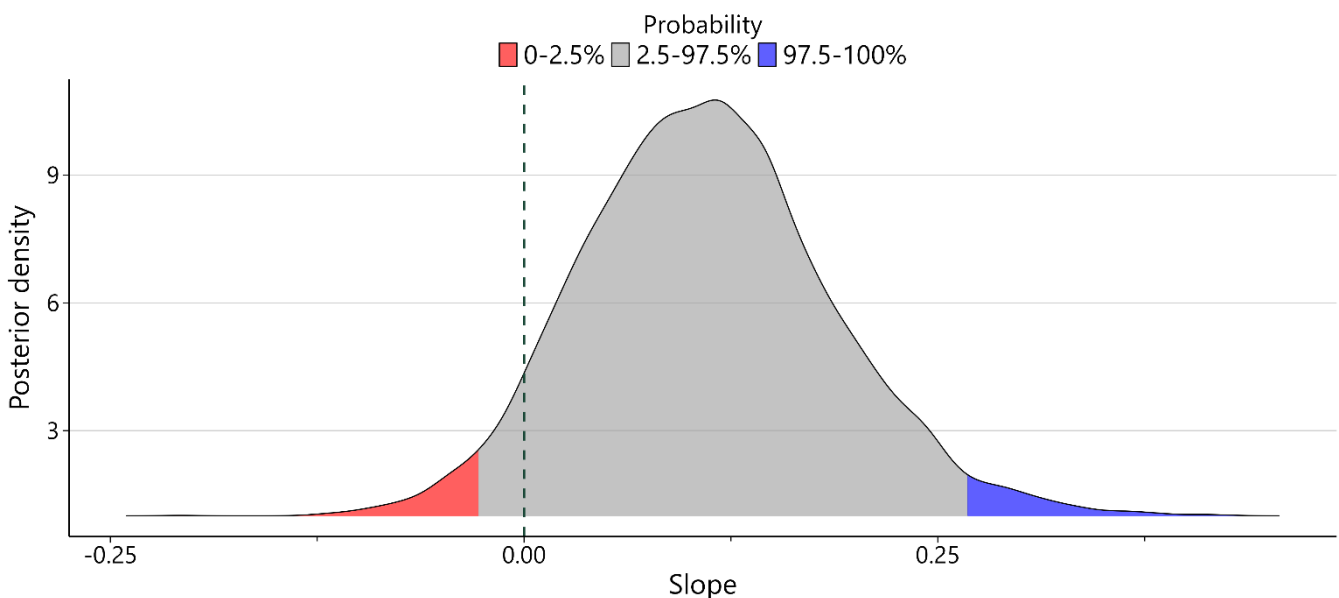


Figure 5-4. Estimated values for the slope generated from Bayesian modelling for the frequency of years that annual barrage flow was ≥ 730 GL between 2000 and 2023. Data used in trend assessment was from both MSM-BIGMOD (July 2000–December 2010) and DEW (January 2011–June 2023). Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

5.4.4 Dredging

Dredging of the Murray Mouth commenced in 2002 and continued in response to low to no barrage flows during the Millennium Drought (Figure 5-5). High flows returned to the River Murray system in 2010–11 and resulted in dredging operations ceasing. Dredging resumed in December 2014 with low to moderate flows having occurred for the two years prior. From December 2014 to June 2023, dredging has continually occurred except for during and immediately post the high flow periods of 2016–17 and 2022–23. Dredges have been in operation for 67% of years since Basin Plan adoption in 2012.

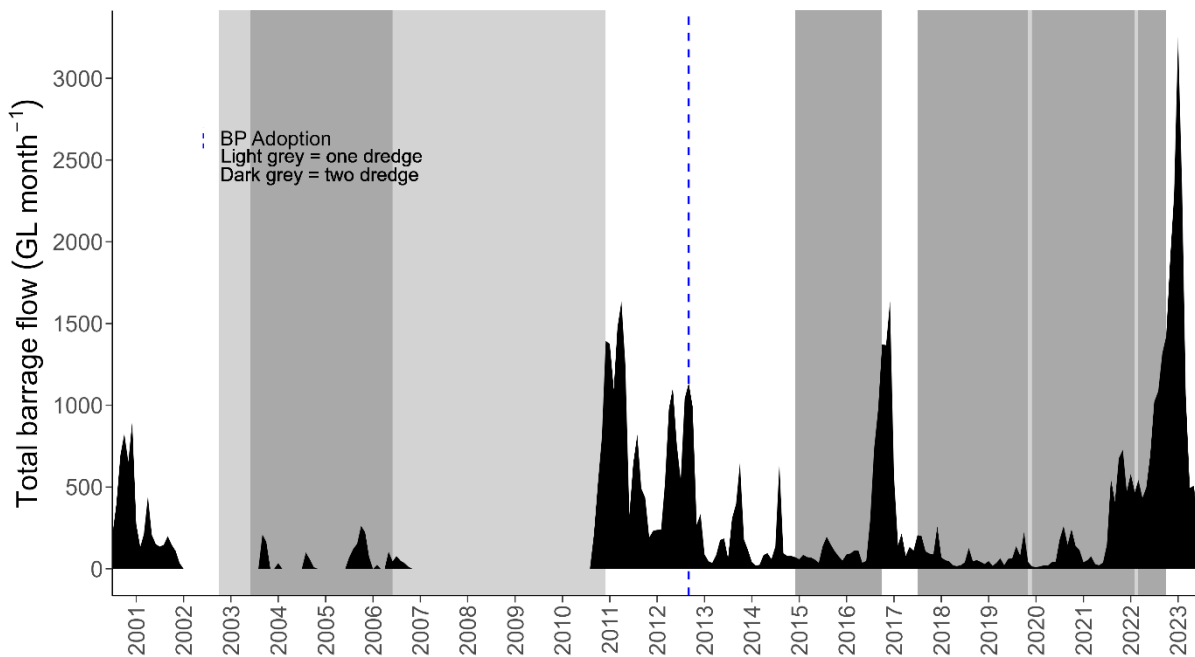


Figure 5-5. The total monthly barrage flow (GL month⁻¹) from 2000–01 to 2022–23. Data sources: MDBA’s MSM-BIGMOD (July 2000–January 2011), DEW barrage calculator (February 2011–June 2023). Also shown are periods of dredging operations (shaded rectangles).

5.4.5 Diurnal Tidal Ratio

Diurnal Tidal Ratio (DTR) values have improved over the assessment period (DTR data: 8/9/2002 – 30/6/2023). At the commencement of dredging in 2002, DTR values were below 0.2, indicating that the Murray Mouth was constricted (Figure 5-6). During the Millennium Drought, DTR values were regularly below 0.3 and at times below 0.2, suggesting that a functionally open Murray Mouth was rarely recorded over this period. The period of high to moderate barrage flows between 2010–11 and 2012–13 greatly improved DTR values. Since adoption of the Basin Plan in 2012, DTR values have largely remained above 0.3, and the times with DTR values less than 0.3 have typically coincided with high river flow events and barrage flow that have dampened the tidal signal.

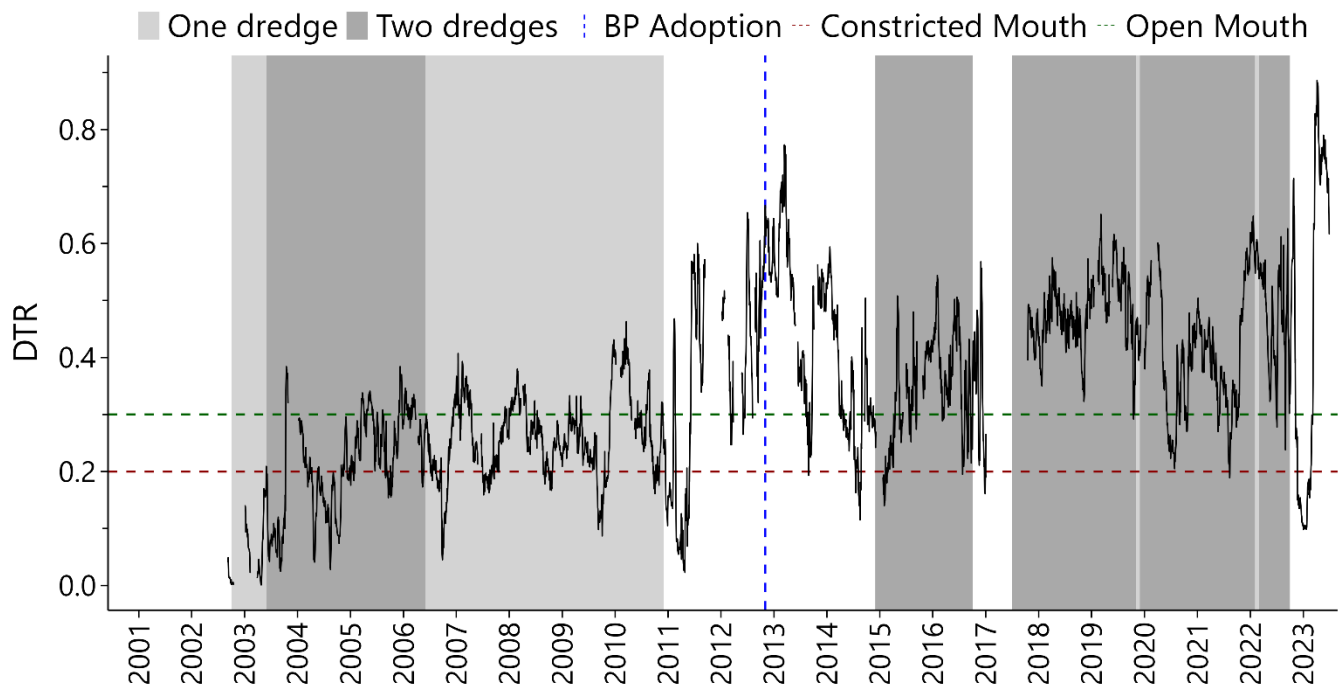


Figure 5-6. The Diurnal Tide Ratio (DTR) recorded in the Murray Estuary (Goolwa Barrage), between August 2002-03 to June 2022-23. Also shown are periods of dredging operations (shaded rectangles). Data sources: MDBA's MSM-BIGMOD (July 2000–January 2011), DEW barrage calculator (February 2011–June 2023), and SA Water (DTR and dredging).

5.4.6 Daily barrage flow

Since 2011–12, the percentage of days with daily barrage $\geq 2,000$ ML has ranged between 19% in 2018–19 and 97% in 2011–12. Generally, the number of days with $\geq 2,000$ ML day⁻¹ barrage flow has fluctuated in association with annual barrage flow volumes; although very high barrage flow, such as in 2022–23, had a comparable percentage of days to lower flow years such as 2011–12 (Figure 5-7). Years with greater than 50% of days with $\geq 2,000$ ML day⁻¹ have had over 1,000 GL of total annual barrage flow.

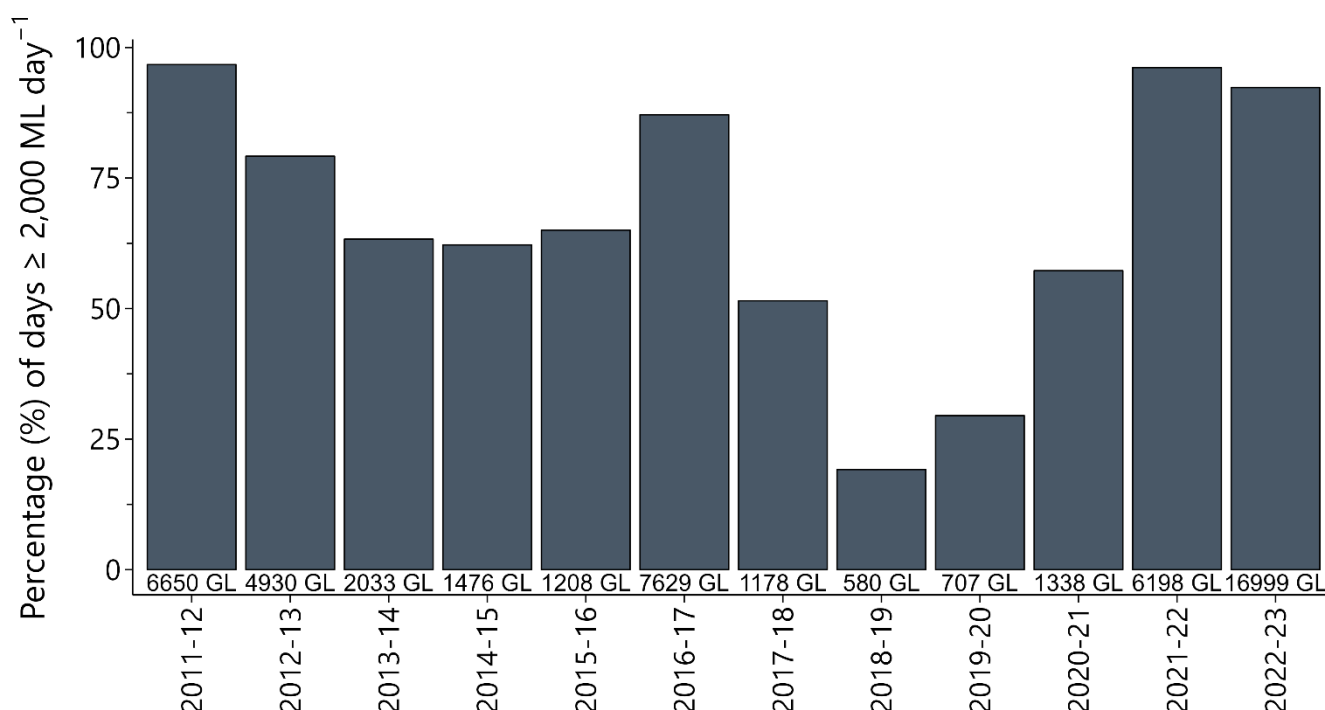


Figure 5-7. The percentage of days per water year with barrage flow at least 2,000 ML between 2011–12 and 2022–23. Show below each column is the total annual barrage flow. Data sources: DEW barrage calculator (July 2011–June 2023).

5.4.7 Information reliability

The information reliability rating for Murray Mouth openness was **good** (final score of 10). Justification for the scoring of Murray Mouth openness information reliability is provided in Table 5–4.

Table 5–4. Reliability of data to assess the trend and condition of Murray Mouth openness. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Partially. The expected outcomes were assessed using modelled estimates of barrage flow from the MDBA’s MSM-BIGMOD model (MDBA 2014) and the DEW barrage calculator (DEW 2021), which does not directly assess the openness of the Murray Mouth. Contextual datasets of DTR, dredging and tide over the assessment period have been used to help assess the expected outcome.	1
Standard methods	Has the same method been used over the sampling program?	Partially. Modelled estimates of barrage flow between July 2000 and December 2010 were from the MSM-BIGMOD model and estimates between January 2011 to June 2023 were from the DEW barrage	1

Methods	Question	Answer and justification	Score
		calculator. Both methods produce total daily barrage releases.	
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Murray Mouth with equal effort?	Yes. The MSM-BIGMOD model estimates barrage flow from a water balance below Lock 1 (MDBA 2014). The DEW barrage calculator estimates barrage flow using weir equations based on barrage bay type, dimensions, open configurations, and the observed upstream and downstream water levels (DEW 2021). Both models generate estimates of total barrage flow from Lake Alexandrina.	2
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. Modelled estimates of barrage flow from the MSM-BIGMOD model and DEW barrage calculator cover the assessment period (2000–01 to 2022–23).	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. Modelled estimates of barrage flow from the MSM-BIGMOD model and DEW barrage calculator have covered the same spatial area (i.e. all barrages).	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes. Both the MSM-BIGMOD model and DEW barrage calculator estimate barrage flow at daily timescales.	2
Final score			10
Information reliability			Good

5.5 Evaluation

Water delivered since the adoption of the Basin Plan, including water for the environment, has improved the achievement of the minimum annual barrage flow requirement (730 GL) to maintain an open Murray Mouth. This improvement indicates we are likely on-track to meet the 2029 expected Murray Mouth openness outcome of, 14 out of 17 years (82%) to exceed 730 GL. Despite this improvement, barrage flow volumes alone have been insufficient to maintain and open Murray Mouth. Dredging has been required, particularly during low flow conditions, to maintain hydrological connectivity between the Murray Estuary and the Southern Ocean (Bourman et al. 2018; Brookes et al. 2023). During the assessment period, dredging has been required from October 2002 to December 2010, January 2015 to October 2016, and August 2017 to October 2022 and again from November 2023. Since adoption of the Basin Plan in 2012, dredges have been in operation for 67% of years to ensure the maintenance of a permanently open and functional Murray Mouth.

The factors (see section 5.5.1) associated with the inability to maintain an open Murray Mouth through freshwater barrage flows included; upstream extraction of water, the condition of the Murray Mouth at the start of the assessment period, inadequate freshwater flows to limit sand ingress, the influence of highly active offshore environment (e.g. influence of tides and storms) and a lack of scouring flows.

5.5.1 Key factors contributing to outcomes

Upstream water extraction and rainfall

River regulation and upstream water extraction over the preceding decades has led to the entrance of the Murray Mouth becoming more shoaled and prone to closure without intervention (BMT WBM 2009; Bourman et al. 2018). Barrage flows have been reduced by ~70% when compared to natural flows due to upstream extraction of water and associated management of the River Murray, primarily for irrigation. As a result, modelling indicates that water ceases to flow through the Murray Mouth 40% of the time under current conditions in contrast to 1% under natural flow conditions (CSIRO 2008). The rainfall decile maps of the Basin from 2006–07 to 2022–23 (BOM 2023) show prolonged dry periods broken by years of above-average to record rainfall (Figure 5-8). The Millennium Drought that commenced in 1996 was broken in 2010 by two consecutive years (2010–11 and 2011–12) of significant rainfall, preceding larger barrage flows. Between 2012–13 (barrage flow: 4,930 GL) and 2015–16 (barrage flow: 1,208 GL), average to record low rainfall was recorded over most of the Basin. In 2016–17 (barrage flow: 7,629 GL), above-average rainfall was recorded for much of the Basin, with most significant relative rainfall increases within the southern Basin. Drought conditions commenced in 2017–18 (barrage flow: 1,178 GL) and continued throughout 2019–20 (barrage flow: 707 GL). Consecutive years in 2021–22 (barrage flow: 6,198 GL) and 2022–23 (barrage flow: 16,597 GL) accompanied greater rainfall over this period.

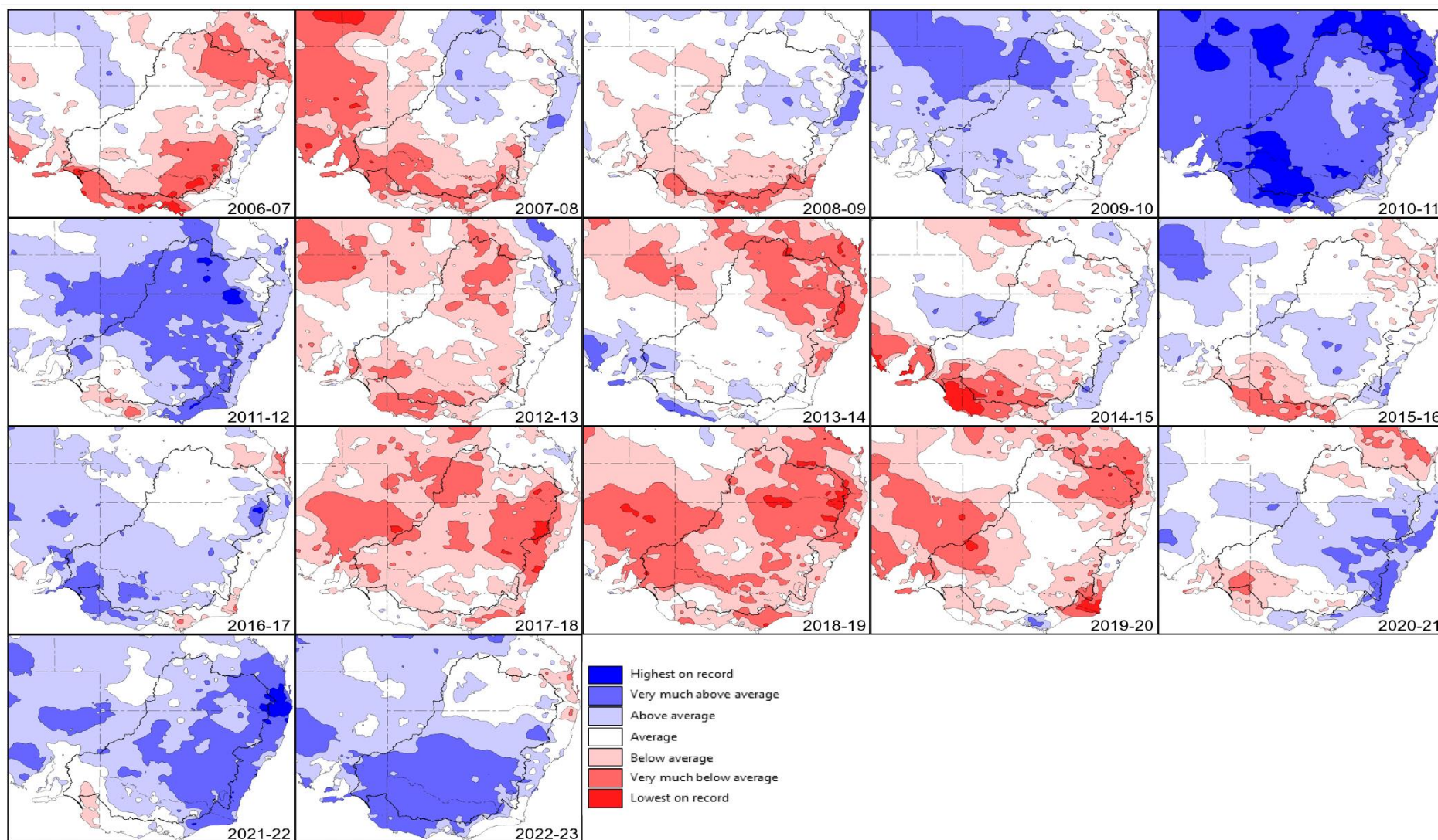


Figure 5-8. Murray-Darling Basin (MDB) rainfall deciles between 1 of July and the 30 of June each year since 2006-07. Data source: BOM 2023.

Starting condition and scouring flows

Low barrage flow conditions threatened to close the Murray Mouth in 2002 and necessitated the commencement of dredging to keep it open (Kingsford et al. 2011; Thom et al. 2020). Although the Tauwitchere and Goolwa channels were dredged for the entirety of the Millennium Drought, large accumulations of sand were deposited in the vicinity of the Murray Mouth during this period (i.e. the Bird Island region). This accumulation of sand has been difficult to clear, with only three high flow events having been recorded since the Millennium Drought.

Two scouring flow events have occurred since the adoption of the Basin Plan in 2012 due to high rainfall across the Basin in 2016–17 and 2022–23 and resulting high or flood flows along the River Murray. Barrage flows required to scour sand from the Murray Mouth is estimated to be between 60,000 and 70,000 ML day⁻¹ (or above) (Brookes et al. 2023; DEW 2018). In 2016–17, there were 31 days of barrage (nine days consecutive) flow greater than 60,000 ML, resulting in notable change to the depth and width of the Murray Mouth, including the Tauwitchere and Goolwa channels. More recently, the 2022–23 flood event led to 113 days (80 days consecutive) with flows exceeding 60,000 ML between December 2022 and February 2023, resulting in a higher rate of scouring than observed in 2016–17 (Figure 5-9). This resulted in depth and width increases in the Murray Mouth, as well as the Tauwitchere and Goolwa channels from October 2022 to February 2023. However, following the recession of the flood event there has been constriction of these channels and the Murray Mouth.

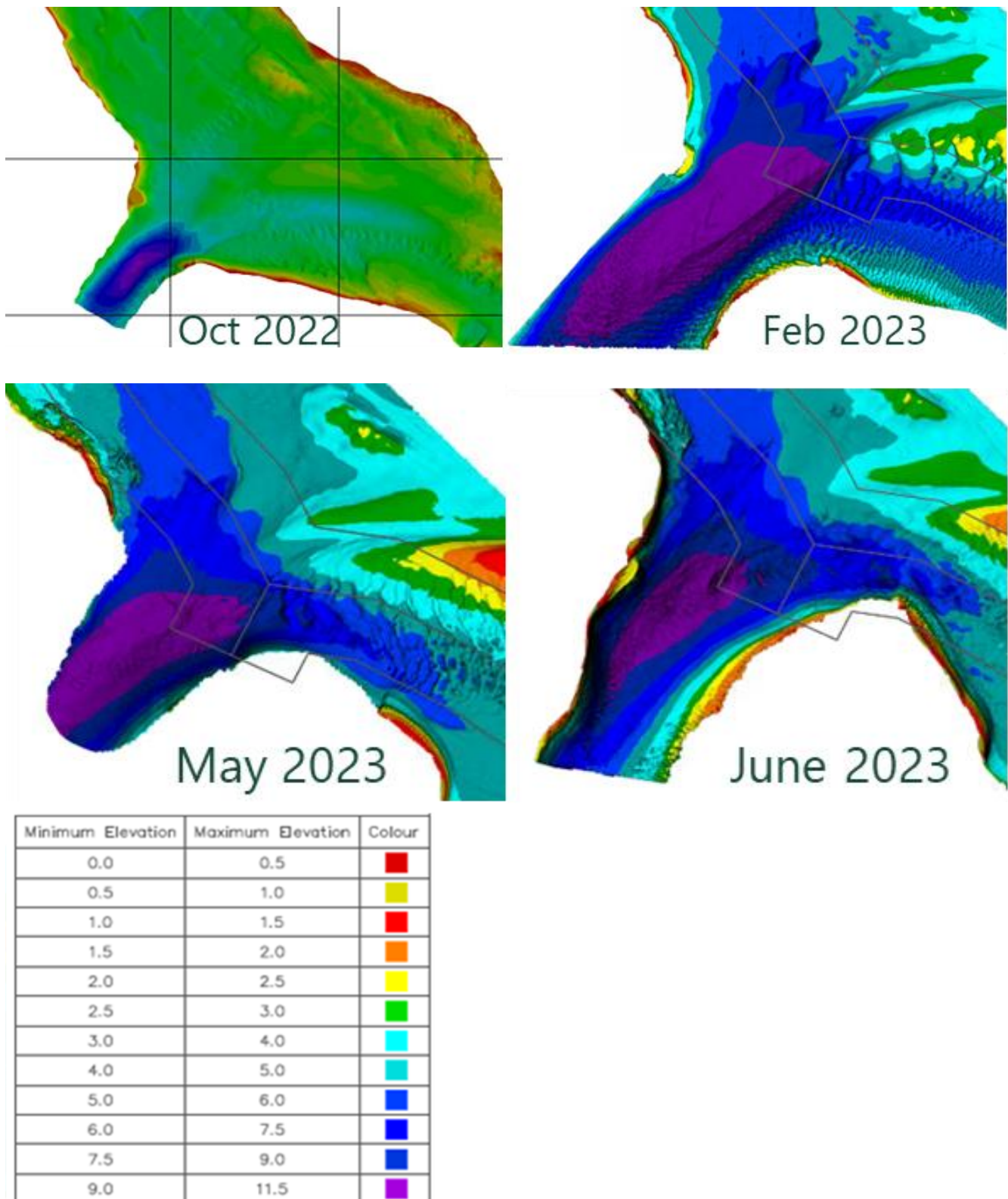


Figure 5-9. Bathymetry (illustrating difference in elevation) of the Murray Mouth in October 2022 and February, May, and June 2023. Lower elevation areas are shown in purple and higher elevation areas are shown in red. Scouring flows commenced in early December 2022 and continued until late February 2023.

Sand ingress

To minimise sand ingress from the adjacent marine environment to the Murray Mouth, barrage flows of approximately 2,000 ML day⁻¹ are required (BMT WBM 2009). Therefore, prolonged periods of low to no barrage flows increase the risk of Murray Mouth constriction or closure without intervention. Since adoption of the Basin Plan in 2012, years that have had at least 80% of days exceeding flows of 2,000 ML have largely been comprised of unregulated flow in the River Murray. However, under drier conditions in the southern MDB, water for the environment has significantly contributed to supporting daily flows up to, and in some cases exceeding 2,000 ML. For example, barrage flows were solely comprised of water for the environment in 2019–20 (Guarino & Sengupta 2022) and supported 108 days with flows greater than 2,000 ML day⁻¹.

Sand ingress into the Murray Mouth is typically greater during winter tide and storm events that can restrict the ability to discharge water from the barrages. Coupled with lower flow inputs from the River Murray, tide and storm events can increase water levels in the Murray Estuary above those prevailing in Lake Alexandrina, in what is referred to as a reverse head event. During these events, barrage gates are closed to prevent the ingress of seawater into Lake Alexandrina. Without the ability to consistently discharge water from the barrages, and yet a constant oceanic force, these seasonal events deposit significant volumes of sand into the Murray Mouth.

5.5.2 Unanticipated outcomes

It was unanticipated that dredging would be required during periods of high (unregulated) River Murray flow conditions from July 2021 to October 2022. During this period, moderate barrage flows occurred with an average of 21 GL day⁻¹, peaking at 84 GL day⁻¹ (14/09/2022). The cessation of dredging was associated with the commencement of the 2022–23 River Murray flood peak arriving at the barrages that lasted from November 2022 to March 2023 with an average barrage flow of 75 GL day⁻¹, peaking at 120 GL day⁻¹ (30/01/2023). This flood event scoured the Murray Mouth, increasing the depth to more than 11 m (see scouring flows in section 5.5.1) and resulted in a shift of the Murray Mouth. However, the impact was less than expected due to the level of sand accumulation prior to the flood peak (i.e. the starting condition of the Murray Mouth). The accumulation of sand at the Murray Mouth since the flood peak of early 2023 has also been faster than anticipated.

5.5.3 Actions to achieve environmental outcomes

Current volumes of water recovery and physical and operational constraints to water delivery, mean that barrage flows are unlikely to be adequate to maintain an open Murray Mouth without the need for dredging. With full implementation of the Basin Plan, increased volumes of water for the environment and the relaxation of constraints are expected to increase the percentage of days with barrage flows above 2,000 ML day⁻¹ required to prevent sand ingress. However, as the frequency of large (unregulated) flows (>60,000 ML day⁻¹) that support scouring events have declined long-term (Brookes et al. 2023), dredging is expected to be required into the future to maintain an open and functional Murray Mouth.

The ability to maintain an open Murray Mouth in the future through intervention will be improved through the deployment of a new, large, and more efficient dredge (the “sawfish”) that has replaced the two dredges that formerly operated.

Targeted delivery of water through the barrages preferentially occurs through automated rather than manual barrage gates. This has led to more defined flow paths downstream of automated gates and sediment accumulation downstream of manual gates. To reduce the impact of these defined flow paths, more automated gates would be needed to provide the added benefit of targeted water releases from the barrages to maximise environmental outcomes.

5.6 Conclusion

Water delivered since the adoption of the Basin Plan, including water for the environment, has improved the achievement of the minimum annual barrage flow requirement (730 GL) to maintain an open Murray Mouth. This improvement indicates we are likely on-track to meet the 2029 expected Murray Mouth openness outcome. Despite this improvement, barrage flows alone have been insufficient to maintain an open Murray Mouth without dredging.

Water for the environment has contributed to limiting sand ingress into the Murray Mouth by supporting consistent and higher barrage releases, particularly from Tauwitchere barrage. However, there have been insufficient volumes to scour the Mouth and maintain connection between the Murray Estuary and Southern Ocean. As the frequency of high (unregulated) flows that support scouring events have declined over the long-term, dredging is expected to be required into the future to maintain an open and functional Murray Mouth.

6 Aquatic and littoral vegetation



Trend
Improved



Reliability
Very good

Key findings and messages:

- Aquatic and littoral vegetation condition in the Lakes has improved substantially from spring 2008 to autumn 2023 due to the increased cover of desirable native species and decline in undesirable species.
- All aquatic and littoral habitats within the Lakes (Lake Alexandrina, Lake Albert, Goolwa Channel, and permanent wetlands) have improved.
- Improved aquatic and littoral vegetation condition indicates we are on track to achieve or exceed the 2029 expected outcome.
- The delivery of water for the environment and the management of lake water levels within normal operating ranges and with seasonal variation were key drivers behind the improvement of aquatic and littoral vegetation condition and will be important for continued improvement.
- Periodic high (unregulated) flow events are critical and required more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes and in turn support the condition of aquatic and littoral vegetation.
- Maintaining suitable hydrological and salinity regimes, particularly through seasonal lake level management, will be important to provide conditions for the continual improvement of aquatic and littoral vegetation condition.

6.1 Introduction

Aquatic and littoral vegetation in the Lakes (Lake Alexandrina and Lake Albert) refers to the plant communities that grow from within a waterbody to its high-water mark. Nicol (2017) defined aquatic vegetation as the plant community that requires the presence of surface water at some point in its life history, and littoral vegetation as the plant community that occupies the fringes of waterbodies. In the Lakes, aquatic and littoral vegetation is comprised of submergent species that complete their life histories under water, amphibious species that grow both within and out of water and have a requirement for wetting and drying to complete their lifecycle (Brock and Casanova 1997), and emergent species that require saturated soil or shallow water but also have a requirement for some plant structures (flowers, leaves and stems) to be above the water level (Nicol 2017).

Aquatic and littoral vegetation communities are important for wetland biological diversity and play a critical role in supporting a range of ecosystem functions, services and human values (Campbell et al. 2019; Cronk & Fennessy 2009). These ecosystem functions and services include primary production (supporting food webs), nutrient cycling and uptake that improves water quality, shoreline stabilisation and providing important habitat for microbes, algae, macroinvertebrates, fish and birds, as well as cultural importance (Cronk & Fennessy 2009; Kansime et al. 2007). In the Lakes, healthy aquatic and littoral vegetation communities include compositions with a high native species richness and diversity, which are important for overall ecological health. These healthy aquatic and littoral vegetation

communities are culturally important for the Ngarrindjeri (Ngarrindjeri Nation 2018) and provide critical habitat for nationally or state vulnerable or endangered fauna, including southern bell frog (*Litoria raniformis*) (Murraylands & Riverland Landscape Board 2021), Australasian bittern (*Botaurus poiciloptilus*) (O'Connor et al. 2013), southern pygmy perch (*Nannoperca australis*) and Murray hardyhead (*Craterocephalus fluviatilis*) (Wedderburn & Barnes 2018).

The primary driver of aquatic and littoral vegetation condition and structure in the Lakes is water regime (Nicol et al. 2023), which encompasses water depth, duration, frequency and timing of inundation and exposure (Mitsch and Gosselink 1993). Water regimes drive zonation, change in species composition and diversity of aquatic and littoral vegetation communities, as each functional plant group responds differently to water residence time, depth and level fluctuations based upon their life histories (Gehrig and Nicol 2010; Nicol et al. 2018).

Salinity likely also impacted aquatic and littoral vegetation in the Lakes during the peak of the Millennium Drought (1996–2010), when electrical conductivity (EC; used to measure salinity) at times exceeded 30,000 $\mu\text{S cm}^{-1}$ (Gehrig and Nicol 2010; Nicol et al. 2018). For example, a rapid reduction in surface water salinity in the Goolwa Channel between spring 2009 and 2010 was associated with significant change in the plant community, including an increase in submergent plant species adapted to lower salinity environments (Nicol et al. 2023). However, the causal response to salinity is not well understood (Nicol 2016), as a range of submergent and emergent species considered to have low salinity tolerances have been observed colonising and/or persisting at times of extreme salinities during the Millennium Drought (Gehrig et al. 2011).

Diverse communities of submergent, amphibious and emergent plants in the fringing wetlands of the Lakes were present prior to the peak of the Millennium Drought. These communities were supported by lake levels that ranged from +0.4 to +0.8 m AHD and surface water EC of <2,000 $\mu\text{S cm}^{-1}$ (Kingsford et al. 2011). During the peak of the Millennium Drought, lake levels receded to unprecedented lows (<-0.75 m AHD). This had severe impacts on aquatic and littoral vegetation, with the loss of submergent vegetation, decline in the abundance and diversity of amphibious taxa and disconnection of fringing emergent plants from the water line. Surface water level and salinity regimes in the Lakes have largely returned to pre-drought conditions since the breaking of the Millennium Drought in September 2010, to the benefit of the aquatic and littoral vegetation (Nicol et al. 2023).

Delivery of water for the environment to the Lakes aims to improve the condition of aquatic and littoral vegetation by protecting a minimum inundation of fringing aquatic habitats, providing opportunities for growth and reproduction through seasonally variable lake levels, and providing suitable water quality conditions (e.g. salinity) that are preferable to the aquatic and littoral vegetation communities.

6.2 Ecological objective, target and environmental outcomes

The ecological objective and target for aquatic and littoral vegetation in the Lakes is outlined in the [South Australian River Murray Long-term Watering Plan](#) (LTWP) (DEW 2020b) and also described in Table 6–1. The vegetation indices used to quantify a measure of aquatic and littoral vegetation in the Lakes and its habitats are provided in Appendix A.

Table 6–1. Ecological objective and targets set for aquatic and littoral vegetation in the Lakes (Nicol 2017, DEW 2020b).

Ecological objective	Ecological target
Maintain or improve aquatic and littoral vegetation in the Lakes.	Maintain or improve diversity of aquatic and littoral vegetation in the Lakes as quantified using the Lower Lakes, Coorong and Murray Mouth (LLCMM) vegetation indices (see Appendix A).

The expected environmental outcomes for whole of icon site scores (referred to herein as icon site score) in 2019, 2029 and 2042 are given in Table 6–2 and Figure 6-1. These were determined by elicitation with key experts and form the basis of the assessment of aquatic and littoral vegetation environmental outcomes. It was expected that the icon site score would slightly increase between 2019 and 2042, however, the confidence of this prediction attenuates with time.

Table 6–2. Expected environmental outcomes for Lakes aquatic and littoral vegetation in 2019, 2029 and 2042. Expected outcomes were estimated by experts and were informed by Basin Plan hydrological modelling scenarios.

Expected environmental outcome	Year		
	2019	2029	2042
The whole of the icon site score for Lakes littoral and aquatic vegetation will be:	0.5 (80 % confidence interval of 0.40-0.60)	0.51 (80 % confidence interval of 0.33-0.62)	0.53 (80 % confidence interval of 0.27-0.72)

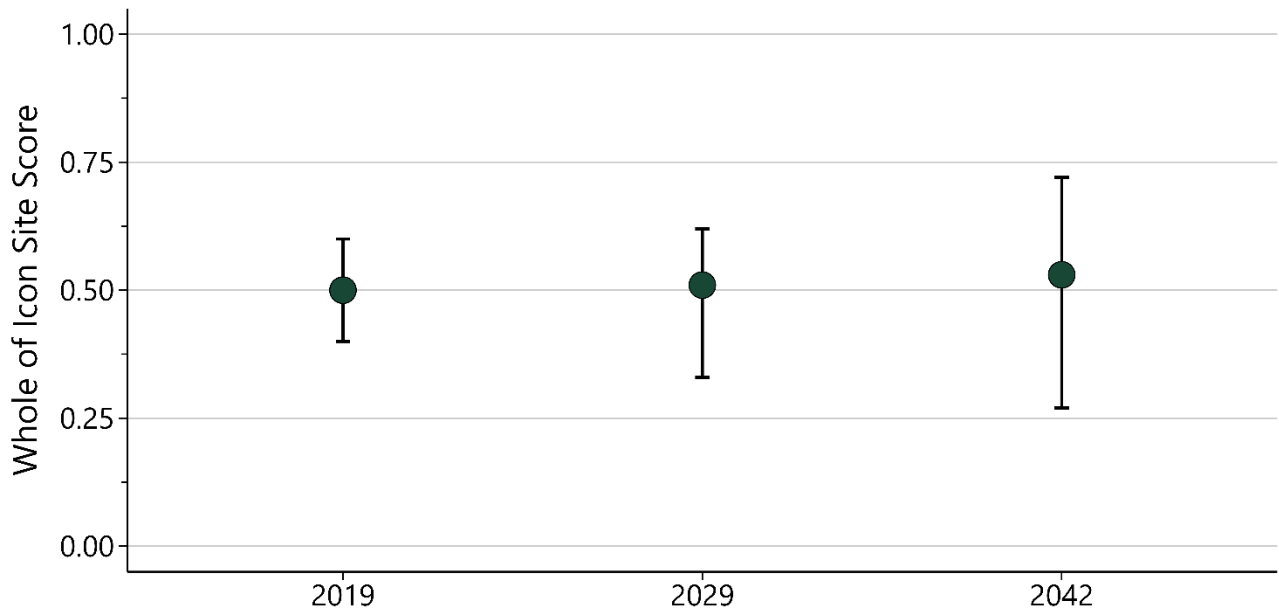


Figure 6-1. Expected environmental outcomes for Lakes aquatic and littoral vegetation in 2019, 2029, and 2042, based on the whole of icon site score. Expected outcomes were estimated by experts and were informed by modelled water recovery conditions.

6.3 Method

6.3.1 Data source

Data were sourced from the Lower Lakes Vegetation Condition Monitoring program conducted by the South Australian Research and Development Institute (SARDI) (Aquatic Sciences) and funded by the TLM program.

6.3.2 Data collection

The methodology for the Lower Lakes vegetation condition monitoring is described in the Lakes vegetation chapter (Nicol 2017) of the Lower Lakes, Coorong and Murray Mouth (LLCMM) Condition Monitoring Plan (DEWNR 2017). Selected wetland and lakeshore sites across Lake Alexandrina and Lake Albert, the Goolwa Channel, lower Finniss River, lower Currency Creek, and the mouths of the Angas and Bremer Rivers were used for vegetation condition monitoring. Sites established in spring 2008 and 2009 were re-surveyed. At each site, transects were established perpendicular to the shoreline and three, 1×3 m quadrats, separated by 1 m were located at regular elevation intervals (defined by plant community) for wetlands or elevations (+0.8, +0.6, +0.4, +0.2, 0 and -0.5 m AHD) for lakeshores. The cover and abundance of each species present in quadrats were estimated using a modified Braun-Blanquet (1932) cover abundance score.

Habitat and icon site score

Habitat scores were determined by multiplying the proportion of vegetation indices (see Appendix A) met for each habitat zone by one divided by the number of habitat zones, i.e. all habitat zones were equally weighted for the overall habitat score (Nicol 2017). Habitat scores were calculated using the following equation for:

Lake Alexandrina, Lake Albert and Goolwa Channel habitats

Habitat score = (proportion of indices met in the littoral zone x 0.33) + (proportion of indices in the aquatic zone x 0.33) + (proportion of indices met in deep water zone x 0.33)

Permanent wetlands

Habitat score = (proportion of indices met in the littoral zone x 0.5) + (proportion of indices met in the aquatic zone x 0.5)

Spring and autumn (temporary) wetlands

Habitat score = (proportion of indices met in the edge zone x 0.5) + (proportion of indices met in the bed zone x 0.5)

Whole of icon site scores was calculated using the following equation:

Icon site score = (Lake Alexandrina habitat score x 0.2) + (Lake Albert habitat score x 0.2) + (Goolwa Channel habitat score x 0.2) + (permanent wetlands habitat score x 0.2) + (temporary wetlands habitat score x 0.2)

6.3.3 Trend assessment

Trend analysis for the whole of icon site and each habitat was undertaken as per section 4.2.2 using a Bayesian generalised linear model. Trend in the whole of icon sites scores were assessed over the assessment period (2008 spring to 2023 autumn) using a beta distribution (with logit function). Time step (years since the commencement of the assessment period) was included as a fixed effect, with integers and half integers (e.g. 1, 1.5, 2, 2.5) used to discern between sampling seasons in the model.

The model specification was:

Icon site score ~ time step

Trend in scores for each habitat were assessed over the assessment period (2008 spring to 2023 autumn) using a beta distribution (with logit function) but included an interaction effect between time step and habitat, to assess if trend differs between the levels of aquatic habitats sampled. The model specification was:

Habitat score ~ time step * habitat

6.3.4 Information reliability

The information reliability assessment for aquatic and littoral vegetation condition in the Lakes was conducted as per section 4.2.3.

6.4 Results

6.4.1 Environmental outcome assessment

The environmental outcome assessment in 2019 found the condition of the Lakes aquatic and littoral vegetation were lower than expected. We expected a whole of icon site score of 0.5, but the whole of icon site score vegetation was below this, at 0.43 in spring 2018 (Figure 6-2).

Since the 2019 outcome assessment, the whole of icon site score has increased from 0.48 (spring 2019) to 0.67 (autumn 2023), indicating improved condition of aquatic and littoral vegetation in the Lakes over this period. In 2029 we expect a whole of icon site score to be 0.53 (80 % confidence interval of 0.27–0.72). This score has been exceeded in all seasonal surveys since spring 2020, therefore icon site scores are on-track towards the 2029 expected outcome.

Whole of icon site scores

Icon site scores increased from 0.32–0.36 between spring 2008 and spring 2009 to 0.56 between autumn and spring 2011 (Figure 6-2). Scores declined following spring 2011 and from 2012 to 2019 remained relatively stable (0.43 to 0.55). Since spring 2019, icon site scores have improved and are approaching 0.7.

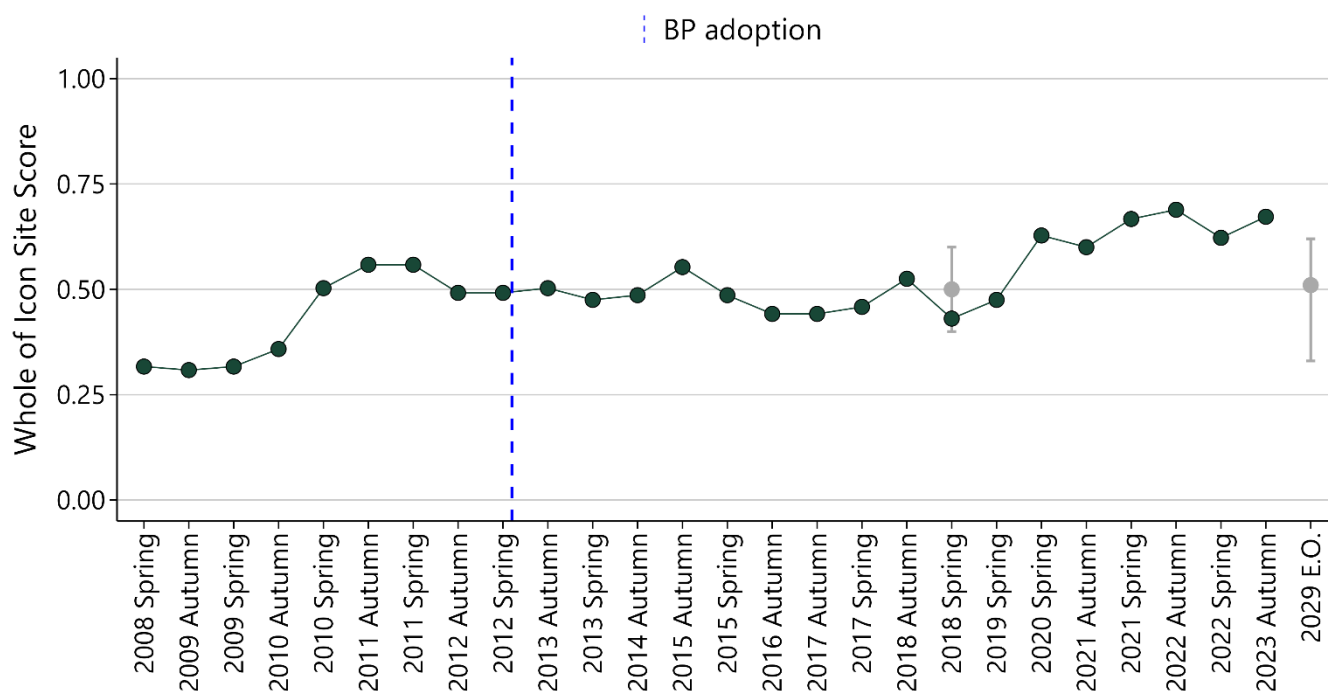


Figure 6-2. The whole of icon site score for aquatic and littoral vegetation in the Lakes from spring 2008 to autumn 2023. The grey dots and associated 80% confidence intervals represent the 2019 and 2029 expected outcomes. Data source: SARDI.

Habitat scores

Habitat scores in the Goolwa Channel, Lake Albert, Lake Alexandrina, permanent wetlands and temporary wetlands have increased since spring 2008 (Figure 6-3). There are substantial differences in the level of variability in scores between habitats. Habitat scores in Lake Albert, Lake Alexandrina and permanent wetlands have low variability between surveys, while scores in the Goolwa Channel and temporary wetlands are more dynamic. Since spring 2019, habitat scores have been maintained in Lake Alexandrina and Lake Albert and have improved in the Goolwa Channel, permanent wetlands and temporary wetlands. This indicates that improvement in habitat scores in the Goolwa Channel, permanent wetlands and temporary wetlands have had the greatest contribution to the improvement in icon site scores.

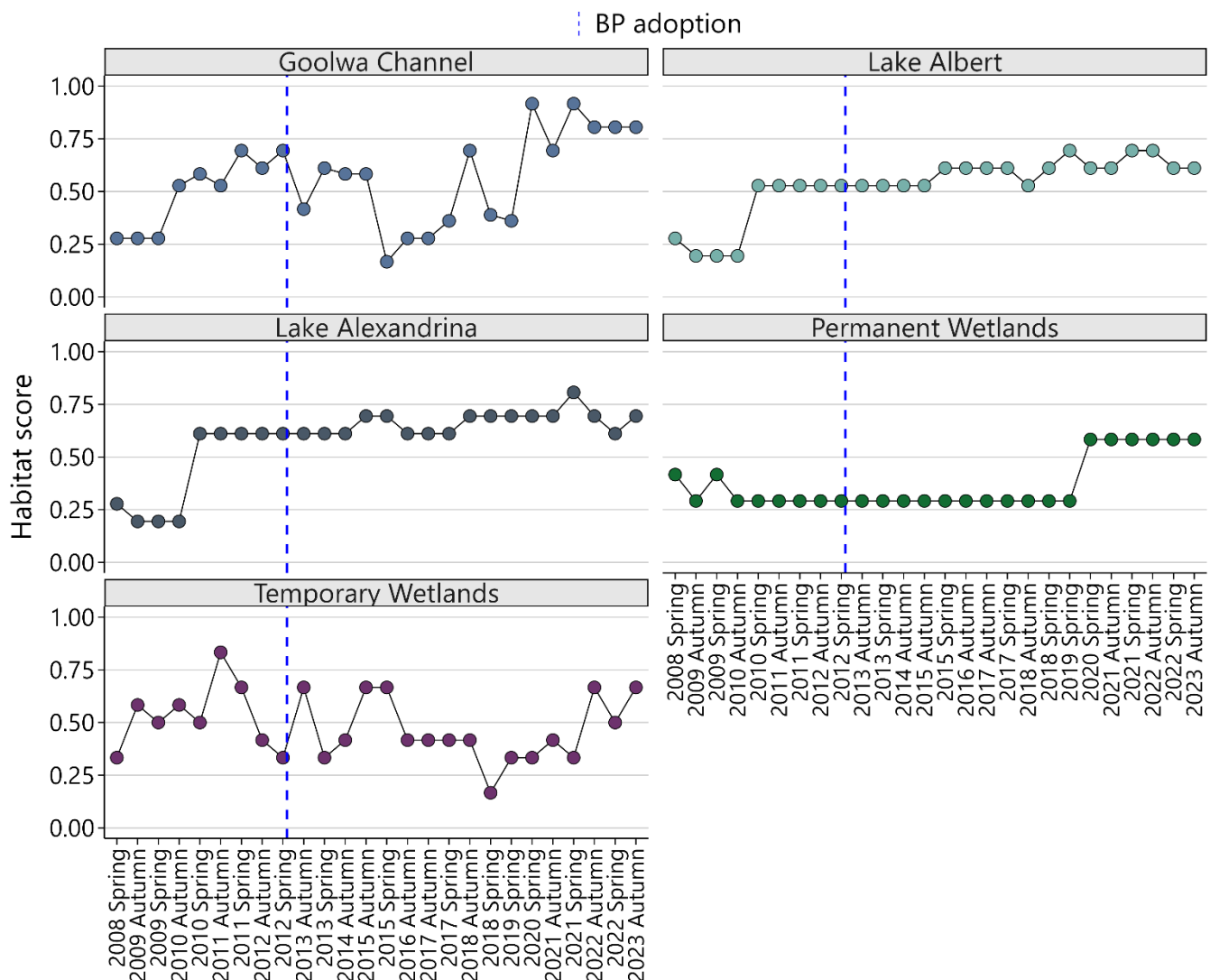


Figure 6-3. Habitat scores for each wetland type: Goolwa Channel, Lake Albert, Lake Alexandrina, permanent wetlands and temporary wetlands from spring 2008 to autumn 2023. Habitat scores are averaged to calculate the whole of icon site score. The adoption of the Basin Plan in 2012 is marked by a vertical dashed blue line. Data Source: SARDI.

6.4.2 Trend

Icon site scores for aquatic and littoral vegetation in the Lakes were virtually certain (99% probability) to have **improved** (Table 6–3; Figure 6-4). Trend assessment for individual habitat scores was performed separately. Results indicate most habitat zones in the Lakes are virtually certain to have **improved**, aside from estimated slope values for temporary wetlands which suggest that condition here is likely (84% probability) to have **declined** (Figure 6-5). The trend result for this habitat was likely influenced by the outlier diversity score (0.83) in autumn 2011, considering that the diversity in this habitat is now (2023) substantially higher than 2008.

Table 6–3. Outcomes from the Bayesian modelling assessment of trend for the icon site and each habitat. The probability of trend direction in the icon site score and habitat scores are presented and allocated to a trend category.

Location	Outcome	Probability	Trend category
Whole of icon site	Virtually certain to have increased	99%	Improved
Lake Alexandrina	Virtually certain to have increased	100%	Improved
Goolwa Channel	Virtually certain to have increased	100%	Improved
Lake Albert	Virtually certain to have increased	100%	Improved
Permanent Wetlands	Virtually certain to have increased	99%	Improved
Temporary Wetlands	Likely to have decreased	84%	Declined

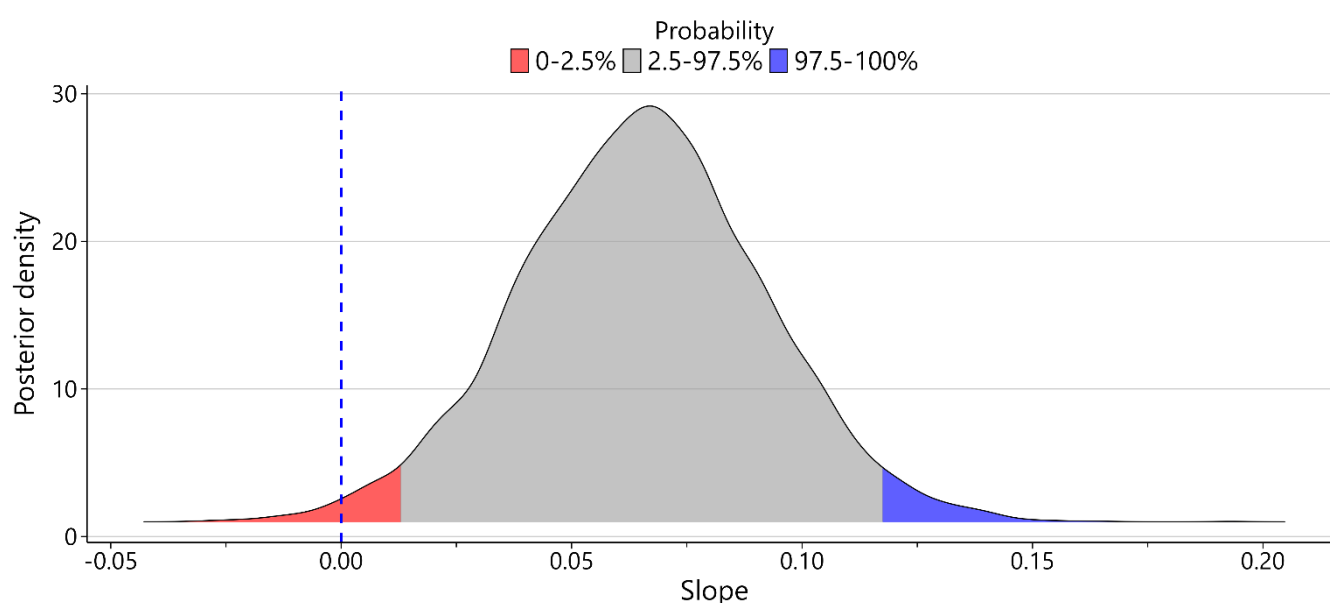


Figure 6-4. Estimated values for the slope generated from Bayesian modelling for the icon site score from spring 2008 to autumn 2023. Posterior slope values >0 infer a positive trend (improvement) and values <0 infer a negative trend (decline).

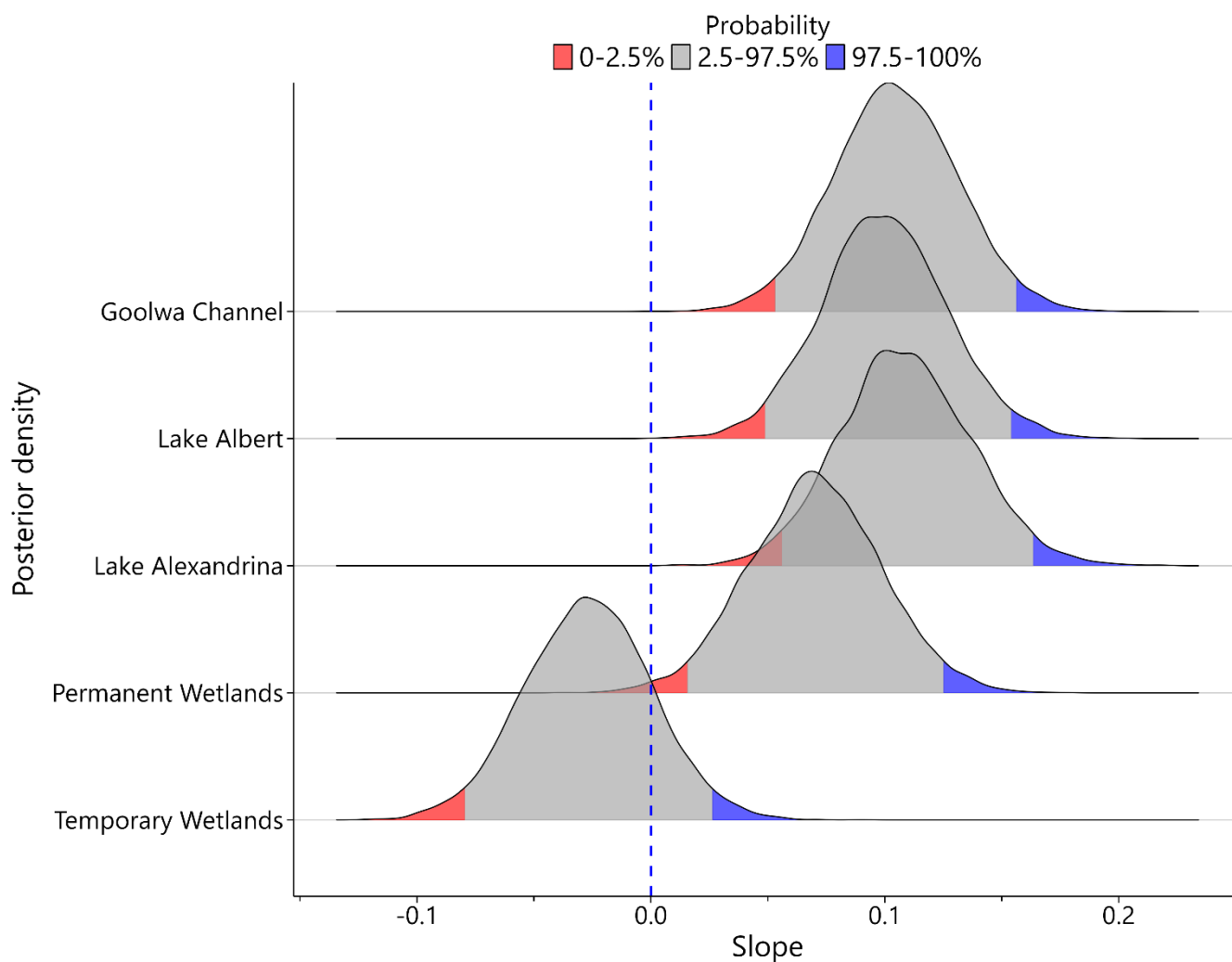


Figure 6-5. Estimated values for the slope generated from Bayesian modelling for habitat scores from spring 2008 to autumn 2023. Posterior slope values >0 infer a positive trend (improvement) and values <0 infer a negative trend (decline).

6.4.3 Information reliability

The information reliability rating for Lakes aquatic and littoral vegetation condition was **very good** (final score of 11). Justification for the scoring of Lakes aquatic and littoral vegetation condition information reliability is provided in Table 6-4.

Table 6–4. Reliability of aquatic and littoral vegetation data to assess the trend and condition of Lakes vegetation. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Yes. The same method has been used over the monitoring program (spring 2008 to autumn 2023).	2
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Lakes and wetlands with equal effort?	Partially. Sampling effort has been spread over the Lakes, however, is greater in Goolwa Channel than the other habitats.	1
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. Sampling has been conducted from 2008 to 2023, and therefore, includes a range of hydrological conditions.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. All sites were established by 2009 and are monitored during each assessment period.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes. Sampling has been conducted annually at a minimum and bi-annual data (autumn and spring) is collected in most years.	2
Final score			11
Information reliability			Very good

6.5 Evaluation

The icon site scores of aquatic and littoral vegetation in the Lakes has improved substantially from spring 2008 to autumn 2023. All habitats within the Lakes have an improved diversity score in 2023 compared to 2009. As such, trend indicates that all habitats have likely improved, except for temporary wetlands due to the effect of an outlier score in autumn 2011. Since 2019, there has been considerable improvement in icon site scores and all habitats within the icon site. The magnitude of this improvement has meant that the expected environmental outcome for aquatic and littoral vegetation in 2029 is on-track. As there is progress towards the achievement of LLCMM vegetation indices that are yet to be met, it is expected that if current hydrological conditions continue, the icon site scores and habitat scores will improve into the future (Nicol et al. 2023).

The improvement of aquatic and littoral vegetation condition in the Lakes over the assessment period (2008–2023) was influenced by water regime (see section 6.5.1), which included the return and maintenance of normal operating

lake levels and their seasonal management. Additionally, complementary management actions (see section 6.5.2) have also influenced the condition of aquatic and littoral vegetation in the Lakes over the assessment period.

6.5.1 Key factors contributing to environmental outcomes

Water regime

Water regime is a key driver of diversity in aquatic and littoral vegetation communities (Brock and Casanova 1997; Nicol et al. 2023). The water regime of the Lakes has improved the condition of the aquatic and littoral vegetation community through the return and maintenance of normal operating lake levels following the Millennium Drought and their seasonal variation over the past decade. The Lakes were able to be managed within normal operating ranges and with seasonal variation through (held) water for the environment delivery in association with the planned (not licensed) environmental water (PEW) component of South Australia's Entitlement and unregulated flows.

Management of lake levels

Lake levels need to be maintained above +0.4 m AHD to ensure permanent inundation of habitats supporting aquatic vegetation (Nicol et al. 2023). During the Millennium Drought, lake levels fell below sea level between 2008 and 2010 (Figure 6-6) and led to the extirpation of submergent plants and the colonisation of terrestrial plants in the littoral zone (Nicol et al. 2023). Widespread flooding in the MDB in 2010–11, led to the return to normal operating lake levels. This was associated with significant improvement in icon site scores due to the inundation of aquatic habitat and an increase in the abundance of emergent, amphibious and submergent species from 2010 to 2013 (Frahn et al. 2014). Since adoption of the Basin Plan (November 2012), lake levels have been maintained above +0.4 m AHD. The delivery of water for the environment to the Lakes has been imperative in the maintenance of lake levels above +0.4 m AHD during years of low River Murray flows and prevented lake levels from approaching sea level in autumn 2020 (Guarino & Sengupta 2022).

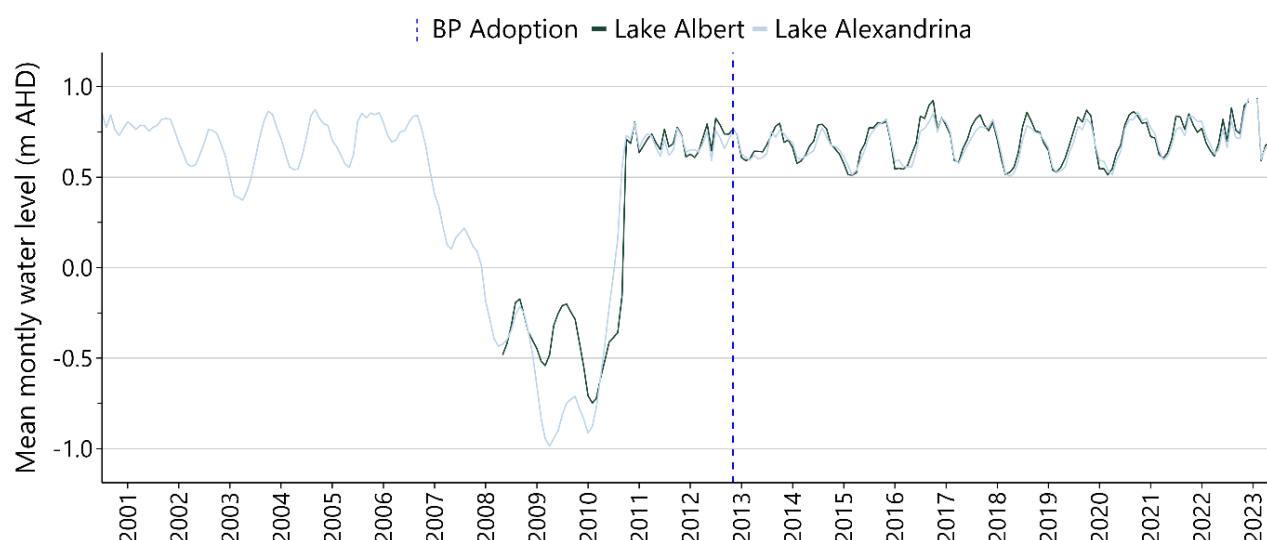


Figure 6-6. Mean monthly lake levels (m AHD) at Lake Albert (A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2001 to 2023 with respect to Basin Plan (BP) adoption as shown by the dashed blue line. Data source: Water Data SA.

Seasonal lake levels

Water level fluctuations strongly influence the zonation and floristics of aquatic and littoral vegetation in freshwater lakes (Dai et al. 2016; Grabas et al. 2019; Krolova et al. 2013). In the Lakes, the seasonal management of lake levels between +0.5 m AHD and +0.85 m AHD from 2013 to 2022 (Figure 6-6) has improved the species richness and coverage of aquatic and littoral vegetation communities. Autumn drawdowns provide opportunities for the recruitment of amphibious taxa in areas protected from wave action (Nicol et al. 2023). Seasonal variation in lake levels also reduces dominance of *Typha domingensis* and *Phragmites australis*, which can form undesirable monotypic stands, particularly in areas of stable water levels (Blanch and Walker 1997; Deegan et al. 2007; Nicol et al. 2023).

High (unregulated) flows in 2021–22 and 2022–23 meant that lake levels in autumn could not be drawn down below +0.6 m AHD (Figure 6-6), which may have caused a decrease in mean native amphibious species richness at +0.6 m AHD (Nicol et al. 2023). However, species richness has been maintained at +0.8 m AHD, suggesting that these species should recruit at lower elevations when drawdowns below +0.6 m AHD occur in the future (Nicol et al. 2023).

Lake levels during the flood (comprised of unregulated flows) in 2022–23 exceeded 1 m AHD for the first time in over 20 years. This meant that plant communities at higher elevations, such as saltmarsh, which are not inundated with surface water from the lakes at normal operating ranges were inundated. The flood conditions may have improved the growth rates of species within the saltmarsh community, which are improved under fresher conditions (Nicol 2016).

Salinity

Water regime and salinity are two main drivers of wetland vegetation (Brock and Casanova 1997; Nicol et al. 2003; Nielsen and Brock 2009). Electrical conductivity exceeded 5,000 $\mu\text{S cm}^{-1}$ in Lake Alexandrina and 15,000 $\mu\text{S cm}^{-1}$ in Lake Albert during the Millennium Drought (Figure 6-7). The impact of these elevated salinities on the aquatic and littoral vegetation is difficult to de-couple from the effects of lake levels that receded below sea level. However, at this time, the aquatic and littoral plant community were found to be more resilient to elevated salinities than expected (Jason Nicol, personal communication, August 2023). The reduction in the salinities of the Lakes with the return of River Murray flows in 2010–11 may have positively influenced aquatic and littoral vegetation. For example, there was a significant change in the floristics and cover of the submergent plant community in the Goolwa Channel between spring 2009 and 2010, that coincided with the breach of the Clayton regulator and a rapid reduction in salinity. During this event there was an increase in species richness and a decline in cover, with *Potamogeton pectinatus*, that was dominant under elevated salinities, greatly reducing in cover under fresher conditions (Nicol et al. 2023).

Since adoption of the Basin Plan in 2012, salinities in Lake Alexandrina have largely been maintained below 1,000 $\mu\text{S cm}^{-1}$ and those in Lake Albert have declined from approximately 4,000 $\mu\text{S cm}^{-1}$ to around 1,000 $\mu\text{S cm}^{-1}$ through lake level cycling events, seasonal lake level management, high (unregulated) flow events and the enhancement of barrage outflow with the delivery of water for the environment (Figure 6-7). The magnitude of change in Lake Albert salinity since adoption of the Basin Plan is not considered to be biologically significant for the plant species present (Nicol et al. 2023), however, by managing and maintaining these current salinity levels, the future risk of adverse outcomes induced by salinity on the aquatic and littoral plant community is low.

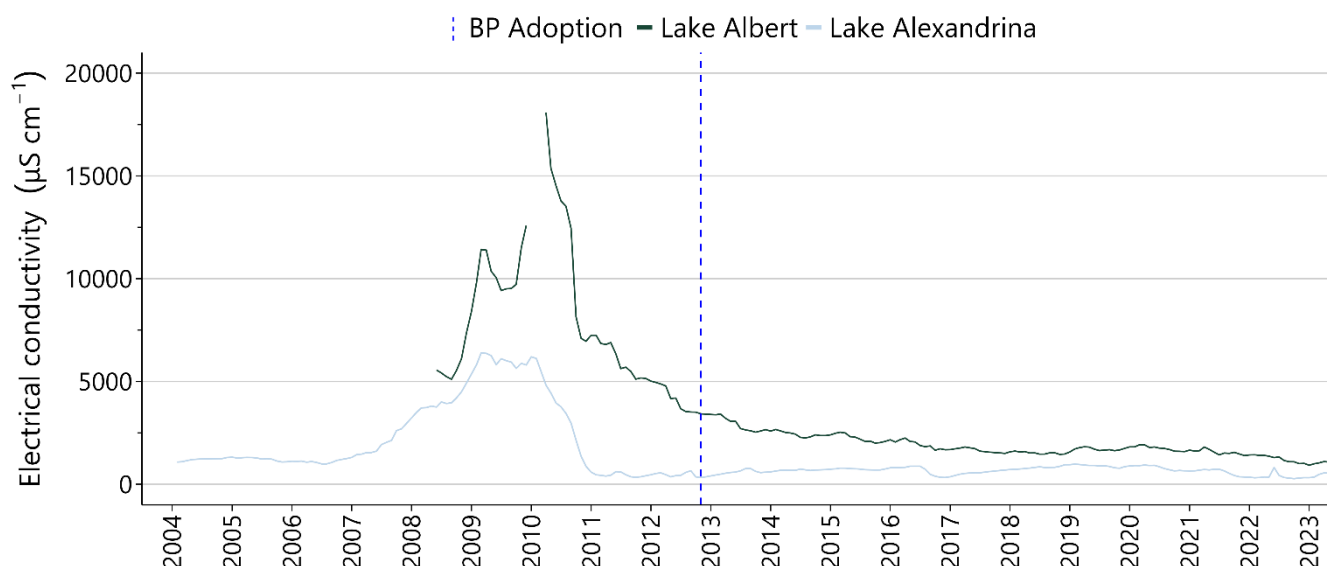


Figure 6-7. Mean monthly electrical conductivity ($\mu\text{S cm}^{-1}$) in Lake Albert (A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2004-2023. Basin Plan (BP) adoption in November 2012 is shown by the dashed blue line. Data source: Water Data SA.

6.5.2 Complementary actions contributing to environmental outcomes

Lakeshore fencing

Fencing surrounding the lakeshore helps protect littoral vegetation. A total of 22% of the shoreline of the Lakes, and 42% of shoreline threatened by grazing, was fenced under the Vegetation Program as part of the Coorong, Lower Lakes and Murray Mouth (CLLMM) Recovery Project in 2012 (DEW 2019). Fencing prevents the impacts of stock, which include over-grazing, pugging and erosion of lakeshores, to the benefit of the aquatic and littoral vegetation condition (DEW 2019). Most fences were established prior to the adoption of the Basin Plan; however, they have likely contributed to the recovery and re-establishment of aquatic and littoral vegetation since Basin Plan. Despite this, the increased protection of sites has increased coverage of pest species such as *Paspalum distichum* and *Cenchrus clandestinus*.

Aquatic plant revegetation

Schoenoplectus tabernaemontani stands were planted over 30 km of shoreline in the Lakes by community groups since 1996 and under the CLLMM Recovery Project from 2012 to 2016 (Nicol et al. 2016). Planted stands of *S. tabernaemontani* have enhanced the condition of aquatic and littoral vegetation by providing a barrier to wave action, sheltering key (and more sensitive) submergent aquatic flora such as *Myriophyllum* spp., *Potamogeton* spp., *Certophyllum demersum* and *Vallisneria australis* (Nicol et al. 2016). As *S. tabernaemontani* does not form monotypic stands, it can grow as part of a diverse aquatic and littoral vegetation community (Nicol et al. 2016). The positive outcomes associated with these plantings may be attenuating at certain sites, with observations of some plantings becoming dominated by *P. australis* and *T. domingensis* (Kate Mason, personal communication, August 2023). As only three of the 24 lakeshore monitoring sites overlapped with where *S. tabernaemontani* were planted (Jason Nicol, personal communication, August 2023), the impact of planted *S. tabernaemontani* stands on icon site scores are expected to be minor.

Wetland management

Management of wetlands fringing the Lakes can enhance the condition of aquatic and littoral vegetation. Actions to improve aquatic and littoral vegetation at managed fringing wetlands include reinstating wetting and drying cycles, preventing mature common carp (*Cyprinus carpio*) from entering wetlands through the installation of carp screens, pumping water for the environment to wetland basins and restoring flow paths to improve hydrological connectivity across wetland systems.

Hydrological management of fringing wetlands in the Lakes enables the reinstatement of natural wetting and drying cycles. Wetting and drying events improve productivity through more rapid nutrient mineralisation by aerobic microbes (Meronigal et al. 1997), consolidate wetland bed sediments can lead to increases in water clarity (when re-wet) (Nias 2002), and provide an opportunity for the germination, growth and recruitment of aquatic and amphibious taxa (Nicol and Ganf 2017; Nicol et al. 2003). By closing carp screens when wetlands transition from dry to wet cycles, the aquatic vegetation that re-establishes on the wetland bed is protected from the feeding habits of mature carp that uproot vegetation and increase turbidity (Vilizzi et al. 2014).

Wetlands with limited connection to the Lakes can have water for the environment pumped in to reinstate a wetting cycle. This has occurred at the Teringie and Narrung wetlands, south basin, and has led to the growth of aquatic plants, such as *Ruppia* spp., and likely positively influenced the condition of the saltmarsh community. The growth of *Ruppia* spp. that was established through the provision of water for the environment has benefitted waterfowl, including black swans (*Cygnus atratus*), a culturally significant species for the Ngarrindjeri who are the traditional owners and manage the Teringie wetland complex.

The restoration of flow paths has also improved the condition of aquatic and littoral vegetation communities around the Lakes. Flow paths can become restricted through the dense growth of reeds (*T. domingensis* and *P. australis*) as well as invasive grasses (*P. distichum* and *C. clandestinus*), meaning that without intervention wetlands can become desiccated and overgrown with terrestrial vegetation. Flow paths to wetlands have been restored through mechanical excavation and dredging, and more recently burning trials have been undertaken. On Hindmarsh Island, the clearance of flow paths is estimated to have benefited 90 ha of wetlands and improved the cover of aquatic plants, such as *Ruppia*, charophytes, hornwort and milfoil (Kate Mason, personal communication, August 2023).

6.5.3 Unanticipated outcomes

The environmental outcomes of aquatic and littoral vegetation in the Lakes are exceeding expectations, with the icon site score in autumn 2023 nearing the upper 80% confidence interval for the 2029 expected environmental outcome. These expectations were exceeded in part due to the unanticipated high level of species richness of native aquatic and littoral plant species, which is now comparable to 2004–05 baseline surveys that occurred prior to the severe impacts of the Millennium Drought (Jason Nicol, personal communication, August 2023). In addition to this, the achievement of indices related to cover of exotic grasses (*P. distichum* and *C. clandestinus*) in the past five years were also unanticipated.

6.5.4 Actions to achieve environmental outcomes

The condition of aquatic and littoral vegetation in the Lakes is expected to continue to improve by maintaining the current water regime (Nicol et al. 2023). It is therefore critical that lake levels are maintained above +0.4 m AHD and recommended that levels vary seasonally between +0.5 m AHD and +0.85 m AHD. Outside of the current management influence, periodic high (unregulated) flow events are also important and are needed more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes and inundating habitats at higher elevations.

Delivery of water, including delivery of water for the environment, will continue to improve the resilience of aquatic and littoral vegetation and help to maintain icon site scores through successive years. Addressing current water delivery constraints and greater water recovery as part of full implementation of the Basin Plan will improve the ability to deliver a water regime that is favourable for aquatic and littoral vegetation in the Lakes. This would include:

- greater flexibility in the timing of water delivery that would improve spring and summer flows into the Lakes,
- the ability to maintain high (+0.85 m AHD) water levels in spring and into summer for extended durations, and
- increased confidence for water managers to lower lake water levels in autumn, knowing sufficient volumes will be available to refill the Lakes the following winter or spring.

Management of wetlands fringing the Lakes benefits the condition of aquatic and littoral vegetation communities as discussed in section 6.5.2. Under the On-Ground Works project of the HCHB program, water delivery and management of wetland infrastructure will be constructed to improve the availability and quality of waterbird habitat at Teringie wetlands (DEW 2020a). Improved hydrological management of these wetlands is expected to also benefit aquatic and littoral vegetation condition. Feasibility investigations are being conducted by the Murraylands and Riverland Landscape Board to identify wetland sites that could be pumped with water to improve their condition, including that of aquatic and littoral vegetation communities (Kate Mason, personal communication, August 2023).

Land management activities may aid in improving the condition of littoral vegetation. These activities may include establishing a light grazing regime for sheep within areas of dense exotic grasses (*P. distichum* and *C. clandestinus*) and over-abundant reeds (*T. domingensis* and *P. australis*). This would aim to reduce the competition of these dominant species with desirable littoral plant species (Jason Nicol, personal communication, August 2023).

6.6 Conclusion

The delivery of water has enabled the Lakes to operate at normal levels and vary seasonally, which has improved the condition of aquatic and littoral vegetation. This water regime, supported through the delivery of water for the environment, provided conditions that were crucial in protecting aquatic environments and providing opportunities for amphibious plants to recruit. The expected environmental outcome for aquatic and littoral vegetation in 2029 is on track or may be exceeded, and the condition of this community are expected to continue to improve under current water regimes.

7 *Ruppia tuberosa*



Trend
Improved



Reliability
Very good

Key findings and messages:

- The distribution and abundance of the *Ruppia* Community is currently exceeding pre-drought levels and has improved across the assessment period (2006-07 to July 2023).
- Improved distribution and abundance of the *Ruppia* Community indicates that they are currently on-track to achieve the 2029 expected outcome.
- Despite the recent improvements to distribution and abundance, *Ruppia tuberosa* seed bank density remains low, indicating the species has poor resilience and is at risk to future perturbations.
- Growth and abundance of filamentous algae and phytoplankton continue to impact the growth and reproductive output of *Ruppia tuberosa* and the overall *Ruppia* Community.
- Restoration actions can increase the abundance and extent of the *Ruppia* Community, but improvements in habitat conditions, including water quality, sediment condition and occurrence of seasonal water levels, are critical for successful growth and reproduction.
- Implementation of the Basin Plan has assisted in preventing salinities in the Coorong reminiscent of the Millennium Drought, through provision of water for the environment, particularly maintaining water levels in spring and early summer for the *Ruppia* Community to complete its lifecycle.

7.1 Introduction

The *Ruppia* Community describes a community of submerged aquatic plants that is distributed throughout the southern Coorong (Lewis et al. 2022; Paton & Bailey 2010; Paton et al. 2015). Within this community currently, *Ruppia tuberosa*, is the most common species, but other species such as *Althenia cylindrocarpa* and at least one unresolved species of *Ruppia* are also present (Lewis et al. 2022).

The *Ruppia* Community of the southern Coorong is dynamic and highly adaptive to changing environmental conditions, therefore other species are likely to be present if environmental conditions allow (salinity, nutrient and organic loads, water clarity). The lifecycles of the species which form the *Ruppia* Community also differ in complexity and reproductive strategies, these strategies can also change in response to environmental conditions. While *A. cylindrocarpa* follows a fairly typical, annual plant lifecycle with growth, reproduction, seed set and senescence, occurring in response to environmental and seasonal conditions (Figure 7-1), *R. tuberosa* has a more complex lifecycle, which likely accounts for its resilience in the harsh conditions of the southern Coorong. *R. tuberosa* has the ability to adapt its reproductive strategy to environmental conditions through sexual reproduction (flowering and seed set), asexual reproduction (starch filled vegetative structures; turions) and where water levels are less variable (i.e. deeper water), *R. tuberosa* can persist year round in a seemingly perennial form (Figure 7-1) (Lewis et al. 2022; Waycott et al. 2022).

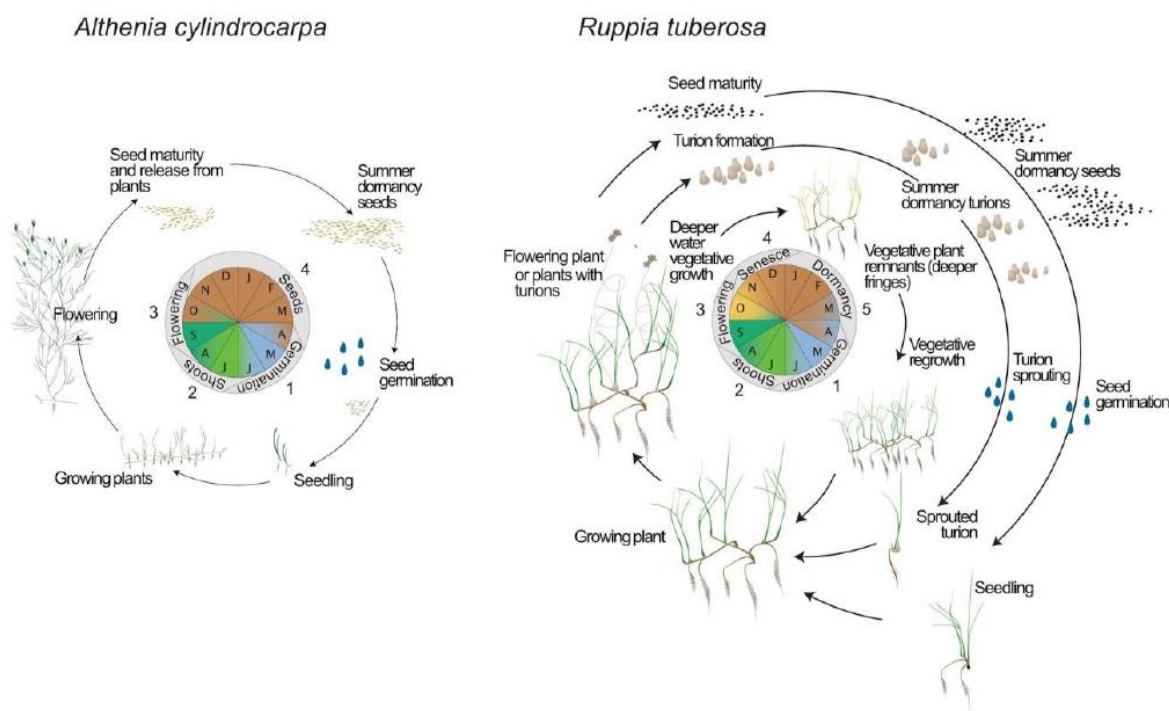


Figure 7-1. Summary schematic of the lifecycles for *Althenia cylindrocarpa* and *Ruppia tuberosa* depicting seasonal changes in the stages of growth, reproduction and senescence and broad timing of each life stage. Attribution: Michelle Waycott, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0/>, via Wikimedia Commons.

The species which form the current composition of the Ruppia Community (*Ruppia* spp. and *A. cylindrocarpa*) are unable to be identified from their vegetative features alone, and therefore, reproductive structures such as flowers and propagules (turions and seeds) are required for species level identification (Lewis et al. 2022, Waycott et al. 2022). Given this, the evaluation of presence-based outcomes (extent of occurrence and area of occupation) consider the Ruppia Community as a whole, while the seedbank outcome can solely be attributed to *R. tuberosa*. Therefore, unless outcomes are explicit to *R. tuberosa* we will refer to the Ruppia Community to describe the mixed species, submerged aquatic macrophyte community of the Coorong.

The Ruppia Community plays an important role in the structure and function of the southern Coorong, where it modifies the physical environment (i.e., sediment capture and stabilisation, and changes to water velocities) and biogeochemical processes (Huang et al. 2022; Lewis et al. 2022; Rogers & Paton 2009; Waycott et al. 2022). Nutrient conditions in the sediment and water column are influenced by the Ruppia Community, which provides longer-term capture of nutrients than phytoplankton and filamentous algae (Asanopoulos & Waycott 2020) and the diffusion of oxygen from their roots, which contributes to active nitrification (Huang et al. 2022; Waycott et al. 2022). It is thought that Ruppia Community meadows in the Coorong are important hotspots for nitrogen loss via coupled nitrification-denitrification (Huang et al. 2022).

Higher trophic order species in the southern Coorong also depend on the Ruppia Community for habitat and food. The Ruppia Community provides substrate for smallmouth hardyhead to attach their eggs (Molsher et al. 1994), and it provides an important, nutritious food source for waterbirds (Delroy 1974; Giatas et al. 2022; Moore 2014; Paton 1982). Vegetative matter (shoots and turions) of the Ruppia Community are grazed by herbivorous waterfowl and dominate their diets (Delroy 1974; Giatas et al. 2022; Paton 1982), and reproductive structures (seeds and turions) are foraged upon by shorebirds (e.g. *Calidris* spp) (Delroy 1974; Paton 1982).

Ruppia Community condition is responsive to a range of environmental and physical factors, including water depth, light availability, water quality (salinity, turbidity and nutrients), sediment quality, disturbance from filamentous algae and waterfowl foraging (Lewis et al. 2022; Paton & Bailey 2010; Waycott et al. 2022). Water depth is a principal environmental driver of Ruppia Community condition (Asanopoulos & Waycott 2020; Collier et al. 2017; Kim et al. 2015; Lewis et al. 2022; Waycott et al. 2022), with water cover of varying depths required for successful completion

of each life stage (Collier et al. 2017; Kim et al. 2015). Salinity is also an important driver of condition, with extreme hyper-salinity (i.e. >60 g L⁻¹) reducing germination, flowering and growth (Kim et al. 2015; Lewis et al. 2022; Waycott et al. 2022). Eutrophication has also impacted Ruppia Community condition, with the retention of excessive nutrients in the system fueling phytoplankton and filamentous algae growth (Mosley et al. 2023; Mosley et al. 2020; Priestley et al. 2022a; Priestley et al. 2022b; Waycott et al. 2022). Excessive phytoplankton and filamentous algae biomass adversely impacts Ruppia Community condition through reducing light availability which reduces growth, physical interference with flowering and fruiting structures. This interference limits seed set, and through the enrichment of sediments with organic matter following their decay that can reduce biomass and turion production (Paton & Paton 2023b; Waycott et al. 2022).

Upstream water extraction and climate change has reduced freshwater discharge from the barrages to the Coorong and combined with increased net evaporation has been detrimental to the Ruppia Community (Mosley et al. 2023; Paton et al. 2015). These changes to hydrodynamic and environmental processes have reduced flushing of the southern Coorong and lead its transition into a persistently hypersaline and hyper-eutrophic state (Mosley et al. 2023). The Millennium Drought (1996–2010), especially the period of no barrage flows (2007–2010), exacerbated the elevation of salinity and nutrient concentrations and reduced water levels (Mosley et al. 2023; Paton et al. 2015). These adverse impacts caused increased stress on the Ruppia Community that was already declining prior to the Millennium Drought (Paton et al. 2015), and led the northward shift in its distribution, establishing in the central North Lagoon and being effectively lost from the South Lagoon (Paton & Bailey 2012). Following the break of the Millennium Drought in 2010–11, the regional scale condition of the Ruppia Community began to improve overall, now exceeding its pre-drought extent and abundance in the southern Coorong (Lewis et al. 2022; Paton & Paton 2023b; Waycott et al. 2022). However, recovery of the *R. tuberosa* seedbank, while showing an increase since the Millennium Drought, have not increased at the same rate as plant abundance and distribution, likely due to inadequate water levels and interference by filamentous algae (Asanopoulos & Waycott 2020; Lewis et al. 2022; Paton & Paton 2023b; Paton et al. 2020; Waycott et al. 2022).

7.2 Ecological objective, targets and environmental outcomes

The ecological objective and targets for *R. tuberosa* described in the [South Australian River Murray Long-term Watering Plan \(LTWP\)](#) (DEW 2020), are presented in Table 7–1. The ecological targets for *R. tuberosa* are from the ‘*Ruppia tuberosa*’ chapter (Paton et al. 2017) of the [Lower Lakes Coorong and Murray Mouth \(LLCMM\) Icon Site Condition Monitoring Plan](#) (DEWNR 2017), also presented in Table 7–1. These targets form the basis of the expected environmental outcomes.

Table 7–1. Ecological objective and targets for *Ruppia tuberosa* in the southern Coorong. Note that the 43 km historical extent ranges from N02E (Magrath Flat) to S41E/W (Tea Tree Crossing).

Ecological objective	Ecological targets
Restore <i>R. tuberosa</i> colonisation and reproduction in the Coorong at a regional and local scale.	Extent of occurrence (EOO) along the Coorong of 43 km, excluding outliers. Area of occupation (AOO) within the 43 km sampled distribution, 80% of sites have plants present in both winter and summer. Long-term resilience (seed bank): i. By 2019: 2,000 seed m ⁻² (≥ 8 seeds per 75 mm diam. × 40 mm deep core) at 50% of sites within the 43 km sampled distribution. ii. By 2029: 10,000 seeds m ⁻² (≥ 40 seeds per 75 mm diam. × 40 mm deep core) at 50% of sites within the 43 km sampled distribution.

The expected outcomes for *R. tuberosa* were based on the expected change in AOO and seed bank densities since adoption of the Basin Plan (2012) (Table 7–2; Figure 7-2). Over time, it is expected that the area of occupation of *R. tuberosa* within the 43 km sampling distribution will decline over time. Expert opinion differed on the long-term resilience expected environmental outcome, with expectations varying from an improvement in the seed bank of *R. tuberosa* to be reflective of a resilient population to the decline and subsequent loss of the seed bank. For all expected environmental outcomes, the confidence in estimates attenuated with time.

Note that the expected outcomes for extent of occurrence (EOO) were removed for this evaluation. Previously, outcomes for this metric were based on the proportion of experts that believed the EOO would be maintained, and therefore did not provide quantitative information to compare observed EOO values against.

Table 7–2. Expected environmental outcomes for *R. tuberosa* distribution (area of occupation) and long-term resilience (seed bank) across the 43 km sampling distribution in the Coorong in 2019, 2029 and 2042.

Expected outcome	Year		
	2019	2029	2042
Area of occupation (AOO)	83% of sites (within the sampled 43 km distribution) will have plants present in both winter and summer, with an 80% confidence interval of 48 to 93% of sites.	58% of sites (within the sampled 43 km distribution) will have plants present in both winter and summer, with an 80% confidence interval of 29 to 73% of sites.	56% of sites (within the sampled 43 km distribution) will have plants present in both winter and summer, with an 80% confidence interval of 27 to 72% of sites.
Long-term resilience (seed bank)	<i>R. tuberosa</i> seed density (seeds m ⁻²) across the 43 km sampling distribution in the Coorong is expected to be 181 seeds m⁻² , with an 80% confidence interval of 68–363 seeds m ⁻² .	<i>R. tuberosa</i> seed density (seeds m ⁻²) across the 43 km sampling distribution in the Coorong is expected to be 238 seeds m⁻² , with an 80% confidence interval of 35–668 seeds m ⁻² .	<i>R. tuberosa</i> seed density (seeds m ⁻²) across the 43 km sampling distribution in the Coorong is expected to be 1425 seeds m⁻² , with an 80% confidence interval of 0–4016 seeds m ⁻² .

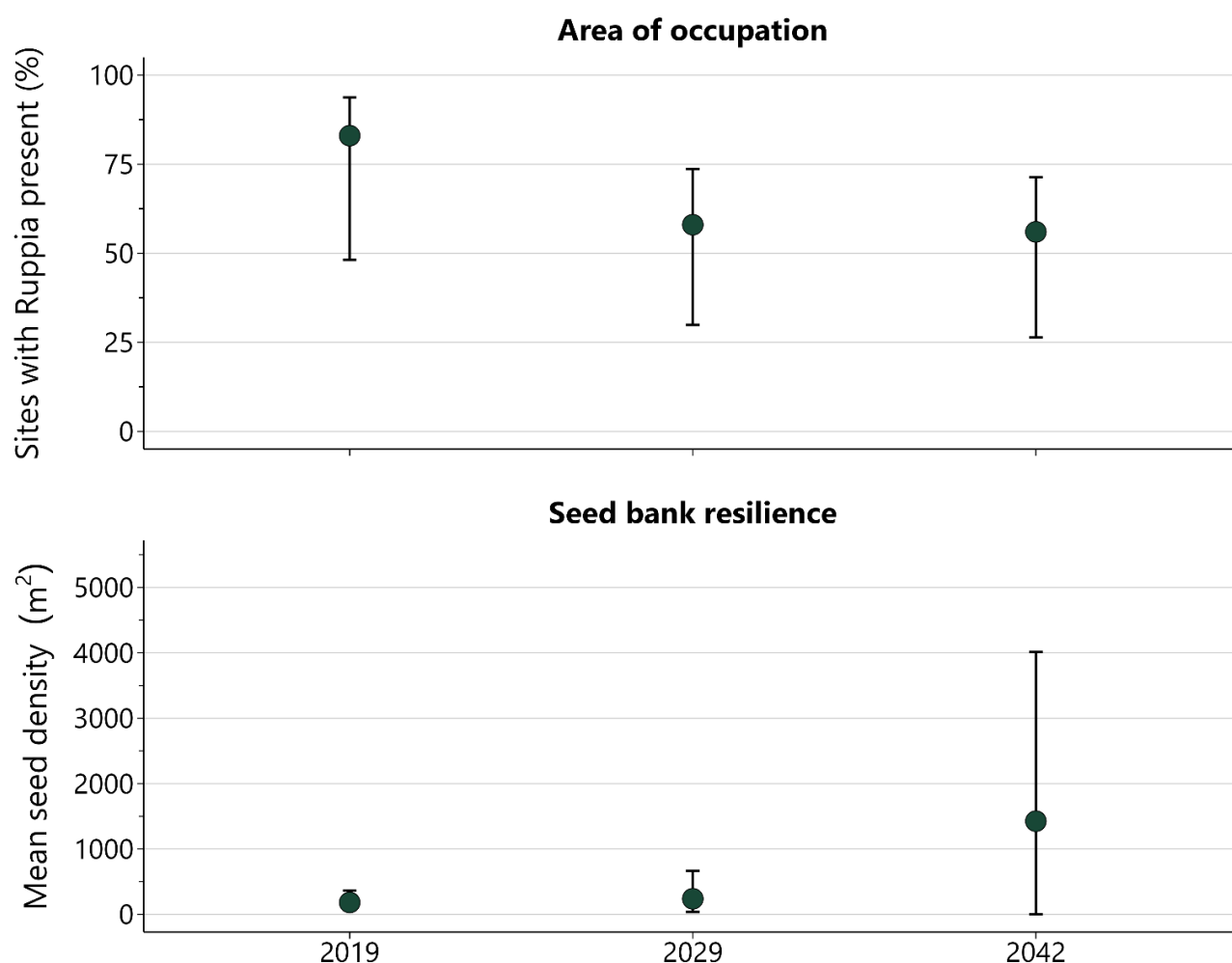


Figure 7-2. Expected environmental outcomes for *R. tuberosa*. Area of occupation (AOO) is the expected proportion of sites with live plants within the 43 km sampling distribution. Seed bank measures reflect the mean seed density across the 43 km sampling distribution to assess the long-term resilience in the Coorong.

7.3 Method

7.3.1 Data collection

The methodology of the summer monitoring and winter monitoring of *R. tuberosa* condition are described in the '*Ruppia tuberosa*' chapter (Paton et al. 2017) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and are summarised below.

The data collected during monitoring activities is made available in the Australian National Data repository (<https://data.gov.au/data/dataset/ruppia-monitoring-southern-coorong>).

Data has been collected by The University of Adelaide/Bio-R for the DEW since 2006–07 primarily through condition and intervention monitoring under the TLM program and other funding sources of the MDBA. Data is used to inform the delivery of water for the environment to the Coorong. The cut-off date for data used in this evaluation was 30 June 2023, any data collected after this date will be included in the next Basin Plan environmental outcome evaluation. This will take into consideration any environmental changes which have occurred since 30 June 2023. However, following evaluation workshop discussion, data from the July 2023 TLM survey was included to capture the 2023 growth period of *R. tuberosa*/Ruppia Community.

7.3.2 Summer monitoring

The distribution of shoots (green and brown), seeds, and turions were assessed annually in January since 2007. Ten sites, spaced 5 km apart, were sampled on eastern shores of the southern Coorong. A further eight sites on the western shore were also sampled. The historical extent (N02E to S41E/W) of *R. tuberosa* includes McGrath's Flat (N02E), which is 2 km north of the junction between the North Lagoon and South Lagoon. At each site, 25 cores (75 mm diameter; 40 mm depth) were placed across four water depths: dry mud, waterline, 30 cm deep and 60 cm deep. The number of live shoots were counted for each core. After which, the core was sieved through a 500 µm Endecott sieve and seeds and turions were counted.

7.3.3 Winter monitoring

The distribution and counts of shoots (green and brown) and seeds were assessed annually in July since 1998. Three sites on the western shore and six sites on the eastern shore of the southern Coorong were sampled.

Winter sampling uses two methodologies:

- 1) The first consists of five permanent transects at each site (25 m apart) running perpendicular to the shoreline. In each transect, two cores were collected at water depths of 20 cm, 40 cm, 60 cm, 80 cm and 90 cm, totalling ten core samples per transect. Live shoots were counted, and cores sieved through a 500 µm Endecott sieve to count seeds and turions.
- 2) The second is complementary to the first, with 50 cores taken at water depths between 40 cm and 70 cm in the four areas between adjacent transects. Within each core, live shoots were counted, however cores were not sieved for seeds.

7.3.4 Assessment of environmental outcomes

Expected environmental outcomes were assessed using data from 2012 to 2023 as there was a large increase in sample effort in winter 2012 and summer 2013. Repeat visits to sites established in winter 2012 and summer 2013 as well as sites established earlier in the monitoring program has occurred up to winter 2023 (end of assessment period). The expected outcome for EOO was not assessed in this report (as discussed above).

7.3.5 Trend

Trend analysis for AOO and seed bank was undertaken as per section 4.2.2 using a Bayesian generalised linear models.

AOO trend

A generalised linear mixed model with a binomial family was used to model the probability of trend in the proportion of sites with live *R. tuberosa* shoots over the eastern and western shores of the southern Coorong during summer (January) and winter (July) assessments from 2009 to 2023. Data used for the trend assessment commenced in 2009 as this was the first year that site N02E was assessed in winter. A binary dataset was used for the analysis, with sites where live shoots were detected allocated a 1, and sites where there were no live shoots detected allocated a 0. Time step (years since the commencement of the assessment period) was used as a fixed effect, with winter (July) assessments assigned a half integer (e.g., 2009 January = 1, 2009 July = 1.5, etc.). Each site was treated as a random effect (slope and intercept).

Seed bank trend

A generalised linear mixed model with a negative binomial family was used to model the probability of trend in seed banks over the eastern and western shores of the southern Coorong during summer (January) assessments from 2007 to 2023. Seed bank was defined as the total (sum) of seed counts (multiplied by 226 to convert to m⁻²) at each site. An offset term (defined as the number of cores collected at a site across all depths in a given year) was

used to account for differences in the number of sampling cores, since any differences between sites would influence the number of (summed) seeds that was used as the value per site. Time step was included as a fixed effect in the model, while site was specified as a random (slope and intercept) term.

7.3.6 Information reliability

The information reliability assessment for *R. tuberosa* was conducted as per section 4.2.3.

7.4 Results

7.4.1 Outcome assessment: Area of occupation (AOO)

The AOO of *R. tuberosa* in the southern Coorong increased from 2012 to 2017 (Table 7–3). Since 2014, *R. tuberosa* plants have been detected at 100% of winter sites, and plants have been recorded at a minimum of 78% of sites in summer since 2017. Therefore, progression towards the LTWP target for AOO has occurred following adoption of the Basin Plan.

The 2019 expected outcome for *R. tuberosa* AOO (i.e., 83% of sites with plants in winter and summer) in the southern Coorong was not met (Figure 7-3). Summer monitoring identified *R. tuberosa* plants at 78% of sites and winter monitoring identified plants at 100% of sites. As a result, the expected environmental outcome of the *R. tuberosa* being present at a minimum of 83% of sites in both summer and winter of 2019 was not achieved. Since 2019, the winter AOO of the *R. tuberosa* has been maintained at 100% and the summer AOO has increased from 78% (summer 2019) to 94% (summer 2023). The average AOO of the *R. tuberosa* across summer and winter monitoring assessments between 2019 and 2023 was 95% and exceeds the average AOO between Basin Plan adoption (2012) and 2019 of 75%.

The 2029 expected outcome for the *R. tuberosa* AOO (i.e., 58% of sites with plants in winter and summer) is currently on-track to be exceeded, with a minimum of 78% of sites having plants in winter and summer since 2017 (Figure 7-3).

Table 7-3. The area of occupation (percentage of sites within the 43 km EOO where live shoots are present) for *R. tuberosa* during January (summer) and July (winter) monitoring periods between 2012 and 2023. Data source: Paton and Bailey (2014); (Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c).

Season	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Summer	11	50	65	78	44	89	89	78	94	89	89	94
Winter	27	64	100	100	100	100	100	100	100	100	100	100

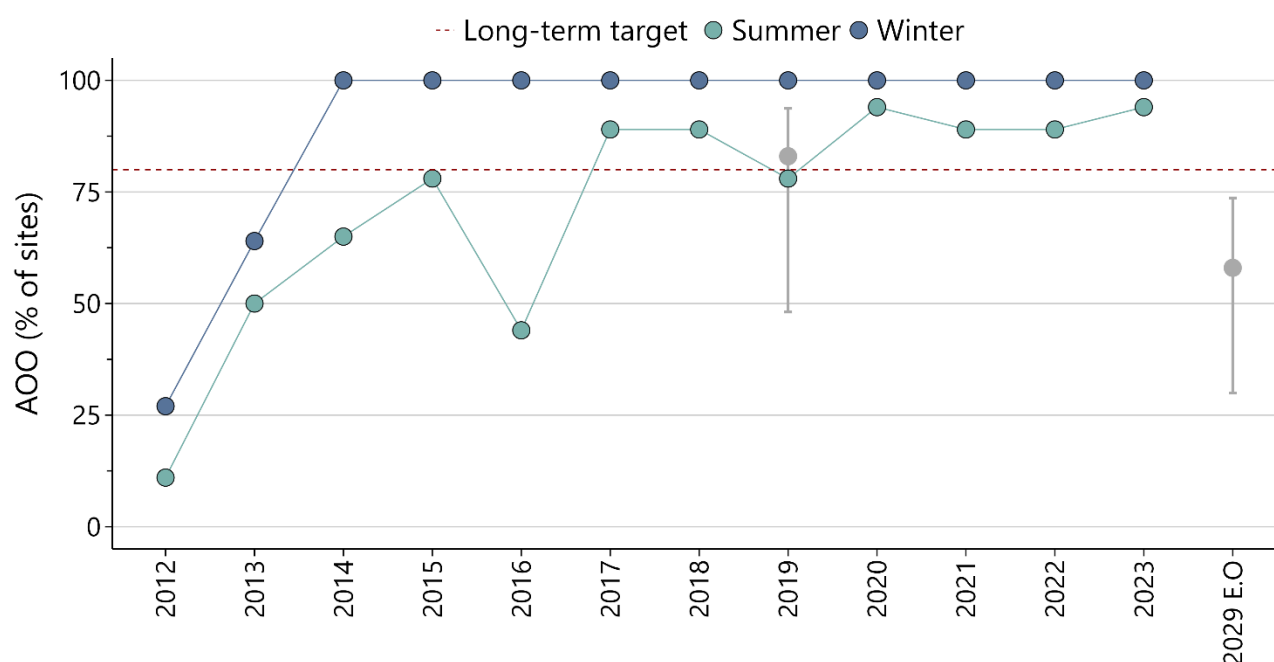


Figure 7-3. The area of occupation (percentage of sites within the 43 km EOO where live shoots are present) for *R. tuberosa* during January (summer) and July (winter) monitoring periods from 2012 to 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars. Data source: (Paton & Bailey 2014; Paton & Paton 2023b; Paton et al. 2016a; 2020; Paton et al. 2016c).

7.4.2 Trend: Area of occupation (AOO)

The probability of live *R. tuberosa* shoots being detected across sites on the eastern and western shorelines of the Coorong (within the 43 km sampling distribution) is virtually certain (100% probability) to have **improved** (Figure 7-4).

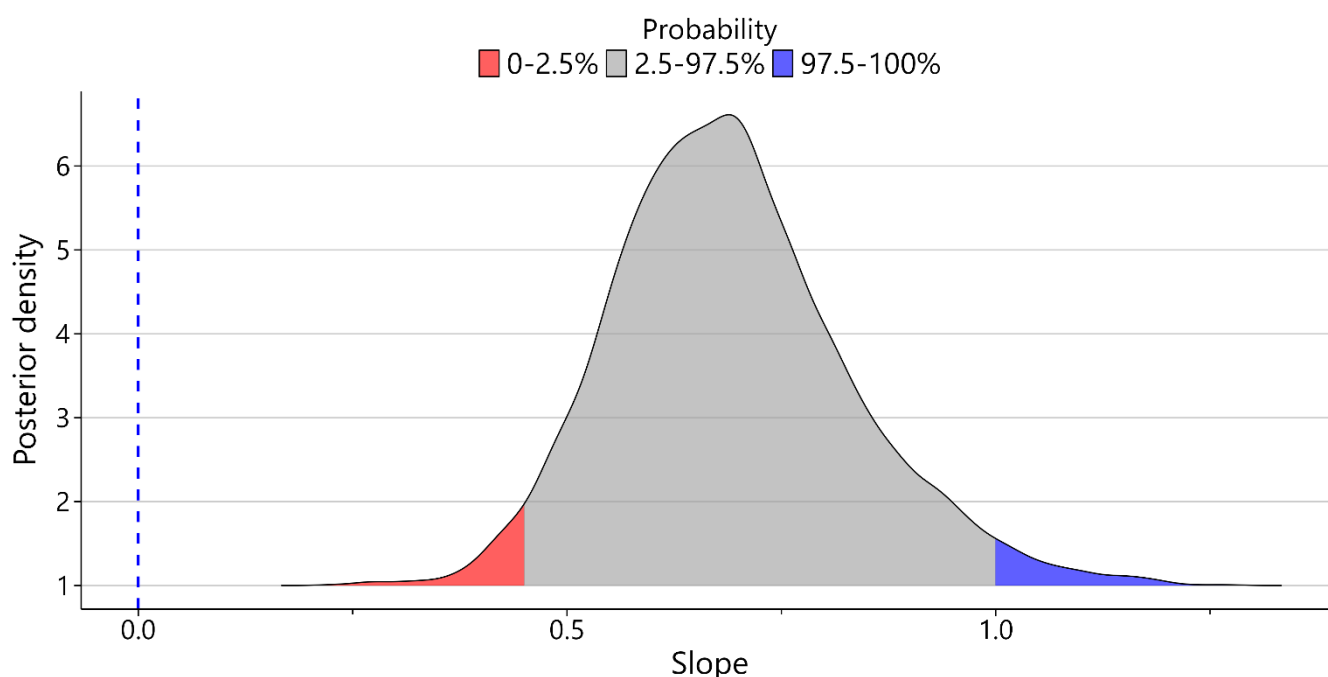


Figure 7-4. Estimated values for the slope from Bayesian modelling for the frequency of sites containing live *R. tuberosa* shoots over the 43 km EOO for both winter and summer between 2009 and 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

7.4.3 Extent of occurrence (EOO)

The EOO of the *R. tuberosa* in the southern Coorong increased substantially from 2012 to 2013, and has since reached its usual 43 km EOO in all summer and winter assessments, except for winter 2016 (Table 7-4; Figure 7-5). The 43 km EOO for *R. tuberosa* in the southern Coorong has been achieved in all winter and summer monitoring assessments since 2019. Therefore, there has been progression towards the achievement of the expected outcome for EOO since adoption of the Basin Plan.

Table 7-4. The extent of occurrence (EOO) for *R. tuberosa* in the southern Coorong during summer (January) and winter (July) monitoring periods between 2012 and 2023. Data source: (Paton & Bailey 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c).

Season	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Summer	1	53	60	53	43	43	43	43	53	53	60	49
Winter	8	45	60	43	41	43	43	56	56	60	43	43

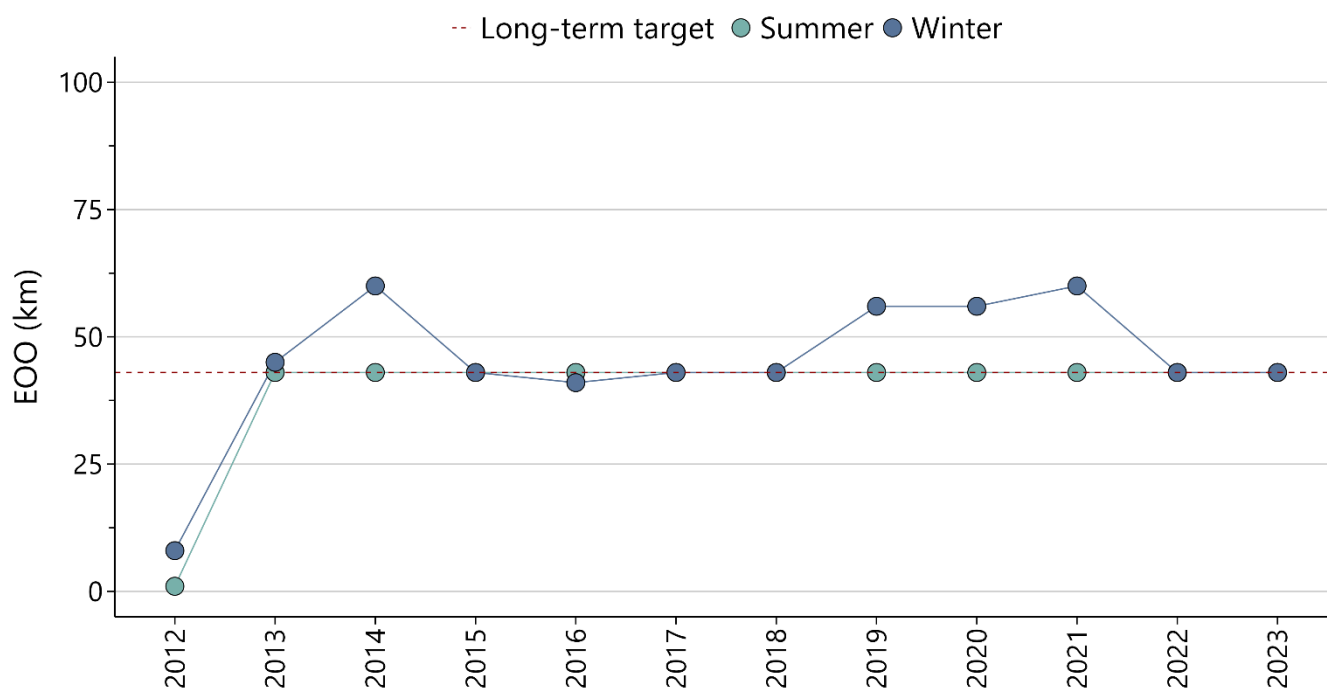


Figure 7-5. The extent of occurrence (EOO) of the *R. tuberosa* in the southern Coorong during summer (January) and winter (July) monitoring periods between 2012 and 2023. Data source: (Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016b; 2018b; 2020; Paton et al. 2016c).

7.4.4 Trend: extent of occurrence (EOO)

The probability of the *R. tuberosa* achieving the 43 km historic distribution in the southern Coorong between 2009 and 2023 was virtually certain (100% probability) to have **improved** (Figure 7-6).

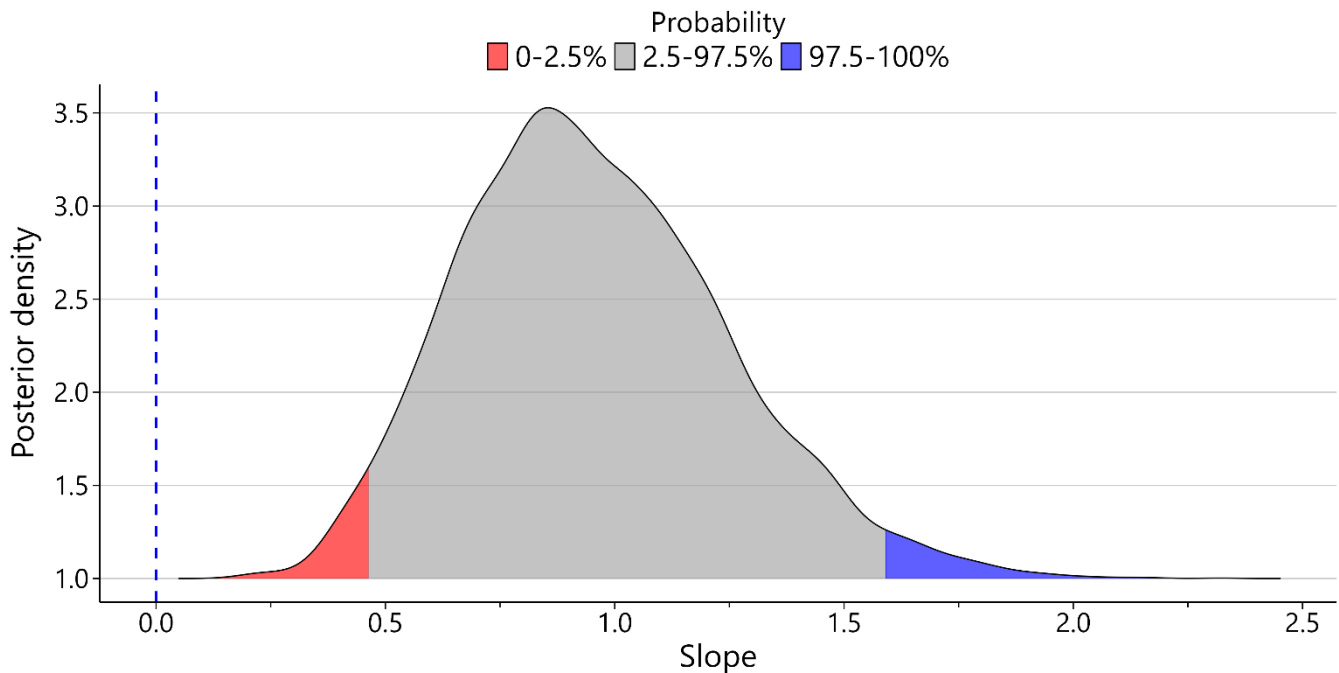


Figure 7-6. Estimated slope values from Bayesian modelling indicating the probability of *R. tuberosa* achieving the 43 km historic distribution in the southern Coorong between 2009 and 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

7.4.5 Outcome assessment: Long-term resilience (seed bank)

Seed bank densities of *R. tuberosa* over the southern Coorong fluctuated from 2007 to 2023 (Table 7-5; Figure 7-7). In 2007, seedbank densities were particularly low, largely in part due to low seed density (36 m^2) at site S06E, where seed densities are typically highest across sampling sites. Seed densities were maintained between $323 \pm 167 \text{ m}^2$ and $330 \pm 176 \text{ m}^2$ from 2008 to 2010, and subsequently reduced to $93 \pm 25 \text{ m}^2$ in 2012. From 2012 onwards, there has been a general increase in seed densities to $375 \pm 146 \text{ m}^2$ in 2023, although there has been annual variability over this time.

The 2019 assessment reported a mean seed density of $280 \pm 73 \text{ m}^2$ (across all sites in the southern Coorong), which was above the 2019 expected environmental outcome of 181 seeds m^2 . Since 2019, mean site seed densities decreased annually ($280.4 \pm 72.5 \text{ m}^2$) to 2022 ($228.6 \pm 48.7 \text{ m}^2$), until 2023 when mean site seed densities ($375 \pm 146 \text{ m}^2$) were the highest recorded for the period between 2007 and 2023. The changes observed in 2023 were mostly driven by the relatively high seed densities at site S06E ($2,604 \text{ m}^2$) and site S16E ($1,335 \text{ m}^2$) (Table 7-5).

While *R. tuberosa* seed bank densities in 2023 (238 m^2 ; 80 % CI 35–668 m^2) were higher than the expected density for 2029, seed banks are still considered to be low and lacking in resilience. The CLLMM LTWP specifies a target of $\geq 10,000$ seeds m^2 at 50% of sites to support a functioning and healthy system; far above what is currently being observed.

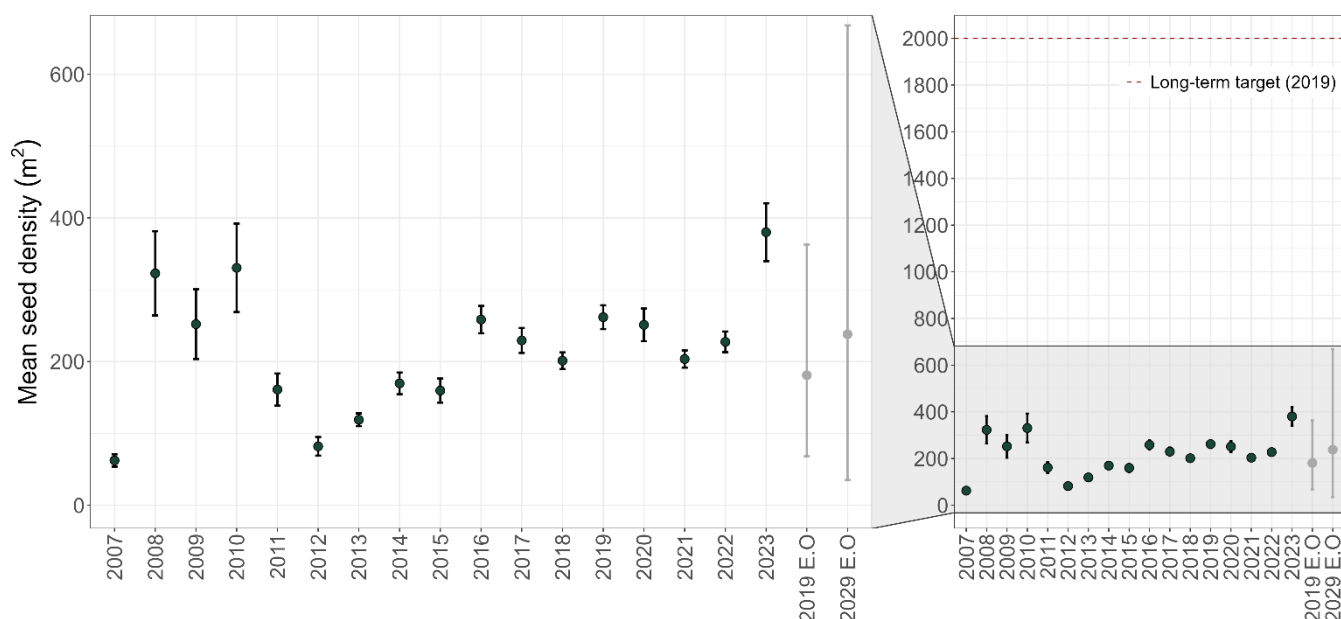


Figure 7-7. The estimated mean and standard error for summer seed density (seeds.m⁻²) of *R. tuberosa* in the Coorong between 2007 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.

Table 7-5. Mean summer *R. tuberosa* seed bank densities (m²) at sites (within the EOO) on the eastern and western shorelines of the Coorong between 2007 and 2023. Letter prefixes in site names denote site location in the either the North or South lagoons, numbers indicate distance (km) from Parnka point (the division between the North and South lagoons), and letter suffixes describe orientation in the Coorong. Overall mean and standard error are given below the individual site data. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.

Site	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
N02E	286	115	184	105	313	61	97	380	228	429	407	154	744	472	432	206	386
S06E	36	2368	1829	2492	786	256	136	233	357	1308	597	208	488	646	233	773	2604
S06W							90	357	481	720	1335	877	943	753	425	565	167
S11E	3	0	3	0	247	23	52	38	61	75	23	223	5	23	199	405	167
S11W							43	29	50	99	316	36	484	244	179	400	118
S16E	42	93	0	18	3	7	0	23	63	23	20	20	29	23	20	95	1335
S16W							102	29	61	127	226	355	353	203	197	142	551
S21E	30	172	33	21	12	16	5	118	104	41	97	104	70	513	108	136	262
S21W							113	61	59	380	139	147	70	497	77	165	262
S26E	60	12	105	105	27	304	262	389	172	621	346	409	339	181	588	527	127
S26W							129	23	7	81	36	20	41	145	29	90	90
S31E	0	3	3	0	0	0	20	9	0	2	5	79	5	7	43	38	0
S31W							203	172	497	7	9	233	27	113	226	138	90
S33E							622	895	404	777	651	630	970	407	503	279	
S36E	12	3	51	6	18	41	104	111	63	79	190	118	25	86	142	52	145
S36W							0	0	5	0	0	5	0	5	14	5	12
S41E	90	139	60	226	42	129	127	357	282	512	79	208	244	176	190	81	45
S41W							20	11	0	27	3	39	211	66	184	18	14
Mean	62.1	322.7	252	330.3	160.9	93	118.1	179.7	160.8	294.9	248.8	214.7	280.4	253.3	210.5	228.6	375
S.E.	19.2	166.5	128.6	176.1	56.6	24.5	32.2	50.9	38.1	81.9	75.7	51.3	72.5	52.4	38.1	48.7	146

7.4.6 Trend: Long-term resilience (seed bank)

The seed density of *R. tuberosa* in summer on both the eastern and western shorelines of the southern Coorong between 2007 and 2023 is virtually certain (100% probability) to have **improved** (Figure 7-8). The median for all estimated slope values was 0.09, (95% CI [0.03, 0.15]), indicating that seed densities have increased.

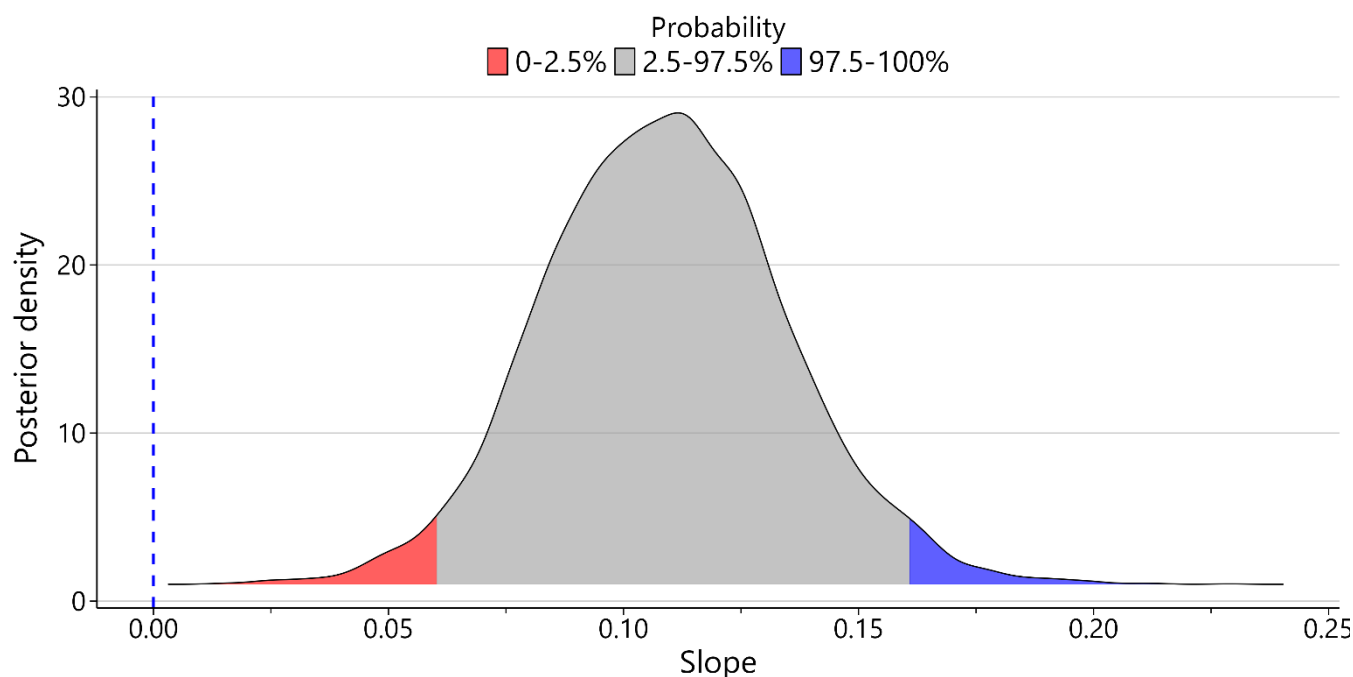


Figure 7-8. Estimated slope values from Bayesian modelling indicating the probability of trend in seed-bank density for *R. tuberosa* between summer (January) 2007 and 2023 in the southern Coorong. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

7.5 Information reliability

The information reliability rating for *R. tuberosa* sampling was excellent (final score of 12). Justification for the scoring of *R. tuberosa* information reliability is provided in Table 7–6.

Table 7–6. Reliability of TLM *Ruppia* data to assess outcomes for *R. tuberosa*. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Yes. The sampling method for <i>R. tuberosa</i> as presented in the Condition Monitoring Plan (DEWNR 2017) were used each year, at the same time of year.	2

Methods	Question	Answer and justification	Score
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Murray Mouth with equal effort?	Yes. A total of 12 winter and 18 summer sampling sites are evenly spread across the southern Coorong.	1
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. The assessment period for <i>R. tuberosa</i> spanned from 2012 to 2023 and therefore has included years of monitoring pre- and post-Basin Plan adoption years.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. All winter monitoring sites have been revisited annually over the assessment period (2012–2023). An additional 8 sites on the western side and one on the eastern side of the South Lagoon were added in 2013 to the 12 existing summer monitoring sites. All summer monitoring sites were revisited annually over the assessment period following establishment.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes. Sampling has been conducted biannually over the assessment period.	2
Final score			11
Information reliability			Very Good

7.6 Contextual and Supporting Information

7.6.1 *Ruppia tuberosa* abundance and reproduction

The overall, long-term trend of *R. tuberosa* shoot density has been variable but increasing since the Millennium Drought (Figure 7-9). Typically, considering the predominantly annual lifecycle of *R. tuberosa*, surveys for growth and biomass should be conducted during the period of active growth (~June–December, but variable depending on water levels), while seedbank surveys should be conducted following the end of the growth period (~January–May) (Lewis et al. 2022). Long-term data from TLM winter surveys indicates that total shoot counts (aggregated across all sites) have remained stable since 2019, although these are the highest observed since the end of the Millennium Drought (Figure 7-10), along with biomass still being present during summer surveys (Figure 7-9).

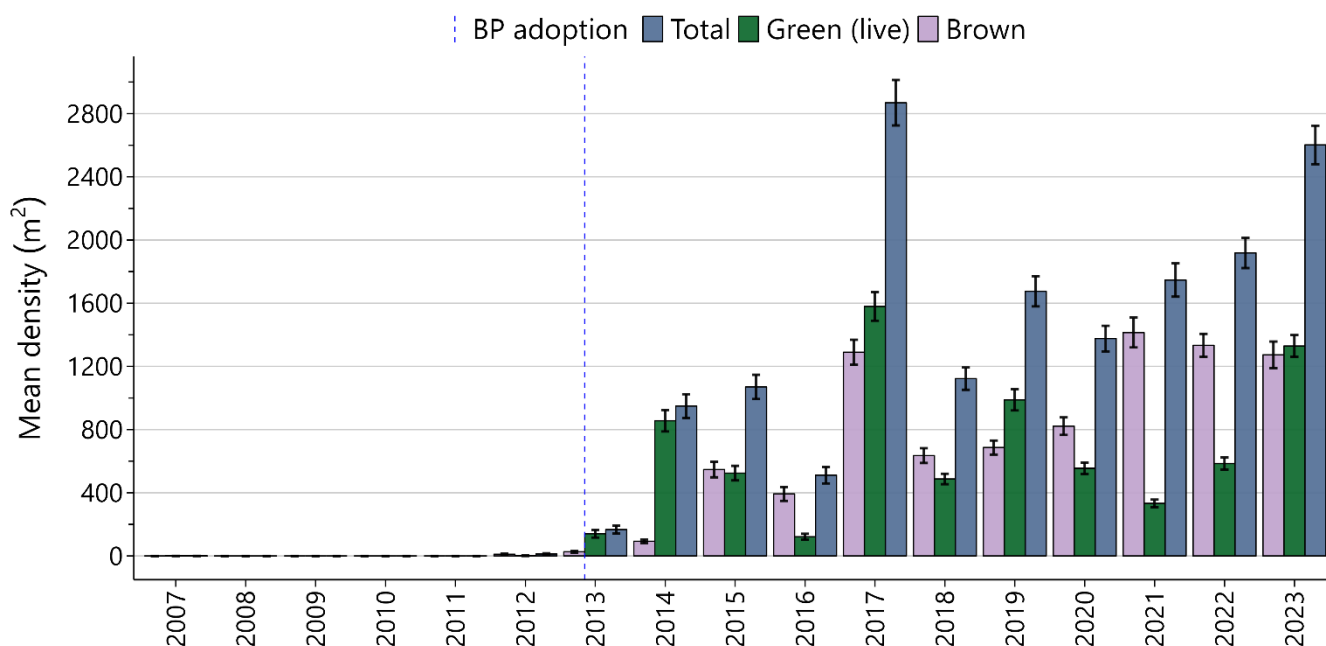


Figure 7-9. Mean shoot density $m^{-2} \pm$ standard error for summer (January sampling) aggregated across all monitoring sites. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.

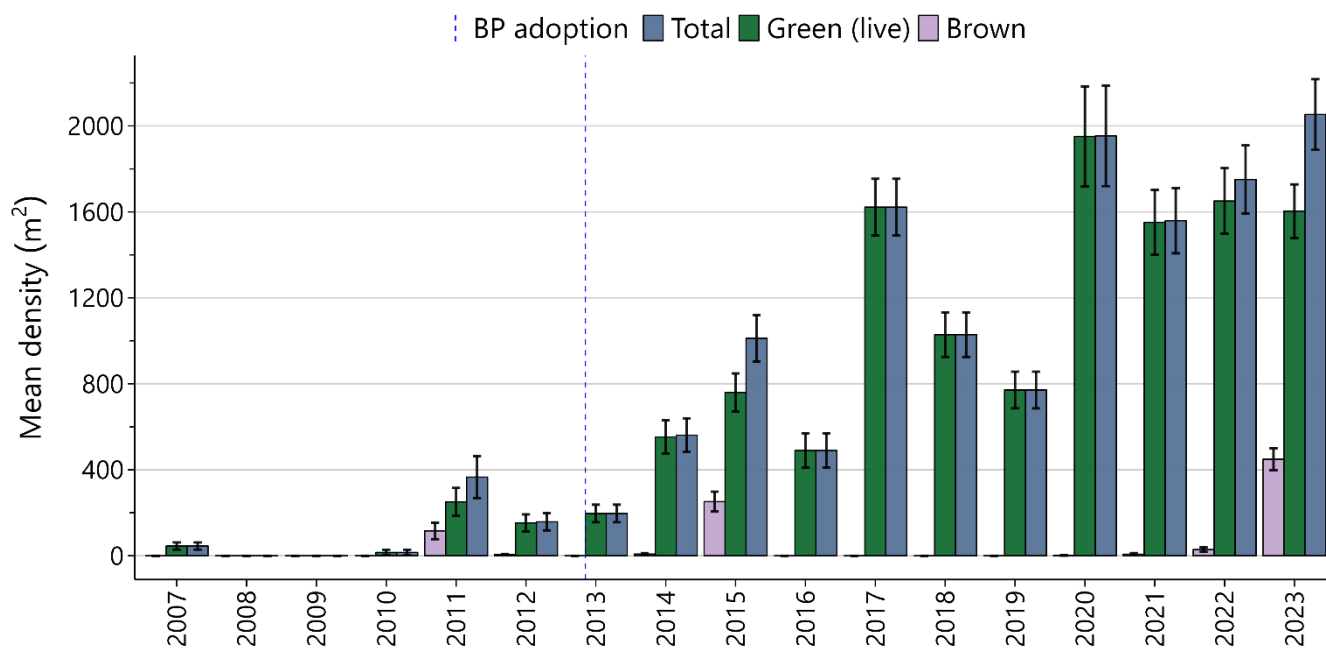


Figure 7-10. Mean Shoot density $m^{-2} \pm$ standard error for winter (July sampling) aggregated across all monitoring sites sampled in a given year. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.

Seed densities and viability remain a concern for *R. tuberosa* and the Ruppia Community overall (Lewis et al. 2022; Overton et al. 2006; Paton & Paton 2023a; Paton & Paton 2023b; Waycott & Lewis 2022; Waycott et al. 2022). The data from TLM, aggregated across sites and seasons (summer and winter surveys) indicate that seed and turion

densities are variable but somewhat stable since the Millennium Drought, with highest seed density being observed in 2023 (Figure 7-11).

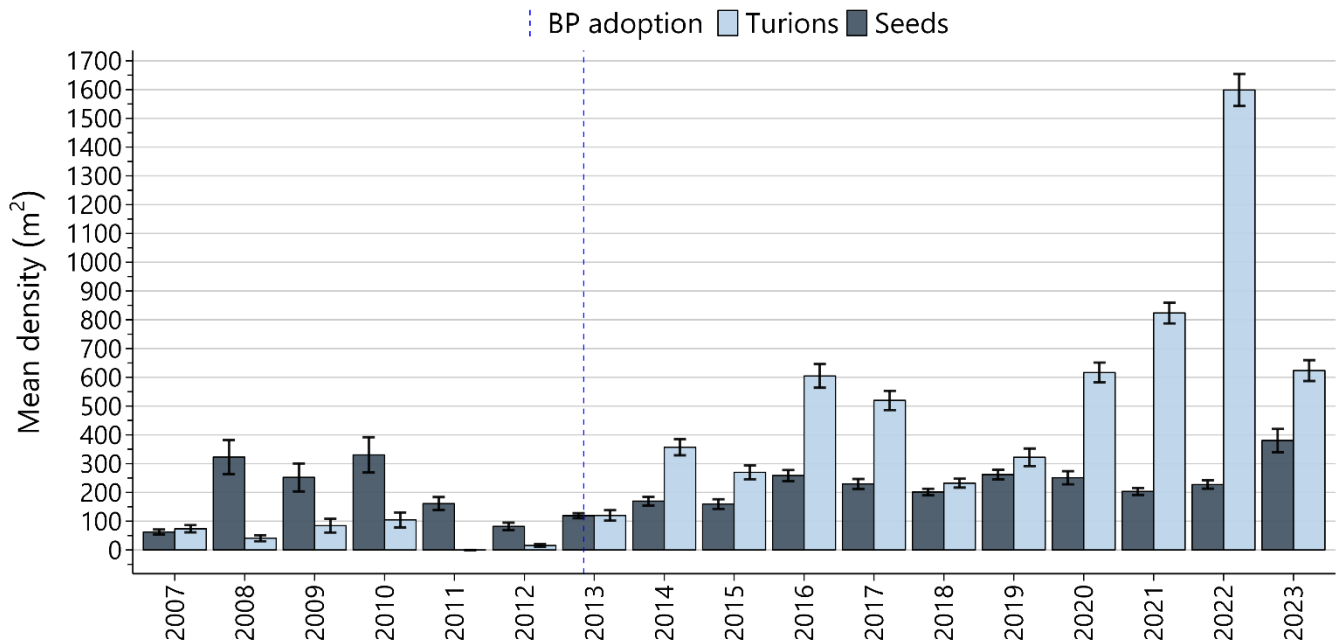


Figure 7-11. Seed density $\text{m}^{-2} \pm$ standard error for summer sampling aggregated across all monitoring sites. Data source: Paton & Bailey 2012; 2014; Paton & Paton 2023b; Paton et al. 2016a; b; 2018b; 2020; Paton et al. 2016c; Rogers & Paton 2009.

7.7 Evaluation

The aquatic macrophyte community is a critical component of the southern Coorong (Lewis et al. 2022; Paton 1986; Phillips & Muller 2006), and currently composed of predominantly *R. tuberosa*, *Althenia cylindrocarpa*, and at least one unknown species of *Ruppia* ('the Ruppia Community', Lewis et al. 2022). The widespread decline of this community during the Millennium Drought, especially during the period between 2007 and 2010 where there was no flow over the barrages, and its slow recovery since the Drought ended has contributed to a decline in food web complexity, further exacerbated by blooms of filamentous algae and phytoplankton over large areas (Brookes et al. 2018; Jamieson et al. 2022; Paton & Paton 2023b; Rogers & Paton 2009; Waycott & Lewis 2022; Waycott et al. 2022).

Waycott et al. (2022) and Lewis et al. (2022) also observed the charophyte, *Lamprothamnium papulosum*, growing from Coorong sediments under experimental, laboratory conditions, which forms part of the Ruppia Community if environmental conditions allow. *L. papulosum* has been previously observed sporadically in surveys and was observed growing in large quantities in several regions of the Coorong during 2022–23, likely due to lower salinity from the River Murray flood (Paton & Paton 2023b; Waycott et al. 2023).

The Ruppia Community in the southern Coorong requires adequate water levels in spring and into summer that enable annual plants to reproduce and complete their lifecycle (Lewis et al. 2022; Paton & Paton 2023b; Paton et al. 2020). Hyper-eutrophic conditions facilitate the growth of filamentous algal and phytoplankton blooms, which limits the growth and reproduction of the Ruppia Community (Collier et al. 2017; Lewis et al. 2022; Paton & Paton 2023b; Paton et al. 2015; Rogers & Paton 2009). Salinities during the height of the Millennium Drought were consistently above 120 g L^{-1} in the South Lagoon, which, combined with low water levels, contributed to the loss of *R. tuberosa* in the southern Coorong, as the germination of seeds and growth of seedlings were impeded (Paton and Bailey 2012; Kim et al. 2013).

The high (unregulated) flow event in 2010–11 increased water levels in the Coorong and restored salinities to those more typical for the system (Paton & Bailey 2012). Following the return of barrage outflows to the system, the extent of *R. tuberosa* recovered to its re-established in the southern Coorong and re-occupied its former usual distribution by January 2013 but it took a further four years before populations of *R. tuberosa* reached an AOO of at least 80%.

Surveys of Ruppia Community distribution, community composition and diversity during the HCHB program and comparing to historical data, have shown that the Ruppia Community which declined significantly during the Millennium Drought has recovered to its pre-drought extent of its distribution but not its pre-drought condition (Lewis et al. 2022). The southern Coorong ecosystem remains hypersaline and at times extremely hypersaline with salinities over 100 g L⁻¹; and has recently been classified as hyper-eutrophic (Mosley and Hipsey 2019, Mosley et al. 2020). In this hyper-eutrophic state, the Coorong exhibits very high nutrient loads, characterised by frequent and severe algal blooms, a shift towards rapid turnover biota rather than slow turnover such as that by the Ruppia Community. However, the delivery of water for the environment, as well as unregulated (high) flows, has helped to limit the spatial and temporal extents of unsuitable salinities for germination of *R. tuberosa* in the southern Coorong.

7.7.1 Factors and summary of influence

Water level

Water levels in the Coorong are critical for the maintenance of the Ruppia Community, particularly ensuring that water levels remain above 0.3 m AHD through spring and into summer, allowing the community (particularly *R. tuberosa*) to complete their reproductive cycle (Collier et al. 2017; Gibbs et al. 2019; Lewis et al. 2022; Waycott et al. 2022).

Since Basin Plan adoption, water levels greater than 0.3 m AHD into summer have been recorded in 2016–17, 2019–20, 2020–21, 2021–22 and 2022–23 (Lewis et al. 2022; Paton & Paton 2023b), however this is likely due to climatic conditions and unregulated flows, particularly in 2022–23 due to the River Murray flood (Paton & Paton 2023b).

Since 2021, although water levels in the Coorong have remained relatively high (i.e. above 0 m AHD), seed density has been low and *R. tuberosa* has appeared to favour asexual production (via turion production) over sexual reproduction (i.e. through flowering and seed production) (Lewis et al. 2022; Paton & Paton 2023b; Paton et al. 2020; Paton 1982; Waycott et al. 2022).

Widescale Ruppia Community surveys conducted as part of the HCHB Trials and Investigations project found that a majority of aquatic plant biomass occurs between -0.4 and 0.4 m AHD within the southern Coorong, however the Ruppia Community was also found as low/deep as -0.8 m AHD (Figure 7-12) (Lewis et al. 2022; Waycott et al. 2022). These populations in deeper water are likely dependent on water quality allowing light penetration for photosynthesis, which could be influenced by increased connectivity and inflows into the southern Coorong (Lewis et al. 2022; Waycott et al. 2022).

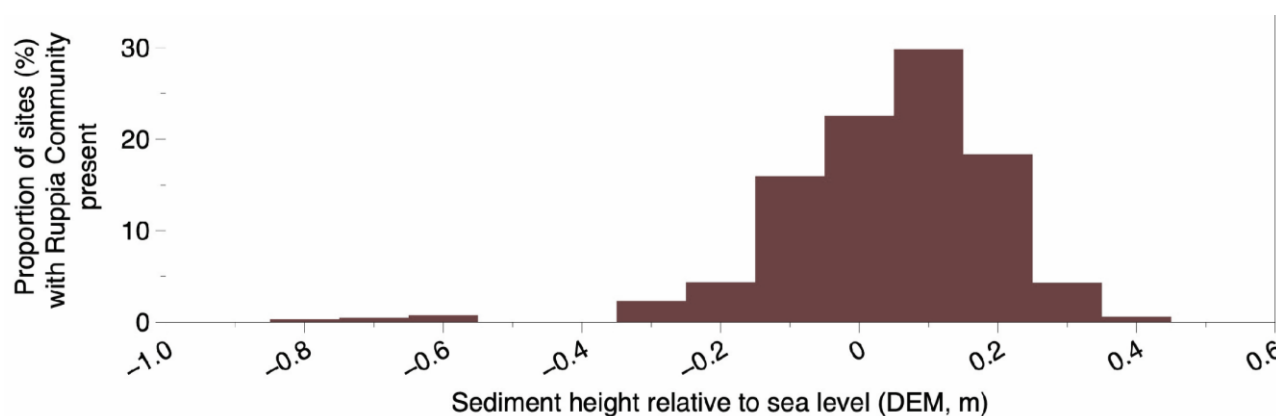


Figure 7-12. The proportion of sites with the Ruppia Community present across elevation gradient in the 2021 growth season (during HCHB Trials & Investigations Project) measured in m AHD calculated from Hobbs et al. (2019); figure derived from Waycott et al. (2022).

Ensuring that water levels are maintained within the Coorong in spring and early summer to allow the populations growing at higher elevations to complete their lifecycle (flowering and seed set), is important for the resilience and condition of the Ruppia Community.

Salinity

While the Ruppia Community can tolerate a wide salinity range, salinity in the southern Coorong can influence how the plants grow and complete their lifecycle (Collier et al. 2017). The Ruppia Community generally germinates and grows between April and June and flowering occurs between August and December before senescence and/or water levels recede (Collier et al. 2017; Lewis et al. 2022; Waycott et al. 2022).

The Coorong Dynamics Model (CDM) Generation 2, Ruppia Habitat Suitability Index developed by Hipsey et al. (2022b), used existing long-term data to develop an Ruppia Habitat Suitability Index (HSI), which indicates optimal Ruppia Community habitat conditions for salinity, water depth, temperature, light and algal biomass. Optimal salinity for seed germination is thought to be 0.1–40 g L⁻¹, while turion sprouting has a wider range, of between 20 and 75 g L⁻¹ (Hipsey et al. 2022a; Hipsey et al. 2022b; Waycott et al. 2022). For plant growth, the Ruppia Community has a wide tolerance range, where optimal is between 19 and 124 g L⁻¹. However, for flower production and seed set, the range narrows to between 47–62 (Hipsey et al. 2022a; Hipsey et al. 2022b; Waycott et al. 2022), although in 2022–23, South Lagoon salinities were within this range and limited flowering success was observed, likely due to other factors aside from salinity (Paton & Paton 2023b; Waycott et al. 2023). While optimal salinity for turion production is thought to be higher, i.e. between 70 and 160 g L⁻¹, during the 2022–23 season salinity was below 60 g L⁻¹ for the majority of the time yet large numbers of turions were produced across the southern Coorong (Paton & Paton 2023b; Waycott et al. 2023). Figure 7-13 and Figure 7-14 highlight the broad salinity tolerance of the Ruppia Community, but also indicate the need for provision of water late in the season to keep water depths suitable for Ruppia Community survival but also to ensure that salinity is kept sufficiently low for successful flowering and seed set to occur (Figure 7-12) (Lewis et al. 2022; Paton & Paton 2023b; Waycott et al. 2022; Waycott et al. 2023). Figure 7-13 shows optimal and sub-optimal salinities for different times in the *R. tuberosa*/Ruppia Community life cycle.

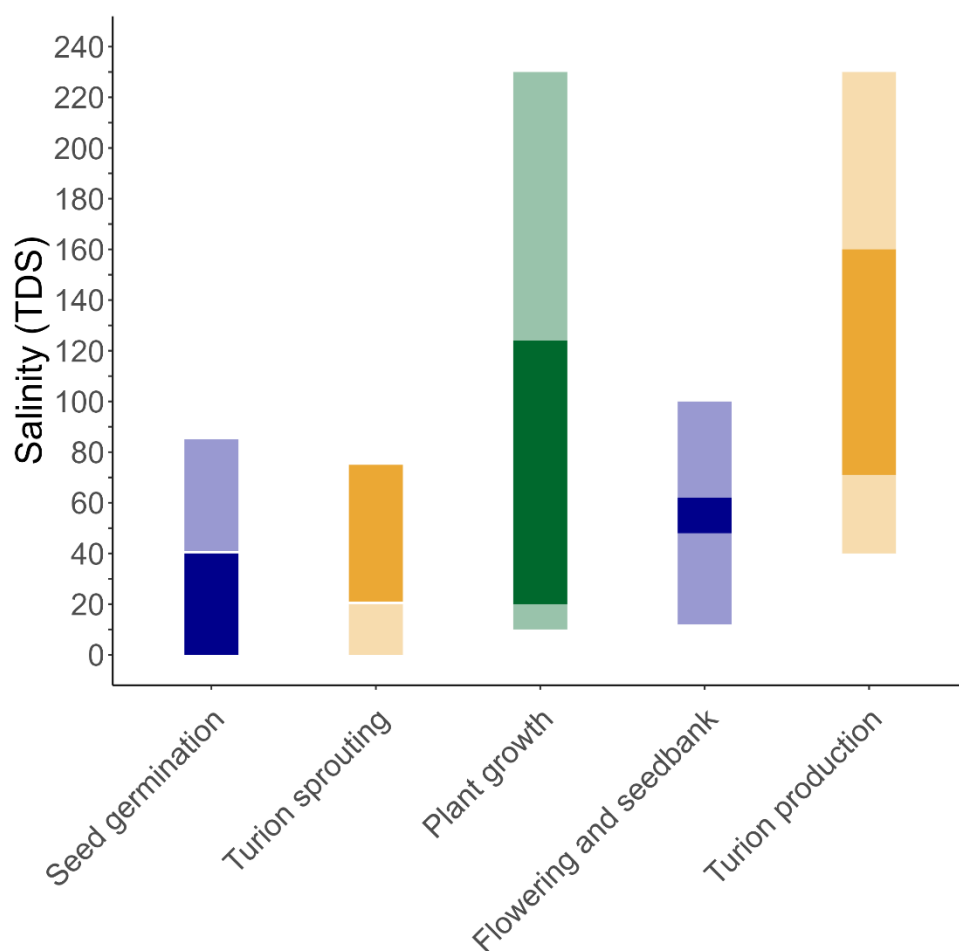


Figure 7-13. Summary of optimal (darker shades) and sub-optimal (lighter shades) salinity ranges for different stages of the *R. tuberosa* life cycle, with conditions separated for sexual reproduction shown in blue, asexual reproduction shown in orange and vegetative growth in green. Unsuitable conditions are not included in this figure (Coorong Dynamics Model, Ruppia Habitat Suitability Index, Gen 2, Hipsey et al. 2022a).

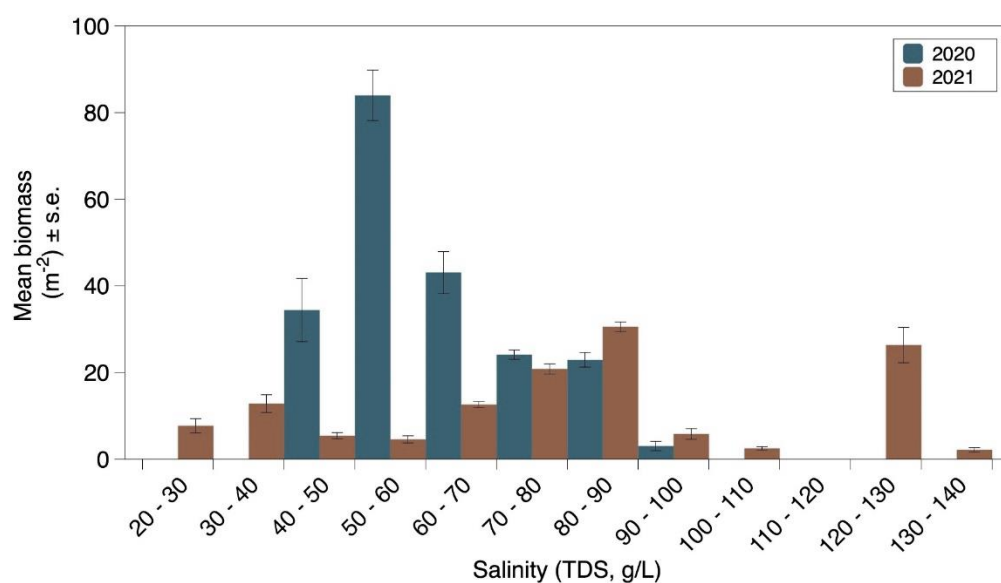


Figure 7-14. Ruppia Community total biomass across salinities derived from Lewis et al. (2022).

Salinity has further indirect impacts on *R. tuberosa* by supporting the growth and abundance of phytoplankton and filamentous green algal mats; specifically, higher salinities can limit algal growth. Collier et al. (2017) and Waycott et al. (2022) found that the growth rate of filamentous algae declined above 60 g L⁻¹ and was negative above 80 g L⁻¹ (Figure 7-15).

Blooms of filamentous algae reduce light and smother *R. tuberosa* flowers and fruit leading to reduced sexual reproductive success in the Ruppia Community and severely impacted growth and survival (Brookes et al. 2018; Collier et al. 2017; Paton & Bailey 2010; Paton & Paton 2023b; Waycott et al. 2022). To manage filamentous algae blooms during flowering and seed set of the Ruppia Community, salinities would have to remain above 60–80 g L⁻¹ (Figure 7-15). However, this range is also above the optimal range for seed germination, flowering and seed production suggested by Hipsey et al. (2022a; 2022b) (Figure 7-13). Therefore, provision of water to the southern Coorong between August and December needs to be carefully balanced to manage salinity (Lewis et al. 2022; Waycott & Lewis 2022; Waycott et al. 2022).

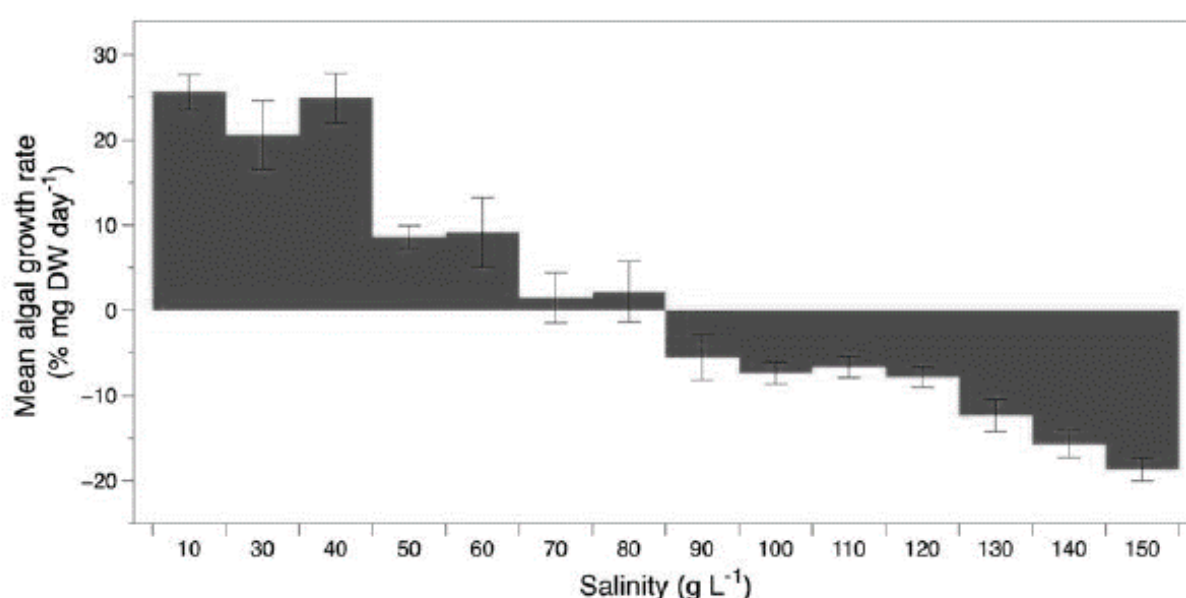


Figure 7-15. Mean growth rate of algal biomass extracted from the southern Coorong under laboratory condition vs salinity derived from Waycott et al. (2022).

7.7.2 Complementary actions

Translocation success

Following the Millennium Drought and recognising the decline in the Ruppia Community, a project was undertaken to translocate seed-laden sediment from Lake Cantara (~15 km southeast of the Coorong) to strategic locations in the Coorong South Lagoon (DEWNR 2014; Sinclair et al. 2021).

Following the translocation works, limited long-term monitoring or evaluation of the success of the project was undertaken (Waycott & Lewis 2022). McCarron (2013) looked at the outcomes of the translocation short-term, however following this, no ongoing monitoring or collection of data was undertaken. Based on the first two seasons following the translocation works, the efforts were successful and resulted in good germination and modest recruitment (McCarron 2013; Paton et al. 2018a).

During the HCHB Phase 1 Trials and Investigations Project 2020–22, Waycott and Lewis (2022) undertook targeted surveys to evaluate the long-term outcomes of the translocation efforts, aiming to determine whether they led to 'significant improvement in the resilience and condition of the Ruppia Community'. This was done by comparing sites where translocation occurred to similar 'control' sites in proximity where no translocation had occurred (Waycott & Lewis 2022).

Overall, the investigations by Waycott and Lewis (2022) indicated that nearly 10 years later, the translocation efforts have had a positive effect on the condition of the Ruppia Community, as measured by biomass. Resilience as measured by seed and turion counts was mixed due to a change in reproductive strategies during the study; it appeared the plants switched from sexual (seeds) reproduction in 2020–21 to asexual (turions) in 2021–22. However overall, the translocation had a localised, positive effect on the resilience of the Ruppia Community (Figure 7-16a) (Waycott & Lewis 2022).

The study by Waycott and Lewis (2022) also investigated the effect of seed-laden sediment removal from Lake Cantara for translocation, using a similar, control vs treatment methodology. The 'donor' site at Lake Cantara showed a 22% reduction in biomass at the 'donor' site, compared to the nearby control and a reduced seedbank, indicating that after almost 10 years, the site was still impacted by the removal of sediment (Figure 7-16) (Waycott & Lewis 2022).

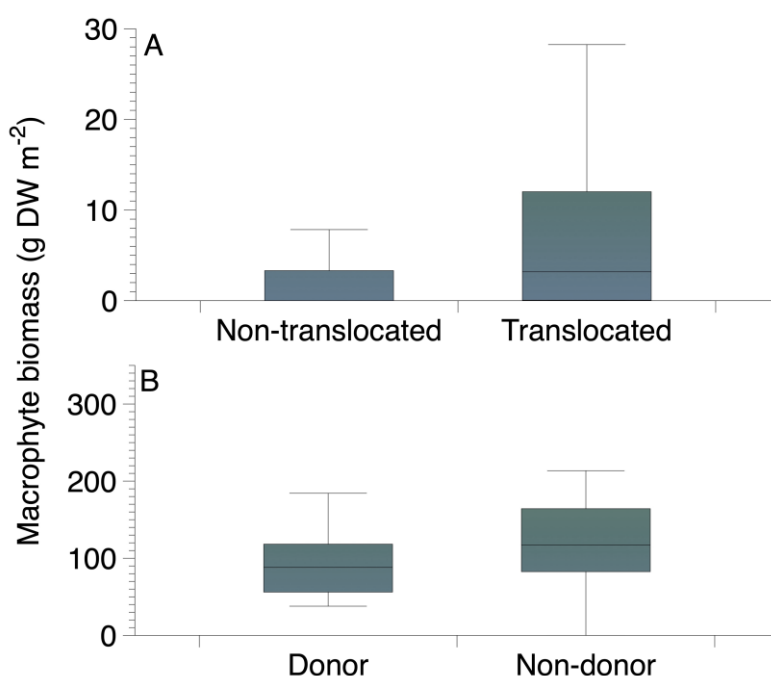


Figure 7-16. Ruppia Community biomass at; a) non-translocated 'control' vs translocated sites in the southern Coorong and, b) donor vs non-donor 'control' sites in Lake Cantara (Waycott & Lewis 2022).

Waycott and Lewis (2022) recommended that if translocation efforts were to be repeated in future, translocation sites should meet the habitat requirements for the Ruppia Community as detailed in Lewis et al. (2022) and consider:

- Sediment condition
- Expected algal biomass
- Existing Ruppia Community biomass
- Timing of translocation in relation to seasonal plant lifecycle.

Along with these requirements, water levels and salinities should be considered when undertaking translocation activities, and where possible, ensure that conditions are optimal for the Ruppia Community to establish and reproduce.

Impacts of sediment condition on Ruppia Community biomass

Sediment condition in the southern Coorong is thought to have declined over time and been exacerbated by the Millennium Drought. Lewis et al. (2022) and Waycott et al. (2022) used a Rapid Assessment Protocol (RAP, Hallett et al. 2019) to evaluate current sediment condition in the southern Coorong. This method allowed field researchers to quickly assign a sediment condition value to a sample while in the field and assesses the texture, colour and odour of the sediment; scores from these three categories are tallied to give an overall sediment condition score.

While the results were not significantly different, based on the data collected from 2021, biomass of the Ruppia Community increased with improved sediment condition, as assessed by RAP (Figure 7-17). This suggests that remediating sediments within the southern Coorong could lead to an increase in Ruppia Community biomass. Conversely, the presence of the Ruppia Community likely leads to an improvement in sediment quality (Lewis et al. 2022; Waycott et al. 2022).

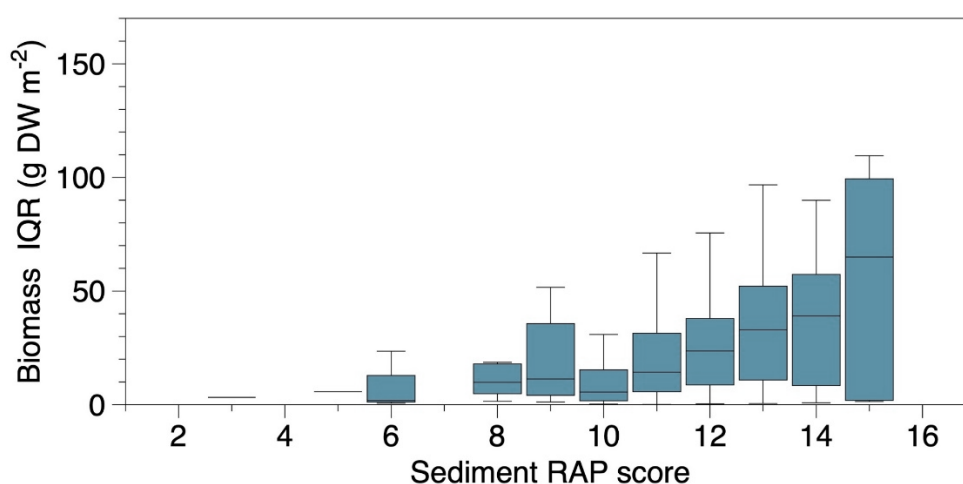


Figure 7-17. Overall Rapid Assessment Protocol Sediment Condition Scores from 2021 *Healthy Coorong*, *Healthy Basin* (HCHB) Phase 1 Trials and Investigations Project Ruppia Community sampling.

It was also found that the presence of macroinvertebrates in Coorong sediments had remediating values which could oxygenate and improve sediment condition (Huang et al. 2022; Lam-Gordillo et al. 2022a; Lam-Gordillo et al. 2022b; Mosley et al. 2022; Waycott et al. 2022). Additional water for the environment would assist remediation of sediments through increased connectivity and flow to the Coorong, with the aim of managing nutrient loads and salinity.

7.7.3 Unanticipated outcomes

Conditions within the Coorong can be unpredictable and are heavily influenced by environmental and climatic conditions, such as inflows (marine and freshwater), wind, temperature, rainfall and evaporation.

The period of 2021–23 saw relatively high flow conditions with 26 months of unregulated flows through the barrages. This influenced water levels and salinity in the Coorong, leading to lower salinities and water levels remaining high into summer in 2021, 2022 and the River Murray flood in early 2023.

Reduced salinities and increased freshwater flows saw a change in the composition of the Ruppia Community. Species such as the *Lamprothamnium papulosum* and other aquatic macrophytes, which had historically been observed in the Coorong, were again present in the North and South Lagoons (Paton & Paton 2023b; Waycott et

al. 2023). These species likely require lower salinities than is currently typical in the Coorong to persist (Brock 1982a; b).

While seed density has somewhat increased, the resilience and viability of *R. tuberosa* seeds remains a knowledge gap. The outer case of some seeds observed appeared to be softer and easily damaged when pressure applied. This could suggest that the seeds are not fully developed, less resilient or possibly unviable, however whether these seeds are capable of germinating has not yet been investigated (Collier et al. 2017; Lewis et al. 2022; Waycott et al. 2022; Waycott et al. 2023).

Waycott and Lewis (2022) found that although the *Ruppia* translocations following the Millennium Drought had a positive, localised influence on the *Ruppia* Community in the southern Coorong, the sediment donor site at Lake Cantara had less biomass and seedbank than comparable undisturbed areas.

7.8 Actions to achieve environmental outcomes

To further improve the health of the *Ruppia* community in the Coorong and enhance its resilience, the following actions are required:

- Maintain favourable water levels between September and January to keep water depths suitable for the survival of *Ruppia* and ensure salinity is adequate for successful reproduction
- Maintain water levels in the Coorong South Lagoon above +0.3 m AHD in spring and then into summer to support growth and reproduction of *Ruppia*
- Ensure variable salinity conditions while remaining within the ranges required to support *Ruppia* reproduction
- Strategically deliver water at the tail end of high flow events to extend more favourable conditions in the southern Coorong, supporting *Ruppia* growth and reproduction.

Full implementation of the Basin Plan, including recovery and delivery of the 450 GL of additional water for the environment and addressing current water delivery constraints is essential to provide sufficient water volumes to support *Ruppia*, particularly during early spring and into summer.

While outside of current management influence, more frequent high (unregulated) flow events are crucial for improving the health of the *Ruppia* community in the southern Coorong. The *Healthy Coorong, Healthy Basin* program is also seeking to implement a range of restoration actions aimed at recovering ecological function and resilience in the Coorong. These include fostering extensive and resilient aquatic plant communities and reducing or removing filamentous algae.

7.9 Conclusion

The *Ruppia* Community has somewhat recovered, currently exceeding pre-drought distribution and abundance, however concerns around the resilience of the community remain, with seed densities well below target density, as well as potentially low viability. Further investigations are required into the viability of seeds which are currently found in the system and the resilience of *R. tuberosa* relying on high levels of vegetative reproduction (turions), if drought conditions and low-water levels were to return to the southern Coorong. The implementation of the Basin Plan has protected flows to the South Australian River Murray and Coorong. Water for the environment has contributed to keeping water levels in the southern Coorong higher in spring and into summer, which has had a positive influence on the abundance and distribution of the *Ruppia* Community.

8 Case study: Nutrient dynamics and problematic algal blooms in the southern Coorong

Nutrients enter the Coorong from water that flows into the system from multiple sources, including the River Murray and Southern Ocean. These nutrients are held and cycled in the Coorong through interactions between water, sediment, microbes, plants and animals.

Over the last few decades, high nutrient levels and unhealthy cycling processes have resulted in a persistently hyper-eutrophic (high nutrients and organic matter/algae) state across a majority of the Coorong (Mosley et al. 2023). Eutrophic and hypersaline conditions generally increase southward with distance from the Murray Mouth (Mosley et al. 2023). Nitrogen and phosphorus are concentrated in surface sediments, with up to 50 times more nutrients in the top 5 cm of sediment, compared to the whole water column (Priestley et al. 2022a; Priestley et al. 2022b).

Nutrients remain trapped within the Coorong's South Lagoon when there is insufficient 'flushing' of water and nutrients out to the North Lagoon and ocean via the Murray Mouth. Narrow constrictions and expansive shallow areas (particularly in spring-summer when evaporation is high) reduce connectivity and water flow between the North and South lagoons. Excess nutrients accumulate and promote the growth of phytoplankton and filamentous algae during spring and summer (Brookes et al. 2018; Mosley et al. 2023; Mosley et al. 2020; Priestley et al. 2022b; Figure 8-1). Filamentous algae can also form widespread mats that interfere with the ability of the aquatic plant community (the *Ruppia* Community dominated by *Ruppia tuberosa*) to grow and produce seed and impede waterbird foraging.

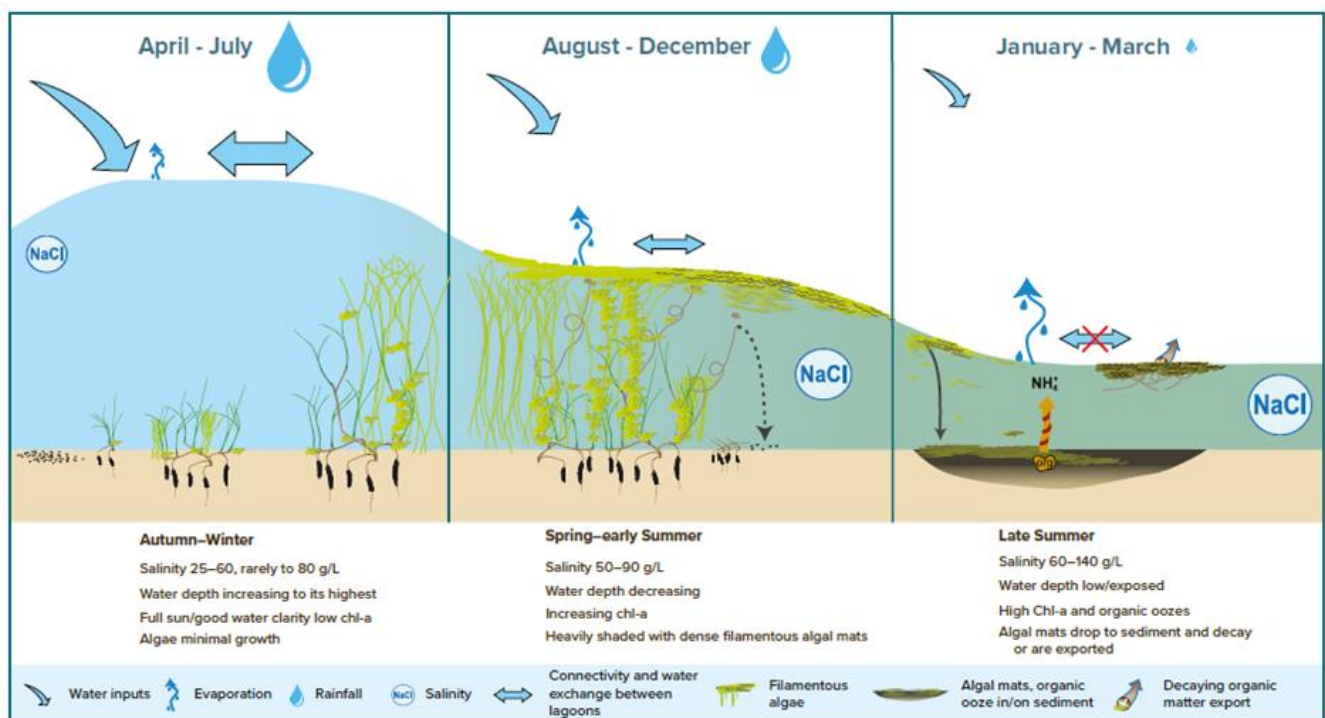


Figure 8-1. Typical seasonal water conditions, aquatic plant growth and filamentous algae lifecycle in the southern Coorong.

After first forming in the water column, phytoplankton and filamentous algal later break down on the sediment surface, increasing sediment nutrient and organic carbon loads. Organic matter is then decomposed by bacteria that consume oxygen and create anoxic (no oxygen) sediments. These oxygen-poor, sulfide-rich sediments of the southern Coorong have impaired healthy nutrient cycling and led to an accumulation of nitrogen and phosphorus in the sediments and water column (Huang et al. 2022; Mosley et al. 2020). Cumulatively, these processes and conditions have led to the formation and build-up of black, organic and sulfide-rich sediments called 'monosulfidic black ooze', which are toxic to macroinvertebrates and aquatic plants. Monosulfidic black ooze's have been observed to be the dominant sediment type throughout much of the South Lagoon and southern region of the North Lagoon (Mosley et al. 2022a; Mosley et al. 2022b). Large burrowing and bioturbating macrofauna (e.g. worms, cockles), that promote healthy nutrient cycling and break down of organic matter and black oozes, are largely absent from the South Lagoon due to persistent hypersalinity (Lam-Gordillo et al. 2022b).

8.1 Sources of nutrients

Import and export of nutrients in the Coorong is strongly influenced by hydrology, with areas flushed by River Murray inflows and tidal exchange, generally exporting nutrients and areas of hydrological restriction, such as the South Lagoon, importing and retaining nutrients (Priestley et al. 2022a; Priestley et al. 2022b; Figure 8-2). Nutrients were continuously imported into the South Lagoon for the past decade, except under periods of high barrage flows (2016–17 and 2022–23) (Priestley et al. 2022a).

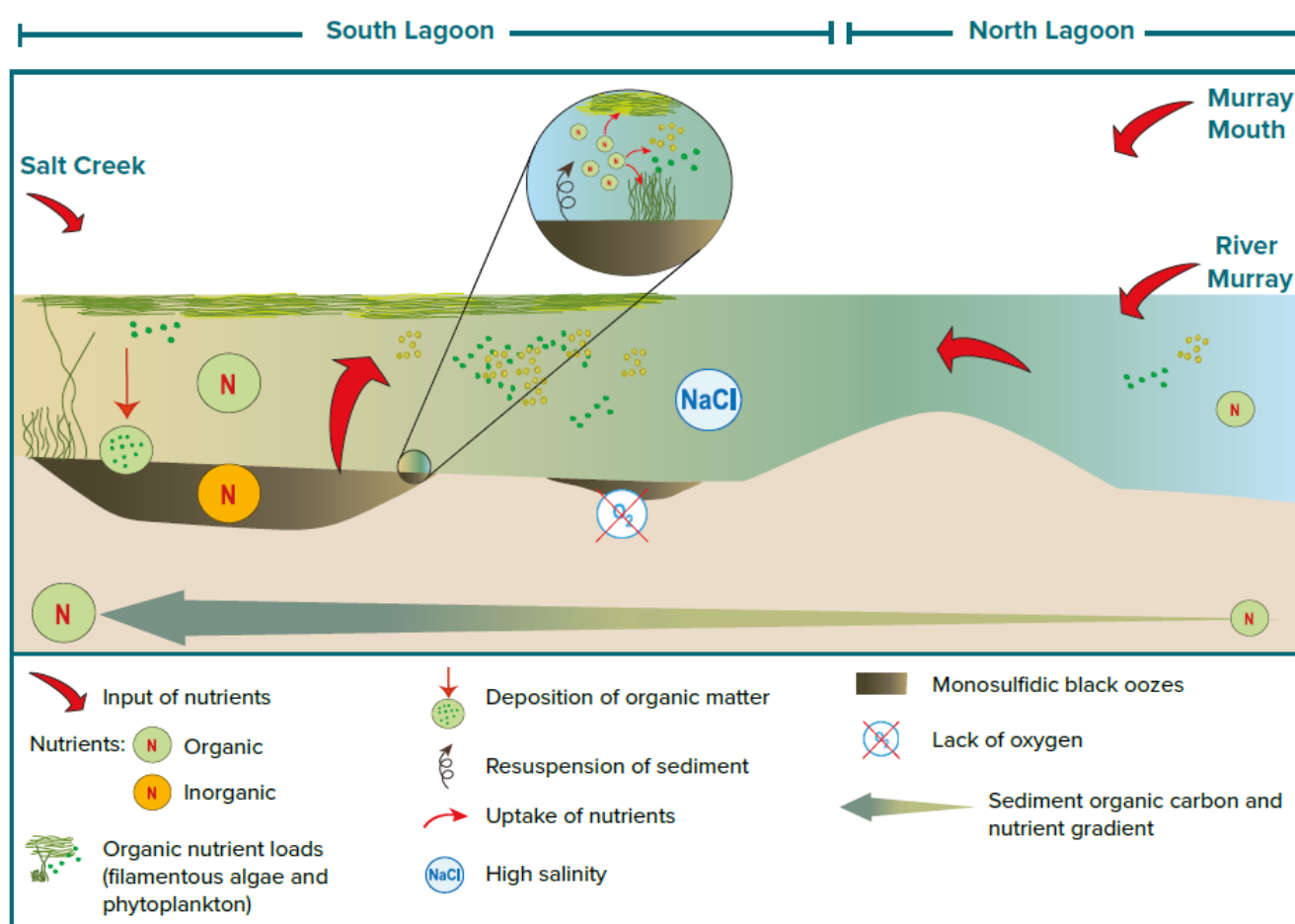


Figure 8-2. Nutrient sources and cycling in the southern Coorong.

The release of nutrients from the sediment into the water column is likely to continue, even under high flushing scenarios, due to long-term accumulation (Priestley et al. 2022a). Reducing the occurrence of high levels of filamentous algae and phytoplankton biomass is critical for a healthy ecosystem, which would in turn, assist with reducing nutrient loads in the southern Coorong (Lewis et al. 2022). Restoring the South Lagoon to a mesotrophic (moderate nutrient) state requires an integrated management approach, but is critical for the recovery of ecological functions, including healthy nutrient cycling (Huang et al. 2022).

To improve the condition of the southern Coorong, the following are required:

- Nutrient loads need to be significantly reduced, system wide.
- More frequent high flows from the River Murray are required to improve lagoon flushing and connectivity, diluting and exporting salt and nutrients, and helping to reinstate healthy nutrient cycling.
- Enhanced lagoonal flushing will also reduce organic matter (e.g. from decaying algae), deposition of organic matter to the sediment, and promote healthy, oxygenated sediments.
- Reduced salinity (<60 g/L) and nutrient concentrations in the South Lagoon will promote aquatic plant and macroinvertebrate recolonisation and reinstate the critical functions they play to improve sediment and water quality conditions. Specifically, the *Ruppia* Community and burrowing macroinvertebrates help to oxygenate sediments, which in turn improves nutrient cycling and sediment condition (Huang et al. 2022; Lam-Gordillo et al. 2022a; Lam-Gordillo et al. 2022b; Lewis et al. 2022). Persistent hypersalinity impacts the abundance and condition of the *Ruppia* Community and burrowing macroinvertebrates, restricting their ability to improve sediment condition (Lam-Gordillo et al. 2022b).
- Improved water movement in shallow littoral zone (i.e. via flows and flushing effects) would assist in preventing filamentous algae from forming mats.
- Monitoring microalgal communities for changes in community composition can provide early warning evidence of functional changes in sediments.
- Other potential management options to enhance seawater exchange with the South Lagoon could also be beneficial to help achieve these objectives, particularly during periods of low River Murray flows.

8.2 Effects of the 2022–23 River Murray flood on water quality in the Coorong

High rainfall during 2022 and near-capacity storages led to flooding in many parts of the MDB and very high flows via the barrages to the Murray Mouth and Coorong in late 2022 to early 2023. This flood was the largest since 1956 and provided a rare opportunity to evaluate water quality outcomes for the Coorong.

Overall, the 2022–2023 flood event had a positive effect on the water quality of the Coorong, in particular the South Lagoon (Mosley & Leyden 2023). The increased flows into the Coorong, increased flushing and connectivity, leading to a reduction in salinity and nutrient loads. However, the discharge of River Murray flood water also led to short-term increases in nutrient (primarily, phosphorus and nitrogen) loads and chlorophyll levels near the barrages in the North Lagoon. Ongoing monitoring of the North Lagoon and South Lagoon can further investigate how these nutrient loads affect the Coorong ecosystem (Mosley & Leyden 2023).

It is important to recognise that for short-term improvements in the Coorong to translate into sustained long-term improvements of the ecological health in the system, more frequent and higher volume flushing events (i.e. increased inflows and connectivity and/or management options) are required (Mosley & Leyden 2023).

9 Black bream and greenback flounder



Trend
Improved



Reliability
Excellent

Key findings and messages:

- The population condition of black bream and greenback flounder in the Murray Estuary and Coorong improved from 2008–09 to 2022–23.
- Since 2019, the population condition of black bream and greenback flounder improved from very poor to moderate and good.
- Delivery of water for the environment helps to maintain estuarine salinities and connectivity, enhancing productivity and food resource availability in the Murray Estuary and Coorong to support both species.
- Strategic management of barrage flows, including delivery of water for the environment, generated salt-wedge conditions that are required for black bream spawning and recruitment, and supported the provision of attractant flows for larval and juvenile greenback flounder to locate nursery habitats.
- Dredging and recent high (unregulated) flow events have helped to maintain an open Murray Mouth, critical to the maintenance of estuarine condition and connectivity between the estuary and the sea, which both species are reliant upon at various life stages.
- High (unregulated) flow events are important for maintaining estuarine conditions and increasing the extent of such conditions in the Murray Estuary and Coorong to support black bream and greenback flounder populations.
- With full implementation of the Basin Plan, we anticipate continued increases in connectivity and favourable habitat conditions. Coupled with effective fisheries management, the population conditions of black bream and greenback flounder is expected to be maintained or improved.

9.1 Introduction

9.1.1 Black bream

Black bream (*Acanthopagrus butcheri*) is a large-bodied fish (typically <1.5 Kg) that is endemic to the estuaries and coastal waters of southern Australia (Bice 2010; Hindell et al. 2008). It is considered an estuarine-dependent species and can complete its lifecycle within the natal estuary (Chaplin et al. 1997; Elsdon & Gillanders 2006). The life history of black bream is characterised by slow-growth ($k=0.04-0.08$), high longevity (29 years), intermediate age of maturity (>2 years) and high fecundity (average of 1.5 million eggs for a large female) (Sarre & Potter 1999; Ferguson et al. 2010).

In the MDB, black bream is restricted to the Murray Estuary and Coorong, where it is an important cultural, recreational and commercial fisheries species, and forms part of the Lakes and Coorong Fishery (Earl et al. 2016; Earl 2023; Ye et al. 2023a). The catch of black bream in the Lakes and Coorong Fishery accounts for approximately 70%

of commercial catches at a state fishery level (Earl et al. 2016). However, stocks within the Lakes and Coorong Fishery are classed as depleted, with annual catches having declined from around 30 t in the mid-1980s to less than 3.3 t in most years since 2008–09 (Earl 2023; Ye et al. 2023a).

Black bream have a wide tolerance to temperature, salinity and dissolved oxygen concentrations (Norris et al. 2002; Partridge & Jenkins 2002). Salinity is a key factor that influences the availability and quality of habitat, growth rates, survivorship and physical condition of larvae. Black bream are most abundant in areas where salinities range from 15–25 g L⁻¹, particularly during the spawning period (Hindell et al. 2008). Studies in aquaria determined that salinities of 15–35 g L⁻¹ are optimal for egg survival and result in the lowest proportions of larvae with physical abnormalities (Haddy and Pankhurst 2000). Observations of juveniles in aquaria found that they can survive and grow in salinities of 0–48 g L⁻¹ (Partridge & Jenkins 2002). However, they became osmotically stressed at 60 g L⁻¹ (Partridge & Jenkins 2002) and an LC₅₀ was identified at 88 g L⁻¹ (McNeil et al. 2013). In the CLLMM, black bream inhabit a wide range of salinity environments and have been recorded in the Lakes (Bice 2010) as well as in the hypersaline Coorong lagoons at salinities of up to approximately 70 g L⁻¹ (Ye et al. 2015).

The recruitment of black bream is strongly influenced by volumes of freshwater flows to estuaries. Low to moderate inflows to estuaries can generate salinity stratification of the water column at the freshwater and marine interface, known as salt wedge habitat, which provides favourable spawning and nursery habitat for black bream. Flows also assist with entrainment and drift of eggs and larvae within the salt wedge (Jenkins et al. 2010; Williams et al. 2013; Ye et al. 2019a, 2019b). Salt wedge habitats are important as they provide cues for adults to locate spawning grounds and spawn over spring and summer (Haddy and Pankhurst 1998; Williams et al. 2013; Ye et al. 2019a). These habitats also provide nursery environments for larvae and juveniles to develop and grow (Newton 1996; Ye et al. 2019b). Importantly, salt wedge habitats hold greater food resources (Newton 1996; Williams et al. 2013) and may reduce predation risk (Islam et al. 2006), culminating in increased black bream recruitment (Jenkins et al. 2010).

Population dynamics of black bream in the Coorong are strongly influenced by freshwater discharge from the barrages and the impact of fishing (Ye et al. 2023a). Low to moderate inflow volumes (600 to 24,000 ML day⁻¹) have been associated with strong cohorts (Ye et al. 2019a; Ye et al. 2023a). However, in recent years, fishery production has remained low despite recruitment of young fish to the fishable biomass. This indicates that recruitment levels have not been strong enough for the stock to recover and/or there has been a low survival rate of new recruits (Earl 2023). To improve the resilience of black bream in the Coorong, water for the environment is delivered to promote salt wedge conditions, improve estuarine habitats and enhance recruitment (Ye et al. 2019b), and this is coupled with fishery management actions to protect the spawning biomass (Earl 2023).

9.1.2 Greenback flounder

Greenback flounder (*Rhombolea tapirina*) are a medium-bodied flatfish (typically <300 mm total length, TL) that inhabit bare substrates in estuarine and protected coastal waters of southern Australia and New Zealand (Earl 2014; Ye et al. 2023a). The species is considered a marine-estuarine opportunist, and therefore are marine fishes that enter estuaries, particularly as juveniles (Earl et al. 2014). The life history of greenback flounder is characterised by its fast growth, moderate longevity (~10 years), early sexual maturity (one year) and high fecundity (up to two million eggs) (Ferguson 2006; Sutton et al. 2010; Earl 2014).

In the MDB, greenback flounder are restricted to the sole connection between estuarine and marine environments, which is inclusive of the Murray Mouth, Murray Estuary and Coorong. Greenback flounder in the Murray Estuary and Coorong are also likely to be part of a larger population that includes nearby marine environments (Earl et al. 2017). In the Murray Estuary and Coorong, greenback flounder is an important cultural, recreational and commercial fishery species (Earl et al. 2023).

The distribution of greenback flounder in the Coorong is constrained by salinity. Individuals were recorded up to 50 km from the Murray Mouth during the Millennium Drought and 70 km from the Murray Mouth during high flow periods (e.g., 2010–2011), when salinities were approximately 74 and 80 g L⁻¹ (Ye et al. 2023a). While greenback flounder can occur within hypersaline areas of the Coorong lagoons, they primarily occur within estuarine waters free from osmotic stress (Earl et al. 2017).

Greenback flounder in the Coorong reach sexual maturity when individuals reach approximately 210 mm TL (Earl 2014). Spawning is cued by water temperatures falling below 20°C and occurs from March to October and peaks between April and July when water temperatures are approximately 12°C (Earl 2014). In aquaria, optimum fertilisation rates of eggs occurred at salinities of 35–45 g L⁻¹ and the optimal temperature for egg incubation was 12°C (Hart and Purser 1995).

The population dynamics of greenback flounder in the Coorong are poorly understood. Age structures are truncated with most individuals either one or two years of age (Ye et al. 2023a). The reason for this remains a knowledge gap but may be a result of the removal of older individuals through commercial and recreational fishing (Ye et al. 2023a), or the dispersal of individuals from the Coorong to the sea (Earl et al. 2017).

Freshwater inflows to the Coorong are important to the recruitment and population condition of greenback flounder. High flows are associated with increased abundance and recruitment, expanded distributions, and the establishment of strong cohort(s) (Earl 2014; Ye et al. 2023a). These beneficial outcomes are likely in response to the increased extent of favourable estuarine habitat and greater food resource availability (Earl et al. 2017). In contrast, during the prolonged low to no inflow conditions associated with the Millennium Drought there was a significant reduction in annual catch. Annual catches prior to the drought were regularly above 20 t year⁻¹ and lowered to an average of 4 t year⁻¹ between 2002–2010 which was a consequence of the Millennium Drought (Ye et al. 2023a). Water for the environment is delivered to increase freshwater flows to the Coorong and aims to improve estuarine nursery habitats to enhance recruitment.

9.2 Ecological objective, target and environmental outcomes

The ecological objective for fishes in the Lower Lakes and Coorong, and the ecological targets for black bream and greenback flounder in the Coorong, as described in the [South Australian River Murray Long-term Watering Plan](#) (LTWP) (DEW 2020a), are presented in Table 9–1. The ecological target formed the basis of the expected environmental outcomes for black bream and greenback flounder. The population condition scores are underpinned by ecological indices, including relative abundance, distribution, age structure and recruitment, tallied to generate a single population condition score. A comprehensive method is described in the 'Black bream and greenback flounder chapter' (Ye et al. 2017) of the [LLCMM Icon Site Condition Monitoring Plan](#) (DEWNR 2017) and are also presented in Table 9–1.

Table 9–1. Ecological objective, target and indices for black bream and greenback flounder.

Characteristic	Description
Ecological objective	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lakes and Coorong.
Ecological target	Maintain or improve abundances, distribution and recruitment of black bream and greenback flounder with population condition score ≥ 3 (max 4).
Ecological indices for black bream	1. Relative abundance (based on commercial fishery catch, t year⁻¹) – Annual catch ≥ 8 t or positive trend over previous 4 years (linear regression) 2. Distribution – >50% of the catch from southern part of the Coorong (south of Mark Point) 3. Age structures – Need to meet at least 2 of the following 3 targets: >20% fish above 10 years; at least one strong cohort over the last 5 years;

Characteristic	Description
	≥2 strong cohorts in the population. Note: strong cohort is defined as a cohort representing ≥ 15% of the population.
	4. Recruitment – Catch per unit effort (CPUE) of young-of-year (YOY) >0.77 fish net night ⁻¹ by fyke net and > 50% sites with black bream YOY present. (Note this metric has been updated in future reporting to >0.35 YOY net night ⁻¹).
Ecological indices for greenback flounder	1. Relative abundance (based on commercial fishery catch, t year ⁻¹) – Annual catch ≥ 24 t or positive trend over previous 4 years (linear regression).
	2. Distribution – >70% of the catch from southern part of the Coorong (south of Mark Point).
	3. Age structure – Presence of a very strong cohort (>60%) or at least a strong cohort (>40%) in year 0–2 and >20% of fish >2 years old.
	4. Recruitment – CPUE of YOY >1.04 fish seine net ⁻¹ – YOY distribution in the Coorong: >50% sites with YOY present.

The expected environmental outcomes for black bream and greenback flounder (population condition scores in 2019, 2029 and 2042) were determined by elicitation with key experts. It is expected that the population condition scores for both species will improve, however, the confidence in future predictions attenuates with time (Table 9–2; Figure 9-1).

Table 9–2. Expected environmental outcomes for black bream and greenback flounder in 2019, 2029 and 2042.

Species	Expected outcome	Year		
		2019	2029	2042
Black bream	Maintain or improve abundances, distribution and recruitment of black bream	Population condition score will be 2.25* (80% confidence interval 0.88-3.35)	Population condition score will be 2.75 (80% confidence interval 1.00-3.66)	Population condition score will be 3.25 (80% confidence interval 1.25-4.13)
Greenback flounder	Maintain or improve abundances, distribution and recruitment of greenback flounder	Population condition score will be 2.75 (80% confidence interval 1.86-3.40)	Population condition score will be 3.00 (80% confidence interval 1.65-3.92)	Population condition score will be 3.25 (80% confidence interval 0.89-3.81)

* Noting that expected outcomes are averaged scores with decimal values, while actual scores will be round numbers. Therefore, a score is unlikely to be equal to an expected outcome, rather it would be exceeding or failing.

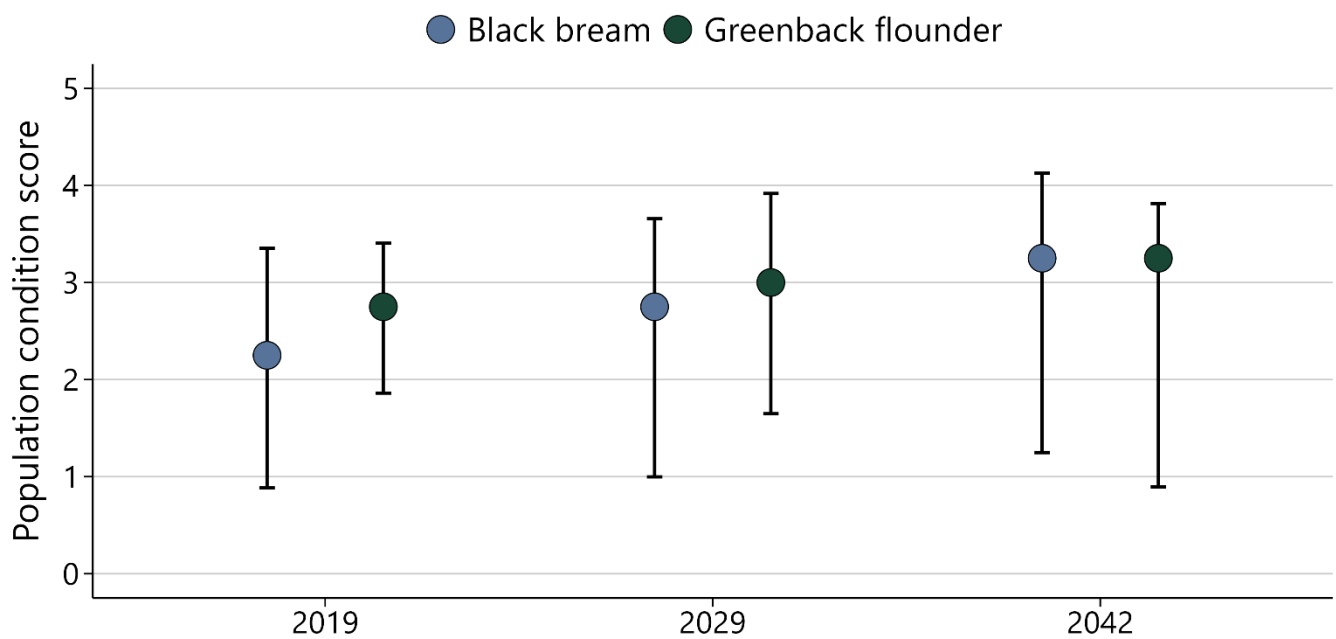


Figure 9-1. Expected population condition scores ($\pm 80\%$ confidence interval) for black bream and greenback flounder in 2019, 2029 and 2042.

9.3 Method

The methodology used to monitor black bream and greenback flounder is described in the black bream and greenback flounder chapter (Ye et al. 2017) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017), summarised below. Data has been collected primarily through TLM program to inform the planning and delivery of water for the environment delivery and barrage operations. Other programs have also contributed to the data collection in recent years.

The relative abundance (catch), adult fish distribution and age structure of black bream and greenback flounder was determined based on data/sample collected from the Lakes and Coorong Fishery. Data from the Lakes and Coorong Fishery included annual catch (kg) and spatial reporting from fishing blocks 6 to 14 located over the Murray Estuary and North Lagoon. Samples from the commercial catches from the Murray Estuary and North Lagoon of the Coorong were obtained to determine the age structure of black bream and greenback flounder. Otoliths were extracted and analysed to assess the age structure of the population and determine the presence of strong year classes.

Fishery-independent sampling was conducted annually between spring and early autumn to quantify the abundance of juvenile black bream and greenback flounder to assess annual recruitment of YOY. Black bream were sampled at nine regular sites in the Murray Estuary and North Lagoon using single-winged fyke nets, with four replicates (nets) at each site. Greenback flounder were sampled at seven to nine sites evenly distributed along the Coorong using a 61 m long seine net that swept an area of approximately 592 m². Sweeps were replicated three times at each site (i.e. 3 replicates). The number of juvenile black bream and greenback flounder from each net were counted and a random subsample of up to 50 individuals per species per net measured for TL (mm).

9.3.1 Trend assessment

Trend analyses for black bream and greenback flounder population condition was undertaken as per section 4.2.2. A logistic generalised linear model was used to assess trends in the condition assessment indicators that comprise the population condition scores for black bream and greenback flounder. The final score (0 or 1) for each of the four condition assessment indicators (i.e. relative abundance, distribution, age structure, and recruitment indices) were used as the response variable for each year. Importantly, this assumes that these population indicators are independent of each another. Time step was used as a fixed effect.

9.3.2 Information reliability

The information reliability assessment for black bream and greenback flounder in the Murray Estuary and Coorong was conducted as per section 4.2.3.

9.4 Limitations and assumptions

9.4.1 Black bream

Due to commercial fishery closures over the black bream spawning seasons in 2018–19, 2019–20, 2021–22 and 2022–23, adjustments were made to estimate the annual catch. The percentage of monthly catch derived from historic data (2013–14 to 2017–18) were used to calculate an estimate of total annual catch if seasonal fishing closures had not been enforced (Ye et al. 2023a). Therefore, the entire catch in these years does not represent an actual reduction of reproductive mature fish from the population.

9.4.2 Greenback flounder

The exceptionally high CPUE of YOY in 2008–09 and 2009–10 is thought to have occurred in response to the aggregation of juveniles into the limited extent of available habitat within the Murray Estuary, which improved catchability (Ye et al. 2023a).

The 2022–23 flood led to un-seasonally high-water levels throughout the Murray Estuary and Coorong. Due to the very high volumes of water in the system, the catchability of YOY was likely reduced due to dilution effects.

9.5 Results

9.5.1 Environmental outcome assessment: black bream population condition

The condition score of black bream populations in 2018-19 (1) was lower than expected (2.25), however, the score was within the 80% confidence interval (0.88–3.35; Figure 9-2). Since 2018-19, black bream population condition scores have increased from very poor (1) to moderate (3) in 2022–23 (Table 9–3; Figure 9-2). Therefore, the 2029 expected outcome is currently on track (in the context of influencing factors outlined in section 9.6.1), with the previous three years having recorded population condition scores ≥ 3 (Figure 9-2).

Black bream

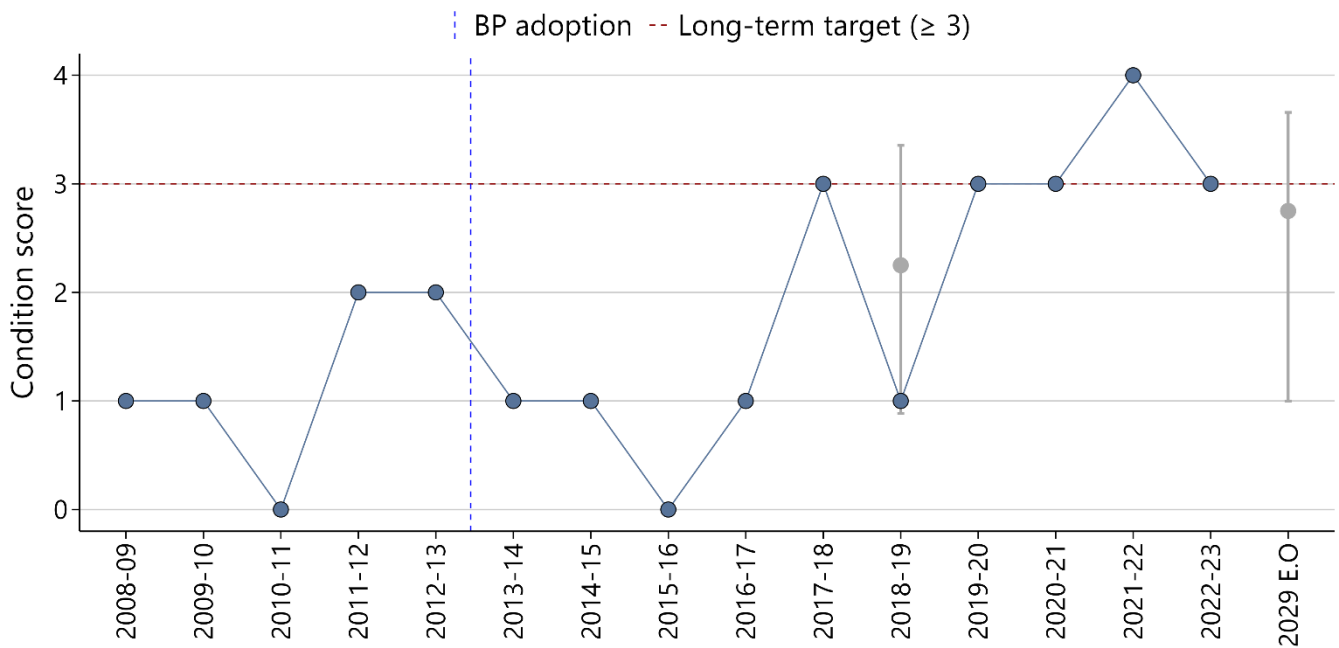


Figure 9-2. Black bream population condition assessment scores from 2008–09 to 2022–23. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.

9.5.2 Environmental outcome assessment: greenback flounder population condition

The condition score of greenback flounder population in 2018-19 was much lower than the expected score of 2.75. The score was also outside of the confidence intervals attached to the outcome (Table 9-4; Figure 9-3). Since 2018–19, population condition scores have increased considerably, with the scores being ≥ 3 for the last three years (Figure 9-3).

Greenback flounder

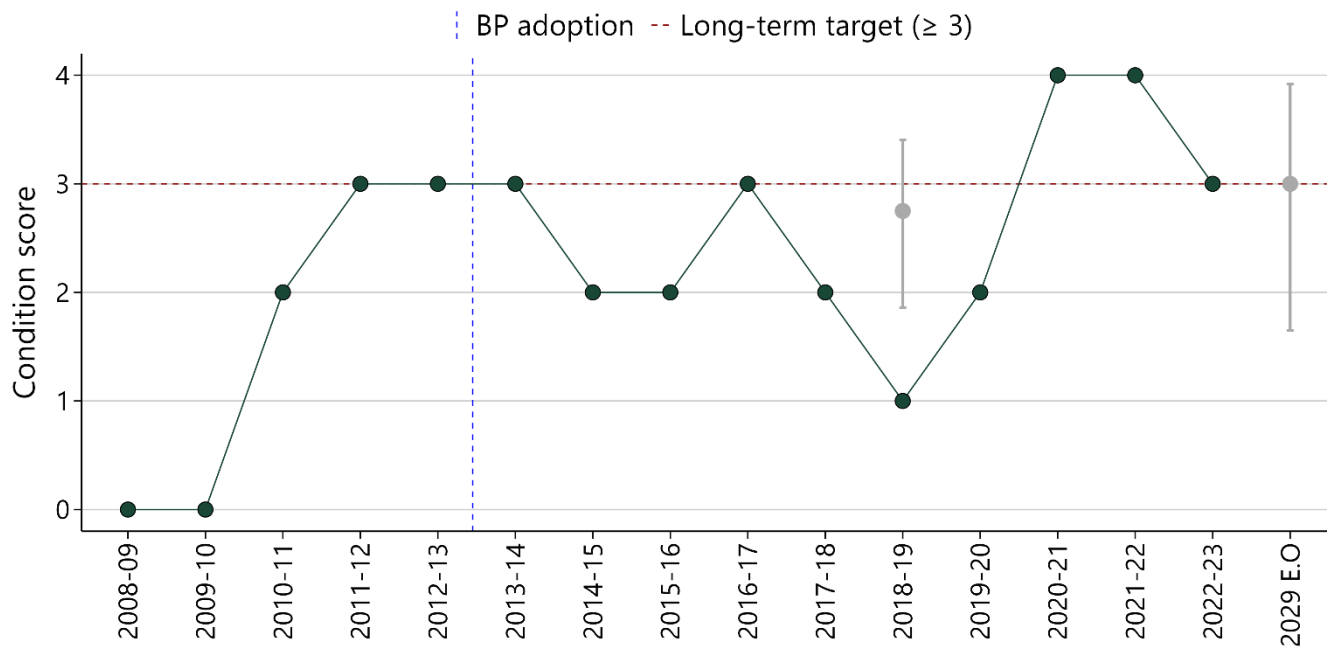


Figure 9-3. Greenback flounder population condition assessment scores from 2008–09 to 2022–23. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars.

Table 9–3. Condition assessment for black bream population in the Coorong from 2008–09 to 2022–23. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of these indices meets the ecological target; (2) Distribution – meets the ecological target; (3) Age structure – a minimum of 2 indices must meet their ecological targets and (4) Recruitment – both indices must meet their ecological targets. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2023a).

Population indicator	Indices	2008–09 Drought	2009–10 Drought	2010–11 Flood	2011–12 High flow	2012–13 Mod flow	2013–14 Low flow	2014–15 Low flow	2015–16 Low flow	2016–17 High flow	2017–18 Low flow	2018–19 Low flow	2019–20 Low flow	2020–21 Low flow	2021–22 High flow	2022–23 Flood	Ecological targets (Reference point)
Relative abundance	Catch (t year ⁻¹)	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	Yes	>8 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Positive (slope)
	Score	0	0	0	1	1	0	0	0	0	0	0	1	1	1	1	
Distribution	Proportional catch	No	No	No	No	Yes	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	>50% from southern part
	Score	0	0	0	0	1	0	0	0	0	1	0	1	1	1	1	
Age structure	% fish >10 years	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	No	Yes	Yes	>20% of fish >10 years
	Number of strong cohorts in first 5 years	Yes	No	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	At least one strong cohort (>15%)
	Number of strong cohorts in population	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	≥2 strong cohorts
	Score	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	
Recruitment	YOY CPUE	Yes	No	No	No	Yes	No	NS	No	No	Yes	No	No	No	Yes	No	>0.35 YOY net night ⁻¹
	YOY distribution	---	---	No	No	No	No	NS	No	No	Yes	No	No	No	Yes	No	>50% sites (detected)
	Score	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	
Icon site total score		1	1	0	2	2	1	1	0	1	3	1	3	3	4	3	
Black bream condition		Very poor	Very poor	Extremely poor	Poor	Poor	Very poor	Very poor	Extremely poor	Very Poor	Moderate	Very poor	Moderate	Moderate	Good	Moderate	

Table 9–4. Condition assessment for greenback flounder population in the Coorong from 2008–09 to 2022–23. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of these indices meets the ecological target; (2) Distribution – meets the ecological target; (3) Age structure – a minimum of 2 indices must meet their ecological targets and (4) Recruitment – both indices must meet their ecological targets. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2023a)

Population indicator	Indices	2008–09 Drought	2009–10 Drought	2010–11 Flood	2011–12 High flow	2012–13 Mod flow	2013–14 Low flow	2014–15 Low flow	2015–16 Low flow	2016–17 High flow	2017–18 Low flow	2018–19 Low flow	2019–20 Low flow	2020–21 Low flow	2021–22 High flow	2022–23 Flood	Ecological targets (Reference point)
Relative abundance	Annual catch	No	No	No	Yes	No	No	No	No	No	No	No	No	No	No	Yes	≥24 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	Yes	No	No	No	Yes	Yes	Yes	Positive (slope)
	Score	0	0	0	1	1	0	0	0	1	0	0	0	1	1	1	
Distribution	% catch	No	No	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	>70% from southern part
	Score	0	0	0	1	1	1	0	1	1	1	1	1	1	1	1	
Age structure	A very strong cohort	No	No	Yes	Yes	Yes	No	Yes	Yes	No	No	No	Yes	Yes	Yes	Yes	Presence of a very strong cohort (>60%)
	A recent strong cohort and % fish >2 years	No	No	No	No	No	Yes	No	No	Yes	Yes	No	No	No	No	No	≥1 strong cohort (>40%) in year 0–2 and >20% >2 years
	Score	0	0	1	1	1	1	1	1	1	1	0	1	1	1	1	
Recruitment	YOY CPUE	Yes	Yes	Yes	No	No	Yes	Yes	No	No	No	No	No	Yes	Yes	No	>1.04 fish seine net ⁻¹
	YOY distribution	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	No	Yes	Yes	Yes	>50% sites
	Score	0	0	1	0	0	1	1	0	0	0	0	0	1	1	0	
Icon site total score		0	0	2	3	3	3	2	2	3	2	1	2	4	4	3	
Black bream condition		Extremely poor	Extremely poor	Poor	Moderate	Moderate	Moderate	Poor	Poor	Moderate	Poor	Very Poor	Poor	Good	Good	Moderate	

9.5.3 Trend

The condition assessment indices (i.e. relative abundance, distribution, age structure, and recruitment indices) that comprise the population condition scores of black bream and greenback flounder were both virtually certain (100% probability) to have **improved** over the assessment period (2008–09 to 2022–23) (Figure 9-4 and Figure 9-5).

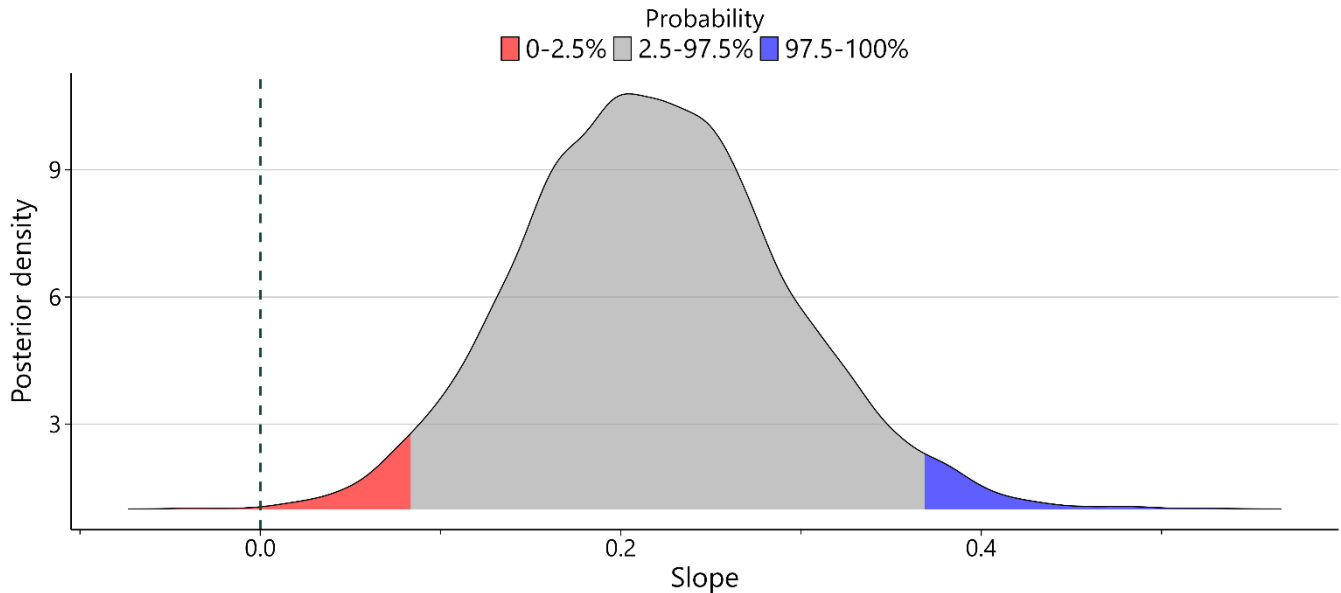


Figure 9-4. Estimated values for the slope generated from Bayesian modelling for the population condition scores of black bream. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

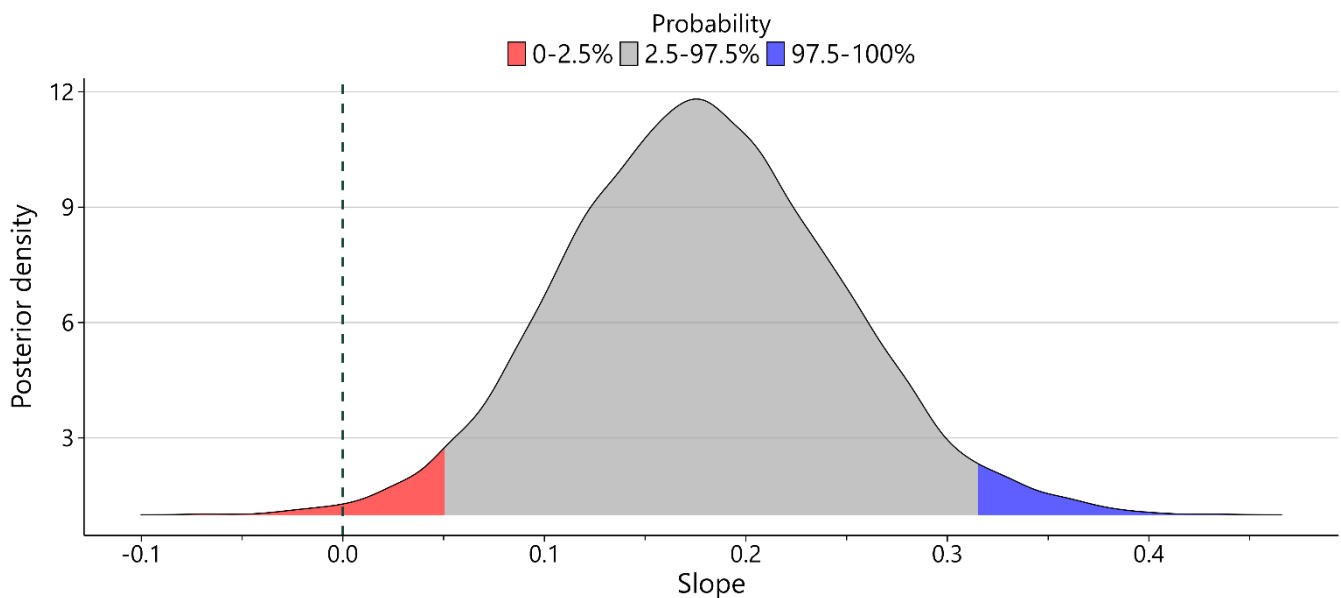


Figure 9-5. Estimated values for the slope generated from Bayesian modelling for the population condition scores of greenback flounder. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

9.5.4 Information reliability

The information reliability rating for black bream and greenback flounder was **excellent** (final score of 12). Justification for the scoring for black bream and greenback flounder information reliability is provided in Table 9–5.

Table 9–5. Reliability of data to assess outcomes of black bream and greenback flounder. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Yes. The respective methods for black bream and greenback flounder as presented in the Condition Monitoring Plan (DEWNR 2017) were used each year.	2
Representativeness			
Space	Has sampling been conducted across the spatial extent of the CLLMM with equal effort?	Yes. Commercial fishery data (annual catch) and sampling sites established by SARDI are well distributed throughout the Coorong estuary and North Lagoon for black bream and additionally the South Lagoon for greenback flounder.	2
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. Sampling was conducted from 2008–09 to 2022–23, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and a range of hydrological conditions.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. Commercial fishery data were collected between fishing blocks 6 to 14 in the Lakes and Coorong Fishery. Sampling of YOY were conducted at nine regular sites for black bream and greenback flounder.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes. Daily catch and effort data from fishery statistics on an annual basis. For age structure assessment, adult black bream are sampled each year particularly in spring/summer, and greenback flounder over the entire year. YOY black bream are sampled annually over summer/autumn. YOY greenback flounder are sampled in late spring/summer with the exception of one year of monitoring.	2
Final score			12
Information reliability			Excellent

9.6 Evaluation

9.6.1 Black bream

Black bream population condition in the Murray Estuary and Coorong improved greatly from 2008–09 to 2022–23. Since the last assessment in 2019, black bream population condition improved from very poor to moderate/good. This improvement in population condition was associated with the achievement of population condition indices for relative abundance, distribution and age structure and a strong recruitment event in 2021–22. The key factors that influenced the population condition of black bream over the assessment period (2008–09 to 2022–23) were barrage flows, including high flows and low-moderate flows, which influence estuarine habitat, black bream recruitment, and fishery catches and management.

Barrage flows: High flows

High flows play an important role in flushing salt out of Murray Mouth from the Murray Estuary and Coorong and reducing salinities, which increases the extent of suitable habitat for black bream (Ye et al. 2023b). These changes in suitable habitat influence the distribution of the commercial catch, with 88% of the catch in 2021–22 coming from areas south of Mark Point in the North Lagoon (Ye et al. 2023a). This was also evident in the fishery-independent catch, with very high YOY abundances coming from the site at Noonameena, located in the southern section of the North Lagoon (Ye et al. 2023a). Moreover, black bream were recorded in the southern South Lagoon, with several individuals captured at the entrance of the Salt Creek fishway in 2021–22 (Ye et al. 2022). This flexibility in habitat use by black bream is attributed to a third of the population being partially migratory and responsive to changes in habitat and food availability in the Coorong (Gillanders et al. 2015).

Reductions in South Lagoon salinities from high flows can have multi-year benefits. For example, it took three consecutive low flow years for salinities to return to levels recorded prior to the high flow event in 2016–17. These lower salinities allowed black bream to access habitats further south in the Coorong that are within their osmoregulatory threshold ($88 \text{ g L}^{-1} \text{ LC}_{50}$; McNeil et al. 2013). Similarly, their prey, such as crustaceans and other fish species, would have also been able to expand their distributions under such conditions (Dittmann et al. 2022).

Pelagic productivity of the Coorong is also improved by periods of high flows. For example, Bice et al. (2016) found that the organic matter and zooplankton that were exported to the Murray Estuary during periods of increased freshwater discharge from the barrages contributed to improvements in estuarine productivity. Moreover, freshwater derived zooplankton became more prevalent within the gut contents of sandy sprat as freshwater discharged increased. This trophic subsidy likely benefitted black bream, as sandy sprat are an important prey species in the diets of larger fish species (Giatas and Ye 2016), and the body condition of black bream juveniles and adults were positively impacted by the high flows of 2021–22 and 2022–23 (Qifeng Ye, personal communication, November 2023).

The population condition of black bream may also be positively impacted by high flows through improving population connectivity with the immigration of a new cohort(s) of sub-adult and/or adult fish from nearby estuaries. The age structures of commercial catches from 2019–20 and 2022–23 had a strong cohort from 2016–17. As YOY were not sampled in the Coorong in 2016–17, this cohort is expected to be comprised of individuals that were spawned in other estuaries and migrated into the Coorong in recent years, noting this may be an artefact of dilution effects or detection error (Ye et al. 2023a). However, such emigration of black bream into the Coorong contrasts with other studies, which found limited evidence of coastal migration and emigration between estuaries (FRDC 2020). Hall (1984) reports one tagged fish observed to migrate between the Murray Mouth and the Inman River estuary (~25 km away) during lower flow years, providing some indication that migration may not be solely due to flushing effects.

Although periodic high flows are important to the life history and ecology of black bream, they may also represent a disturbance to recruitment. Such flows may prevent the formation of salt wedge habitats that are favourable spawning and larval nurse habitats for black bream (Ye et al. 2019a). Therefore, black bream recruitment is usually associated with low to moderate rather than high barrage flows (Ye et al. 2023b).

Barrage flows: Low-moderate flows during spawning period

Recruitment of black bream in the Murray Estuary and Coorong was associated with the timing and volume of barrage flow. Low to moderate ($\sim 600\text{--}24,000\text{ ML day}^{-1}$) inflows prior to and during the spawning season are considered to benefit recruitment by attracting spawning aggregations, providing conditions conducive to the formation of salt wedge habitats, and increasing larval food availability through the transport of zooplankton (Ye et al. 2023b). Although salt wedge habitats are integral to support the recruitment of black bream, the generation of such habitats does not guarantee successful recruitment (e.g., 2014–15). Further research is needed to improve understanding of the mechanisms that influence the recruitment dynamics of black bream in the Murray Estuary and Coorong to better inform management.

YOY recruitment during the assessment period was recorded in 2012–13, 2015–16, 2017–18 and 2021–22 (Ye et al. 2023a). All years of recruitment were low to moderate flow years, except for the high flow year of 2021–22. However, flows in each of these years were low to moderate prior to and during the spawning season. The two most recent years with strong recruitment were 2017–18 and 2021–22. In 2017–18, spawning occurred between late December and early February and commenced one to two weeks after a $\sim 10,000\text{--}12,000\text{ ML day}^{-1}$ flow pulse and corresponded with barrage flow of $600\text{--}5,000\text{ ML day}^{-1}$ and water temperatures of $18\text{--}25^{\circ}\text{C}$ (Ye et al. 2019a). Such flows were demonstrated to lead to the formation of salt wedge habitats in the Murray Estuary and northern part of the North Lagoon, where YOY were found to be evenly distributed (Ye et al. 2019a). In contrast to this, the 2021–22 recruitment event occurred between mid-January and late February and corresponded to water temperatures of $19\text{--}26^{\circ}\text{C}$ and barrage flow of $\sim 11,000\text{--}24,000\text{ ML day}^{-1}$. Due to the higher barrage flow, the YOY in 2021–22 were more abundant in the North Lagoon than Murray Estuary, likely due to the salt wedge forming further south in the system.

Contribution of water for the environment

Water for the environment was particularly important for increasing the extent of suitable black bream habitat, including salt wedge habitats that are conducive to recruitment. With respect to the extent of suitable habitat, the delivery of water for the environment had a strong cumulative impact. For example, if Commonwealth Environmental Water (CEW) had not been delivered from 2017–18 to 2021–22, the area of suitable habitat in 2021–22 would have declined by 38% (Ye et al. 2023b). The increase in suitable habitat due to both water for the environment delivery and high flows is attributed to the positive trajectory of annual catches and distribution over the past four years (Ye et al. 2023b).

Water for the environment supported the establishment of salt wedge habitats during years of low flow, such as 2014–15 and 2017–18. In these years, CEW comprised 46% and 89% of barrage flow in 2014–15 and 2017–18, respectively (Ye et al. 2023b). Management of barrage flow in these years demonstrated that water for the environment can be delivered to generate salt wedge habitats, and in the case of 2017–18, result in a strong recruitment event. Without water for the environment, the conditions required for black bream recruitment in 2017–18 may not have occurred (Ye et al. 2019a). It is important for delivery to occur during the summer months (January to February), which is the key recruitment period.

Fishery management

The stock status of black bream in the Lakes and Coorong Fishery in 2021–22 was classified as depleted (Earl 2023). Long-term fishery catches of black bream have likely contributed to a depleted population with reduced spawning biomass and a truncated age structure (reduced resilience) by removing older and larger individuals from the population (Ye et al. 2023a).

Year-round fishery closures within 150 m of the barrages were established prior to the assessment period and further temporary management arrangements were implemented in 2018–19, 2019–20, 2021–22 and 2022–23 to recover the black bream stock in the Coorong (Earl 2023; PIRSA 2023). These temporary arrangements applied to the Lakes and Coorong Fishery during the reproductive season of black bream and aimed to protect the spawning biomass and minimise fishing interference on spawning events (Ye et al. 2023a). The timing and duration of these closures varied between years and were from 1 September to 30 November in 2018; from 21 September to 30 November in

2019; from 1 August to 31 December in 2021; and 1 August to 30 January in 2022–23 (Earl 2023; PIRSA 2023). Under the arrangements, commercial and recreational fishing nets could not be used within 300 m of the barrages, black bream could not be targeted, and all incidental catch had to be released (Earl 2023).

The population condition of black bream has improved over the period of temporary management arrangements, and the continuation of these closures will help protect the remnant spawning biomass and maximise the survival of new recruits to re-build the abundance and resilience of the black bream population in the Coorong (Ye et al. 2023a).

9.6.2 Greenback flounder

Greenback flounder population condition in the Murray Estuary and Coorong improved substantially from 2008–09 to 2022–23. Since the 2019 assessment of expected outcomes, there has been notable improvement, with population condition having improved from very poor to moderate (and occasionally good). This improvement in population condition was associated with the achievement of population condition indices for relative abundance, distribution, age structure and recruitment. The key factors that influenced the population condition of greenback flounder over the assessment period (2008–09 to 2022–23) were barrage flows, an open Murray Mouth and fishery catch and management.

Barrage flows: High flows

The population condition of greenback flounder over the assessment period (2008–09 to 2022–23) generally improved after high flows and flood. After high flows, there was an increase in both the distribution and CPUE of YOY, along with an expansion in the distribution of adult fish. These positive responses were likely driven by the influence that these flows have on the salinity regime and availability of food resources (Ye et al. 2023a & b).

Although greenback flounder recruit annually in the Coorong, the distribution and magnitude of recruitment is responsive to changes in freshwater inflows, and subsequent effects on the salinity regime and food resources (Ye et al. 2023a). High flow events increase the extent of brackish to near-marine salinities ($<40 \text{ g L}^{-1}$). Such salinities are preferentially used by juvenile and adult greenback flounder as habitat (Earl et al. 2017) and are optimal for the fertilisation ($35\text{--}45 \text{ g L}^{-1}$) and survival ($15\text{--}45 \text{ g L}^{-1}$) of eggs (Hart and Purser 1995). The export of freshwater derived zooplankton that were entrained in flow from the River Murray to the Murray Estuary (e.g., Bice et al. 2016), may also be beneficial to the food resource base for larval greenback flounder.

The export of salt from the Coorong associated with high flow events creates improved estuarine water quality conditions along a greater extent of the Coorong (particularly those areas with higher concentration of salinities), which increases the extent of suitable habitat for greenback flounder (Ye et al. 2023b). These events export such significant volumes of salt from the system can have multi-year benefits on habitat availability, as discussed in section 9.6.1. The fresher environments in the Coorong during and after high flow events enable the longitudinal expansion of ranges of prey items for adult fish, such as amphipods and polychaetes (Ye et al. 2020; Dittmann et al. 2022).

Contribution of water for the environment

Delivery of water for the environment has increased barrage flow, particularly during dry years. In dry years, water for the environment comprised the majority, if not all, barrage flow (Ye et al. 2023b). During these times, water for the environment would have increased estuarine productivity through the transport of nutrients and zooplankton from the River Murray and Lakes to the Murray Estuary (Bice et al. 2016), and also provided olfactory cues for larval and juvenile greenback flounder in marine environments to locate the nursery habitats in the Murray Estuary and Coorong (see Chapter 5 'Murray Mouth openness: annual flow').

The delivery of water for the environment has also increased the extent of habitat for greenback flounder through freshening the salinity gradient. The impact of water for the environment delivery was cumulative and contributed to significant increases in the extent of suitable and preferred habitat. For example, if CEW had not been delivered from 2017–18 to 2021–22, the area of suitable habitat in 2021–22 for greenback flounder would have declined by

36% (Ye et al. 2023b). Moreover, in 2021–22, brackish to near marine salinities ($<40 \text{ g L}^{-1}$) were maintained in the Murray Estuary and North Lagoon, which comprise preferred habitat for adult fish and are required for reproduction (Hart and Purser 1995; Earl et al. 2017). However, if water for the environment had not been delivered for the prior five years, then large expanses of the North Lagoon would have exceeded the preferred salinity level (Ye et al. 2023b). Therefore, delivery of water for the environment is expected to have increased the recruitment of greenback flounder and the distribution of both YOY and adults.

Connectivity - Open Murray Mouth

Greenback flounder rely on an open Murray Mouth for passage between estuarine and marine habitats. As a marine estuarine opportunistic species, system connectivity is needed for the passage of larval and juvenile greenback flounder from marine environments to nursery habitats in the Murray Estuary and the Coorong (Bice et al. 2018). Freshwater flows from estuary mouths provides olfactory cues that attract larval and juvenile fish species that are dependent on estuarine habitats (Whitfield 1994; Teodosio et al. 2016). It is expected that greenback flounder recruitment is enhanced by accessing the nursery habitats within the Murray Estuary and Coorong, as has been documented for estuarine fish in other estuaries (Tweddle and Froneman 2017). The dispersal and movements of adult greenback flounder also rely on system connectivity, with fish in their second or third year of life departing the Coorong for the sea. Most adults do not return to the Murray Estuary and Coorong once departed, however, some individuals have return migrations between the estuary and sea (Earl et al. 2017).

Since the adoption of the Basin Plan in 2012, volumes of barrage flow alone were insufficient to maintain an open Murray Mouth, with dredging required to maintain its openness and function. Dredges were in operation for 67% of months under the Basin Plan and were only ceased during and following periods of high flow.

Fishery catches

The stock status assessment of greenback flounder in the Lakes and Coorong Fishery was classified as 'depleted' in 2021–22 (Earl 2023). Commercial catches of greenback flounder are targeted in the Murray Estuary and Coorong (Earl 2023), where the species has a truncated population age structure. Despite being able to live to more than 10 years of age (Sutton et al. 2010), there are a lack of greenback flounder that are ≥ 3 years old (Ye et al. 2023a). The lack of fish ≥ 3 years old may be due to the removal of larger older fish through commercial and recreational fishing (Earl et al. 2016) or the movement of fish aged two to three years from the Murray Estuary and Coorong to sea (Earl et al. 2017). However, Earl (2023) suggests that low targeted effort and catches of greenback flounder from 2012–13 to 2021–22 reflect low fishable biomass in the Murray Estuary and Coorong, and that recruitment to the fishable biomass was impaired by a lack of higher flows rather than fishing effects.

9.6.3 Unanticipated outcomes

The recruitment event for black bream in 2021–22 was unanticipated as it occurred during a year of high flow, although flows during the spawning season were moderate, as discussed in section '*Low-moderate flows during spawning period*'. While flows during the spawning season of 2021–22 were considered to be moderate (11,000–24,000 ML day⁻¹) they were substantially higher than those recorded during the prior strong recruitment event in the Murray Estuary in 2017–18 (600–12,000 ML day⁻¹). This led to YOY in 2021–22 being in their highest densities within the North Lagoon rather than the Murray Estuary, likely due to the salt wedge forming further south in the system, which was the first time observed over the assessment period.

The population condition of greenback flounder in 2022–23 was expected to be good, however, it was scored moderate. The population condition indices that were not achieved in 2022–23 was associated with the CPUE of YOY. The failure in meeting these indices was un-anticipated as greenback flounder recruitment is known to respond positively to higher flows, as discussed in section '*high flows*'. This outcome is thought to be attributed to dilution effects with the seasonally high-water levels in 2022–23 reducing the catchability of YOY.

9.6.4 Actions to achieve environmental outcomes

Ongoing actions to support the future conditions of black bream and greenback flounder include:

- the recovery and increased delivery of water for the environment to enhance barrage flows during drier periods
- continuous optimisation of delivery of water for the environment and barrage flow management to maintain and enhance estuarine habitat conditions that favour the recruitment of both species
- maintaining an open Murray Mouth to ensure system connectivity (e.g. fish passage between estuarine and marine habitats) and favourable salinity conditions
- implementing ongoing fishery management, including measures to protect spawning biomass and maximise the survival of new recruits, to rebuild population abundance and resilience in the Murray Estuary and Coorong.

While outside of current management influence, regular high (unregulated) flow events are essential for maintaining suitable habitat conditions in the Murray Estuary and Coorong, particularly following low-flow years. These events also enhance the productivity of the system, supporting increased numbers and distribution of both species.

Maintenance of productive estuarine habitat

Key to future management of black bream and greenback flounder is the provision of suitable salinities within the Murray Estuary and Coorong to provide favourable estuarine habitat and facilitate recruitment (Ye et al. 2023a). The enhancement of barrage flow through the delivery of water for the environment will continue to be important in maintaining productive estuarine habitat within the Murray Estuary and North Lagoon, particularly during dry years.

In years with sufficient water, delivering a steady rate of barrage flow, particularly from the Goolwa barrage, from November to February, is important to establish and maintain salt wedge habitat to support black bream spawning and recruitment. Integrated operations of the river can help maximise the pelagic productivity and food resources in these salt wedge habitats for larvae and juvenile black bream. This can include timing the delivery of upstream flow pulses with the recession of managed floodplain inundations and surcharging and then discharge water from the Lakes, to entrain freshwater derived nutrients, phytoplankton and zooplankton in flow that is then discharged into the Murray Estuary.

In order to achieve these outcomes the following are required:

- Constant flow to the North Lagoon to protect/expand estuarine habitat (nursery ground for both species).
- Moderate barrage flows in summer to create salt wedge conditions for black bream recruitment. If during a low-moderate flow year from Goolwa, if a higher flow year then from Tauwichee in the North Lagoon.
- Winter flows through the Murray Mouth to attract larval/juvenile greenback flounder into the estuary.

Open Murray Mouth

Maintenance of an open Murray Mouth is essential to the immigration and emigration of greenback flounder at various life stages (Earl et al. 2017; Bice et al. 2018). It is therefore important that when volumes of barrage flow are insufficient to maintain an open Murray Mouth that dredging is undertaken to ensure system connectivity.

Fishery management

Fishery management is important to the sustainability and resilience of black bream and greenback flounder populations in the Murray Estuary and Coorong. Commercial fishery management actions include temporal and spatial netting closures and restrictions on licenses, net lengths and mesh sizes and legal minimum lengths (Earl 2023). Additionally, fishery closures for black bream help protect the spawning biomass, involving a year-round closure within 150 m of the barrages and the temporary closures within 300 m of the barrages during the spawning season (1 August to 31 January) when flows are $\leq 30,000$ ML day⁻¹ (Earl 2023; PIRSA 2023). These management actions are documented within the *Black bream recovery strategy for the Lakes and Coorong Fishery*, which is being implemented to enable the stock to return to a 'sustainable' stock status (PIRSA 2023). Performance indicators and reference points for each stock classification were developed in PIRSA (2023) to enable stock recovery to be measured.

9.7 Conclusion

Implementation of the Basin Plan, particularly the delivery of water for the environment, has enabled actions that significantly improved the population conditions of black bream and greenback flounder in the Murray Estuary and Coorong. Water for the environment played an important role in increasing productivity and habitat for these fishes and was critical in establishing salt wedge habitats that are needed for black bream spawning and recruitment. Periodic high flows were also particularly important to increasing habitat extent for both species and are required to improve nursery habitat and facilitate strong recruitment events for greenback flounder. With the full implementation of the Basin Plan, we anticipate continued promotion of connectivity and favourable habitat conditions. Coupled with effective fisheries management, the population conditions of black bream and greenback flounder is expected to be maintained or improved. Full implementation of the Basin Plan, particularly the recovery and delivery of the 450 GL of additional water for the environment and addressing current water delivery constraints, will ensure that water is able to be delivered to the Murray Estuary and Coorong during critical times (i.e. spring-summer) to support recruitment and resilience of the population condition of both species.

10 Diadromous fish



Trend
Improved



Reliability
Good

Key findings and messages:

- Recruitment of diadromous fish has improved between 2006–07 and 2022–23, likely due to increased connectivity between freshwater, estuarine and marine habitats.
- Recent years of high (unregulated) flows have increased connectivity supporting populations of congolli and common galaxias.
- Despite overall improvement, recent (since 2019) recruitment of congolli and common galaxias has declined but is still considered on-track toward the 2029 expected outcome.
- The delivery of water for the environment, recovered through the Basin Plan, has assisted in maintaining open barrage gates in winter and operation of fishways in spring and summer, the key periods for migration of congolli and common galaxias.
- Increased opportunity for passage of adults between freshwater and estuarine/marine environments during critical winter spawning migrations contributes to strong recruitment.
- The delivery of water for the environment and associated improved system connectivity through the operation of fishways and barrages and an open Murray Mouth will be important for continued improvement in diadromous fish, with outcomes enhanced through coordinated water delivery and addressing constraints.

10.1 Introduction

Diadromous fish migrate between freshwater and marine environments to complete their lifecycle (McDowall 1997; Verhelst et al. 2021). The dependence of diadromous fishes on connectivity between multiple aquatic environments over large spatial scales means that they are particularly vulnerable to habitat loss, fragmentation and altered flow regimes (Verhelst et al. 2021), while pollution, invasive species and overfishing also threaten populations (Lin et al. 2017). Consequently, diadromous fishes are among the most threatened vertebrate species in the world (Angermeier 1995; Jonsson et al. 1999). River regulation is a key threat to diadromous fishes in Australia, including within the MDB, due to physical barriers to migration and altered flow regimes, which influence migration and spawning (Koster et al. 2023; Miles et al. 2013).

The CLLMM is unique within the MDB as the sole interface between freshwater, estuarine and marine environments. Connectivity among the freshwater, estuarine and marine environments of the CLLMM is critical for providing habitat and migratory pathways to support the population dynamics of diadromous fish (Bice et al. 2018b; Lintermans 2007). The Murray barrages, which separate Lake Alexandrina from the Coorong, prevent incursions of saltwater entering the freshwater lake system, but represent significant barriers to fish movement (Bice et al. 2023). Bi-directional migration through these barriers is supported by releases of freshwater flows through open barrage gates and fishways (Bice et al. 2018a; Bice & Zampatti 2017b; Bice et al. 2023). The importance of system connectivity in the

CLLMM was demonstrated during the Millennium Drought (1996–2010), with the closure of barrages and fishways from 2007–2010 causing diadromous fish populations to decline substantially (Bice et al. 2018a; Bice et al. 2021).

Five diadromous species inhabit the CLLMM, including pouched lamprey (*Geotria australis*), short-headed lamprey (*Mordacia mordax*), short-finned eel (*Anguilla australis*), congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*) (Bice et al. 2018b). The most abundant diadromous fish species in the CLLMM are congolli and common galaxias (Bice et al. 2019) and are thus the focus of this assessment and evaluation.

The life history of the congolli is represented in Figure 10-1 and shows the differences in the life histories between sexes. Adult female congolli are fully catadromous, meaning they migrate from freshwater habitats to marine habitats to spawn (Bice et al. 2021). During winter, adult females move downstream from the River Murray and Lakes and through the Coorong to spawn in the Southern Ocean over winter/spring (Bice et al. 2018a). Adult males primarily reside in the estuarine environments (e.g. Coorong) (Cheshire et al. 2013) and are presumed to also migrate to the Southern Ocean to spawn. Females become sexually mature at 3 to 4 years of age (Hortle 1978 in Bice et al. 2019), however males may mature faster than females (Cheshire et al. 2013). Spawning, and larval and juvenile development occur in the Southern Ocean (Bice et al. 2019), with juveniles then migrating upstream to freshwater habitats in spring/summer (Bice et al. 2021). It is speculated that congolli may undergo environmental sex determination, with individuals that enter freshwater developing as females and individuals that remain in marine and estuarine environments developing as males (Crook et al. 2010).

The life history of common galaxias is represented in Figure 10-2. Common galaxias are semi-catadromous, meaning they migrate from freshwater to estuarine habitats rather than marine habitats to spawn (Bice et al. 2021). Sexual maturity is reached at one year of age, and adults of both sexes migrate downstream from the River Murray and Lakes to spawn in the Coorong estuary in winter/spring (Bice et al. 2021). Freshwater flows disperse larvae to the Southern Ocean, where they develop into juveniles (Bice et al. 2021). Juveniles then migrate upstream in spring/summer to freshwater habitats of the Lakes and tributaries of the eastern Mount Lofty Ranges (Bice et al. 2018b), where they mature into adult fish (Bice et al. 2021).

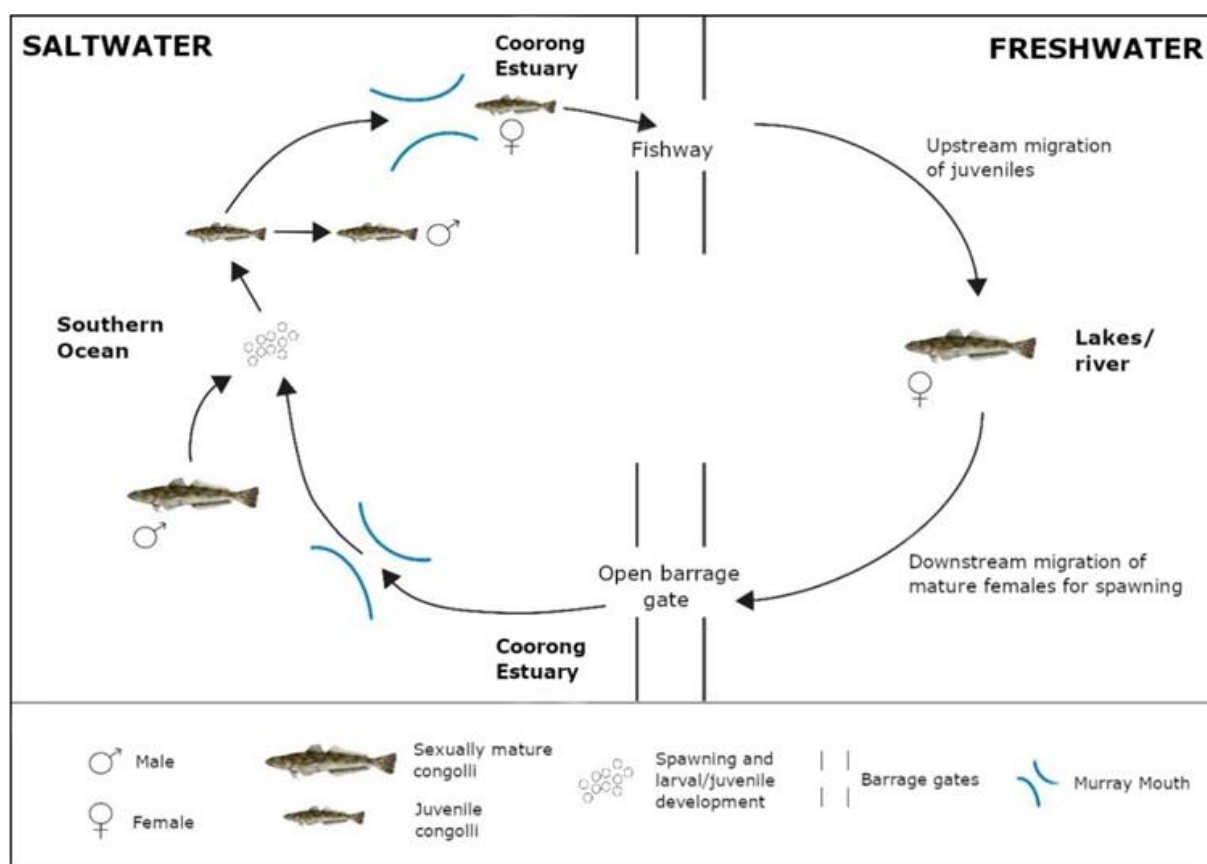


Figure 10-1. Life history of congolli in the Coorong, Lower Lakes and Murray Mouth (CLLMM).

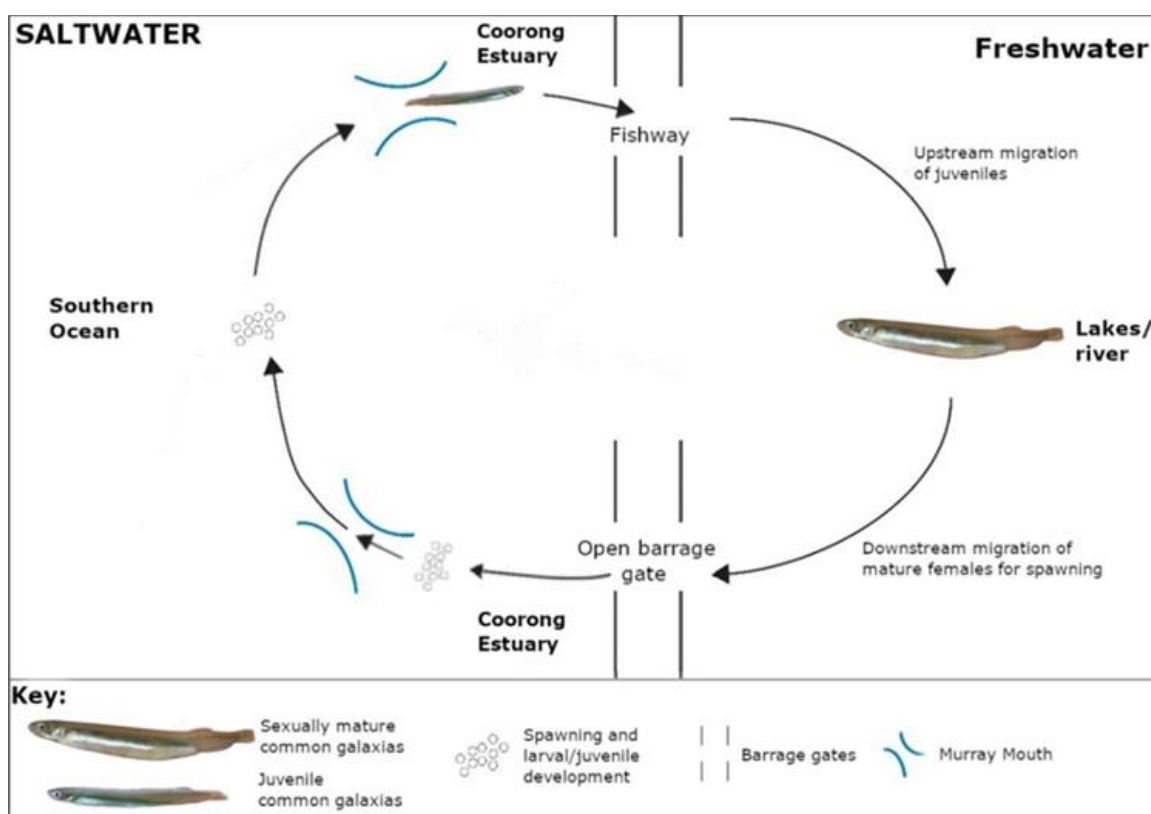


Figure 10-2. Life history of common galaxias in the Coorong, Lower Lakes and Murray Mouth (CLLMM).

10.2 Ecological objective, targets and environmental outcomes

The ecological objective and targets for diadromous fish (congolli and common galaxias) as described in the [South Australian River Murray Long-term Watering Plan](#) (LTWP) (DEW 2020) are presented in Table 10–1. The ecological targets for diadromous fish in the CLLMM are from the ‘Diadromous fish’ chapter (Bice & Zampatti 2017b) of the [LLCMM Icon Site Condition Monitoring Plan](#) (DEWNR 2017). The ecological targets formed the basis of the expected environmental outcomes for congolli and common galaxias in the CLLMM PEA.

Table 10–1. Ecological objective and targets for diadromous fish recruitment in the CLLMM PEA.

Ecological objective	Ecological targets
Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lakes and Coorong	Annual detection of juvenile congolli fish ≥ 44.5 (young-of-year; YOY hr^{-1}) of the defined Recruitment Index (RI)
	Annual detection of juvenile common galaxias fish ≥ 6.1 (young-of-year; YOY hr^{-1}) of the defined Recruitment Index (RI)

The expected environmental outcomes for congolli and common galaxias based on annual Recruitment Index (RI) scores in 2019, 2029 and 2042 were determined by elicitation with key experts. Over time, it is expected that the percentage of years that congolli and common galaxias (Table 10–2) meet their respective RI values will remain relatively stable (Figure 10-3).

Table 10–2. Expected environmental outcomes for annual congolli and common galaxias fish Recruitment Index (RI) values. All expected outcome values are years since Basin Plan adoption (i.e. since 2012).

Species	Expected outcome	2019	2029	2042
Congolli	Annual RI ≥ 44.5 (YOY hr ⁻¹) in:	6.5* of 7 (93%)	15 of 17 (88%)	23 of 30 (77%)
Common galaxias	Annual RI ≥ 6.1 (YOY hr ⁻¹) in:	5.5* of 7 (79%)	14 of 17 (82%)	23 of 30 (77%)

*Note: absence of whole numbers is due to averaged results from three experts. For assessment these numbers have been rounded up.

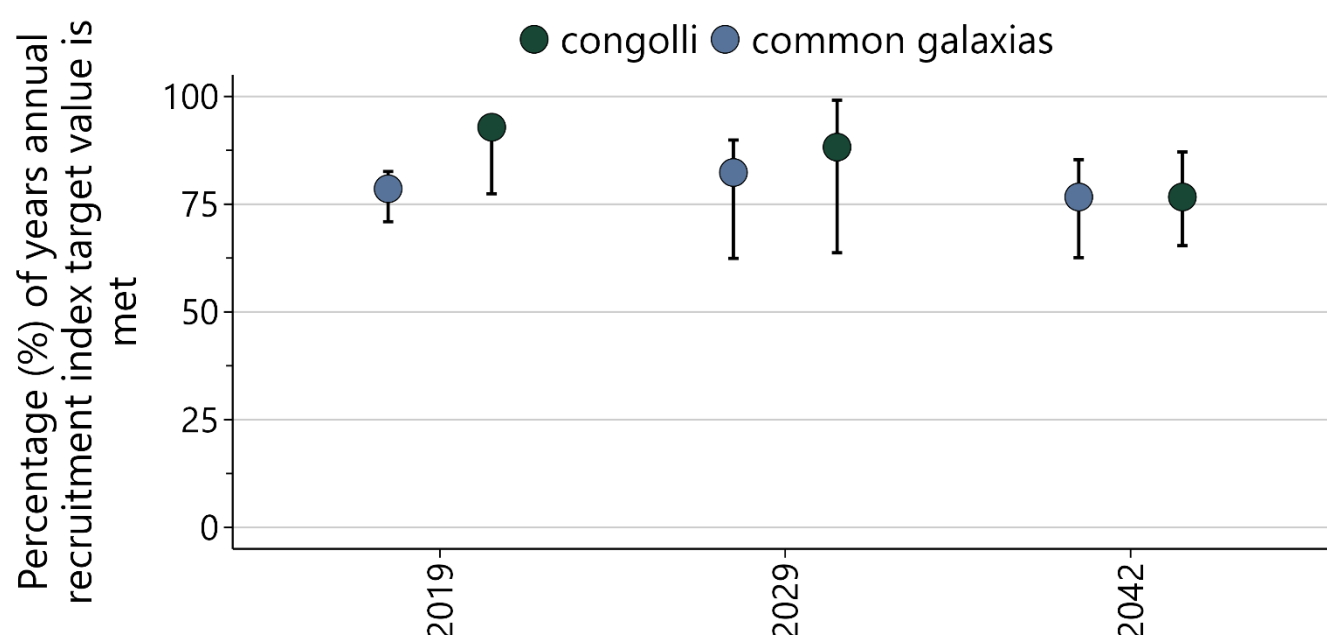


Figure 10-3. Percentage of years ($\pm 80\%$ confidence interval) since adoption of the Basin Plan that annual Recruitment Index target values for congolli and common galaxias were expected to be met in 2019, 2029 and 2042.

10.3 Method

The methodology for diadromous fish monitoring followed that of Bice and Zampatti (2017b) as described in the [LLCMM Icon Site Condition Monitoring Plan](#) (DEWNR 2017) and summarised below. Data collection was funded by TLM program and the MDBA. TLM program is a joint initiative funded by the New South Wales, Victorian, South Australian, Australian Capital Territory and Commonwealth governments, coordinated by the MDBA.

Fish are sampled at up to six sites across the River Murray barrages, including fishways on Tauwitchere and Goolwa barrages, sites adjacent to these barrages, and at Hunters Creek causeway fishway. The entrances to the vertical slot fishways are sampled using cage traps designed to fit in to the first cell of each fishway, while the site adjacent the Tauwitchere rock ramp and adjacent Goolwa Barrage are sampled with a large double-winged fyke net.

A week of fish sampling (four weeks in total) is conducted for each month from October to January. Vertical slot fishways are sampled overnight typically three times per sampling week and the sites adjacent the Tauwitchere rock ramp and adjacent Goolwa Barrage are sampled once overnight per sampling week. All trapped congolli and common galaxias are identified, counted and, during each trapping event, a random subsample of up to 50 individuals are measured to the nearest millimetre (total length, TL) to represent the size structure of the population.

Data has been collected by SARDI Aquatic Sciences for the DEW since 2006–07 primarily through TLM condition and intervention monitoring program in the Lower Lakes, Coorong and Murray Mouth. Data is used to inform barrage and fishway operations and the delivery and management of water for the environment.

10.3.1 Recruitment Index (RI) calculation

The RI calculations are detailed in Bice and Zampatti (2017b) and summarised below.

An annual RI is determined for congolli and common galaxias by calculating the overall site abundance of upstream migrating YOY (i.e. fish hr⁻¹) during the sampling period (Table 10–3). This is then compared against a predetermined reference value that was calculated by using monitoring data from 2006–07, 2010–11, 2011–12 and 2013–14, which comprises of years that had variable barrage flows.

Table 10–3. Sampling period and young-of-year (YOY) size thresholds for congolli and common galaxias.

Species	Sampling period	Young-of-year (YOY) size
Congolli	November to January	<60 mm TL
Common galaxias	October to December	<40 mm TL

Annual RI were calculated for congolli using Equation 1 and for common galaxias using Equation 2.

Equation 1

$$RI = (S_1(\text{mean}((r \cdot A_{Nov}) + (r \cdot A_{Dec}) + (r \cdot A_{Jan})) + S_2(\text{mean}((r \cdot A_{Nov}) + (r \cdot A_{Dec}) + (r \cdot A_{Jan})), \dots, S_n)$$

where S = site, A = abundance (fish hr⁻¹) and r = the percentage of the sampled population comprised of YOY (i.e. <60 mm TL).

The RI value was calculated with the above equation using monitoring data from the years 2006–07, 2010–11, 2011–12 and 2013–14. A final reference value was calculated using the equation below:

$$RI_{\text{final}} = \text{mean} (RI_{2006-07} + RI_{2010-11} + RI_{2012-13} + RI_{2013-14}) \pm \text{half confidence interval.}$$

$$RI_{\text{final}} = 44.26 \pm 21.78 \text{ YOY hr}^{-1}.$$

Equation 2

$$RI = (S_1(\text{mean}((r \cdot A_{Oct}) + (r \cdot A_{Nov}) + (r \cdot A_{Dec})) + S_2(\text{mean}((r \cdot A_{Oct}) + (r \cdot A_{Nov}) + (r \cdot A_{Dec})), \dots, S_n)$$

where S = site, A = abundance (fish hr⁻¹) and r = the percentage of the sampled population comprised of YOY (i.e. <40 mm TL).

The RI value was calculated with the above equation using monitoring data from the years 2006–07, 2010–11, 2011–12 and 2013–14. A final reference value was calculated using the equation below:

$$RI_{\text{final}} = \text{mean} (RI_{2006-07} + RI_{2010-11} + RI_{2012-13} + RI_{2013-14}) \pm \text{half confidence interval.}$$

$$RI_{\text{final}} = 6.12 \pm 3.00 \text{ YOY hr}^{-1}.$$

10.3.2 Trend assessment

Trend analysis was undertaken using the approach detailed in section 4.2.2. The model for diadromous fish assessed the probability of trend (positive or negative) in the change of upstream migrating YOY fishes (YOY hr⁻¹) between 2006–07 and 2022–23. The gamma distribution was used, with an interaction term between time step (years since the commencement of the assessment period) and species to facilitate different intercepts and slopes for congolli and common galaxias. The model specification was:

$$RI \sim \text{time step} * \text{species}$$

10.3.3 Information reliability

The information reliability assessment for diadromous fish recruitment in the CLLMM was conducted as per section 4.2.3.

10.3.4 Limitations

Caution needs to be taken when interpreting results during high-flow years, as the sampling methodology is limited by the sampling season and peak-flows potentially converging at the same time. During flood events, head differential (difference in water upstream and downstream water levels) across the barrages can be reduced for extended periods, allowing fish to bypass the barrages via open barrage gates rather than the fishways. Thus, migratory fish may avoid capture in fishways, and abundance may be underrepresented. In these instances, an assessment of head differential across the sampling season can aid interpretation.

10.4 Results

10.4.1 Recruitment index (RI)

The annual RI value for congolli was very low in 2006–07, with 18.2 YOY migrating upstream per hour (Figure 10-4). Between 2007–08 and 2009–10, recruitment – defined as the abundance of upstream migrating YOY – was minimal, with RI values ranging between 0.07 and 0.14. Annual RI values increased in 2010–11 and 2011–12 to 7.6 and 16.3, respectively. No monitoring was undertaken in 2012–13, when the Basin Plan was adopted. Since then, congolli RI values increased from 183.1 in 2013–14 to a peak of 395.4 in 2014–15. RI values have then been variable ranging between 74.4 in 2015–16 and 190.4 in 2020–21. After 2020–21, RI values have reduced to 46.4 in 2021–22 and 2.7 in 2022–23.

The annual RI value for common galaxias was moderate in 2006–07, with 11.7 YOY hr⁻¹ migrating upstream (Figure 10-4). In 2007–08 and 2008–09, recruitment of common galaxias was minimal with RI values below 0.1. Annual RI values remained low from 2009–10 to 2011–12 but increased over this period from 3.5 to 6.6. No monitoring was conducted in 2012–13, when Basin Plan was adopted. From 2013–14 to 2015–16, annual RI values were relatively high, ranging from 11.6 to 29.4. In 2016–17, there was a great reduction in the RI value to 2.2, however this result should be treated with caution as discussed in section 10.3.4 (Limitations). From 2016–17 to 2020–21, RI values increased year on year to 16.1. RI values reduced to 4.5 in 2021–22 and 1.4 in 2022–23, which were among the lowest observed since the Millennium Drought, however the likely mechanisms behind this decline are discussed in section 10.3.4.

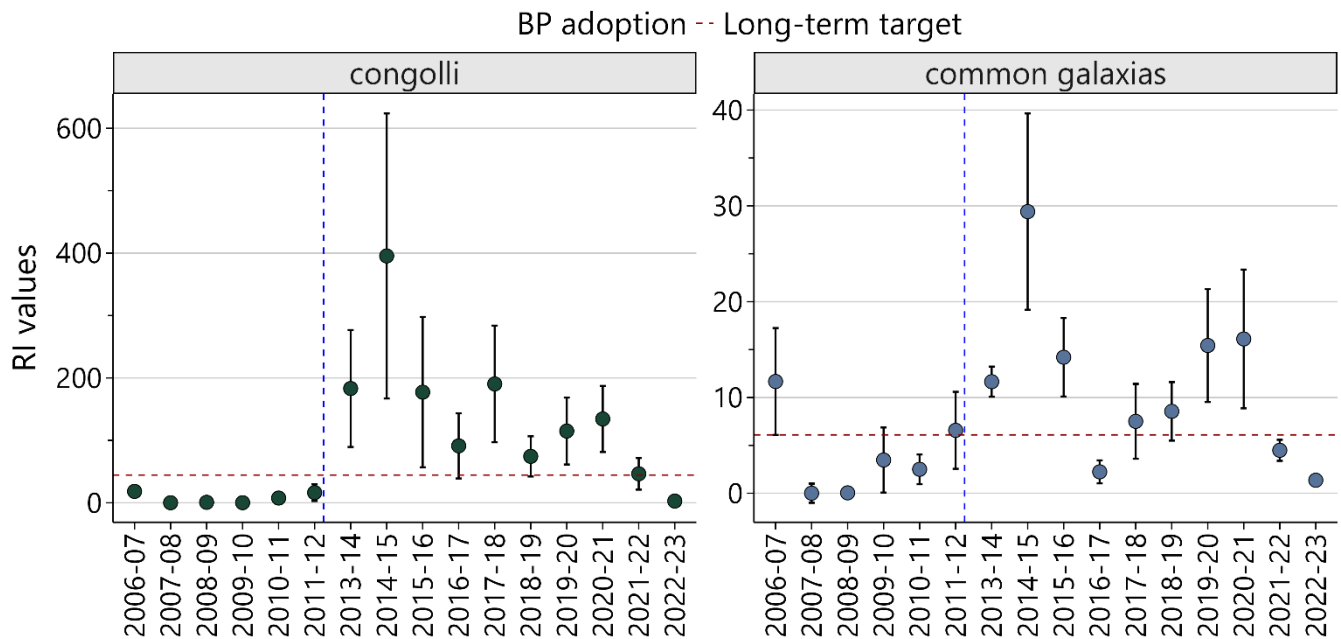


Figure 10-4. Annual recruitment index (RI) value, measuring the number of upstream migrating YOY hr^{-1} congolli and common galaxias from 2006–07 to 2022–23. Basin Plan adoption (2012) is shown as a vertical dashed blue line and the Long-term Watering Plan (LTWP) target is shown as a horizontal dashed red line. NB: no monitoring was conducted in 2012–13. Data source: SARDI.

10.4.2 Environmental outcome assessment

In 2019, it was expected that the RI target values would be exceeded in all monitoring years (2013–14 to 2019–20) for congolli, and 79% (i.e. 6 out of 7 years) of years since the adoption of the Basin Plan for common galaxias. Congolli exceeded their annual recruitment index target value in all six years (100%), while common galaxias met their annual recruitment target value in five of six years (83%) from 2013–14 through to 2019–20. As such, in 2019, the expected outcome was considered met for both species (see Figure 10-5).

Since 2019, the frequency of years that both species have met their recruitment index target values has decreased (Figure 10-5). Congolli had a lower RI value than its target in 2022–23 (Figure 10-5a). This has resulted in a slight decrease in the proportion of years since adoption of the Basin Plan that this species has achieved its RI target value, compared to all years previously (Figure 10-5a). Currently, the RI value for congolli is above the value expected in 2029, and therefore RI values are considered to be on-track towards the 2029 expected outcome. In contrast, the RI value for common galaxias increased slightly (~4%) after 2018–19, but has declined in the most recent years to below the 2029 expected value (Figure 10-5b). It is however, still within the confidence limits of the 2029 expected outcome and thus, RI values are considered likely to be on-track towards the 2029 expected outcome.

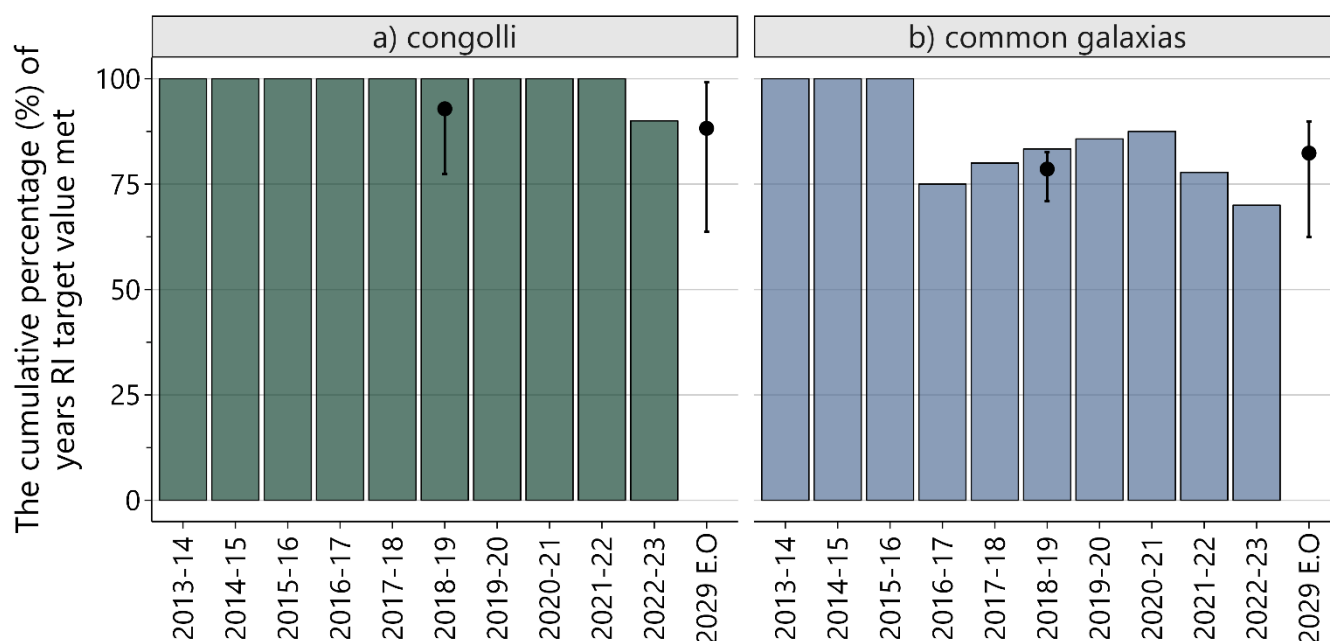


Figure 10-5. The cumulative percentage of years that the annual RI target value has been met through time since adoption of the Basin Plan for a) congolli and b) common galaxias. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars. Data source: SARDI.

10.4.3 Trend

The recruitment index values for congolli and common galaxias were extremely likely (95% probability) and likely (72.5% probability) to have **improved**, respectively (Figure 10-6b). A greater probability for an increase in RI values exists for congolli than common galaxias, yet the uncertainty in this estimate was also greater (as shown in Figure 10-6a). However, there has been a decline in RI values for congolli since 2013–14 and draws for estimated trend lines for this species were strongly weighted by values during the Millennium Drought.

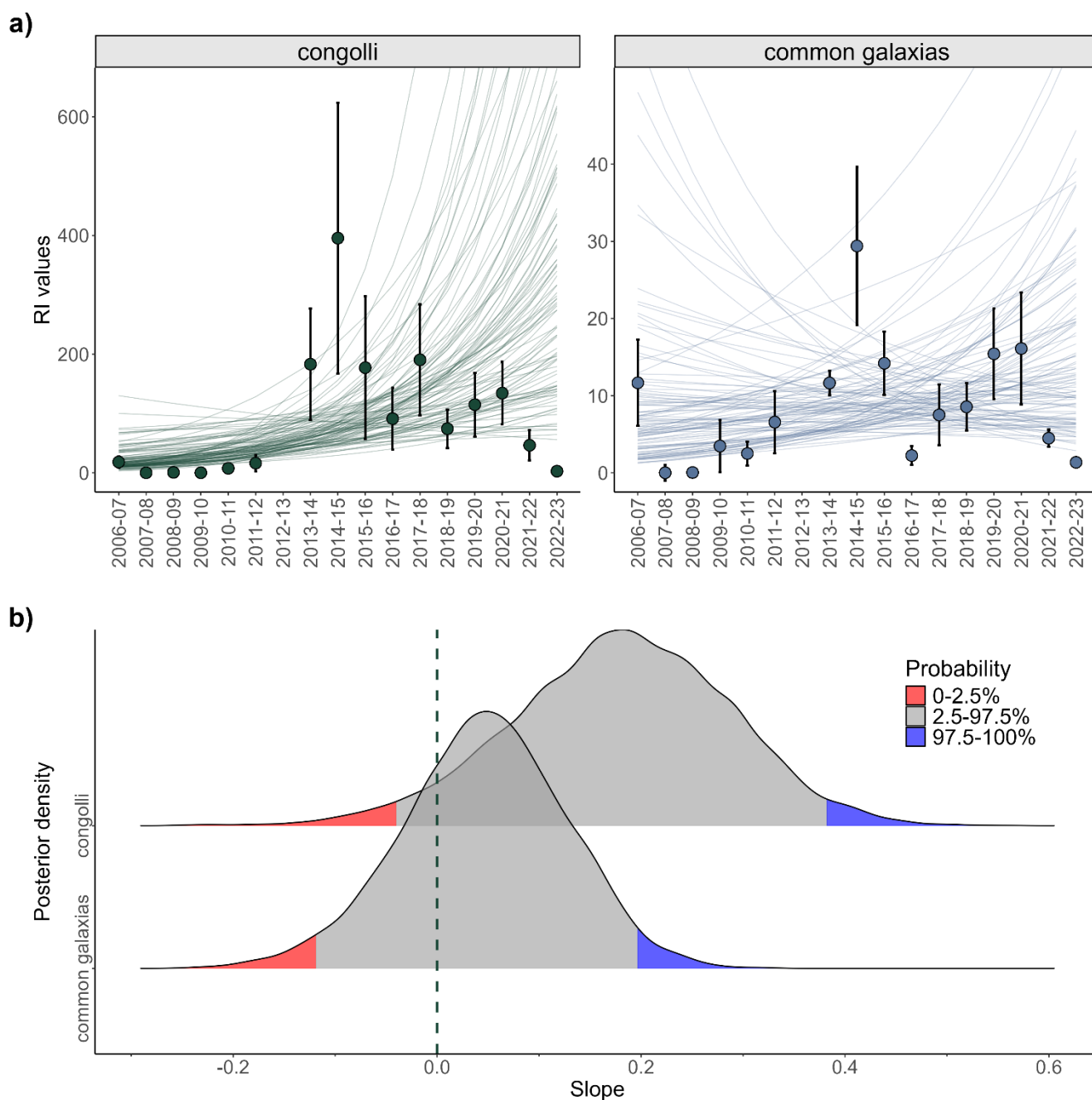


Figure 10-6. a) A hundred randomly drawn estimated slopes from the interaction model, based on expected posterior predictions representing the conditional effect (based on species) of the time step. b) Estimated values for the slope generated from Bayesian modelling for recruitment index values for congolli and common galaxias from 2006–07 to 2022–23. Posterior slope values > 1 infer a positive trend (improved) and values < 1 infer a negative trend (declined).

10.4.4 Information reliability

The information reliability rating for diadromous fish recruitment is **good** (final score of 10). Justification for the scoring for diadromous fish recruitment information reliability is provided in Table 10–4.

Table 10–4. Reliability of diadromous fish recruitment index data to assess the expected environmental outcomes for diadromous fish (congolli and common galaxias). The methods used in data collection as well as the representativeness and repetition of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data collected were scored 2 points – Yes, 1 point – Partially and 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Partially. The same method has been used at individual sampling sites over the monitoring program, however, there are differences in methods between sites due to differences in the size and type of barrage fishways.	1
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Murray Estuary with equal effort?	Yes. Sampling sites are well spread across the Murray barrages.	2
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. Sampling has been conducted from 2006–07 to 2022–23, and therefore includes a range of hydrological conditions.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Partially. There has been an increase in the geographical spread of sites over the monitoring program associated with the construction of new fishways.	1
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Yes. Sampling was conducted on an annual basis (except for the absence of sampling in 2012–13) and over a time period (October–January) that the majority of congolli and common galaxias YOY migrate upstream.	2
Final score			10
Information reliability			Good

10.5 Evaluation

Over the period 2006–07 to 2022–23, the recruitment of congolli and common galaxias have generally improved. These diadromous fish species both exceeded their respective annual RI target values in most years since the adoption of the Basin Plan (congolli and common galaxias, 9 and 7 out of 10 years, respectively).

Years of failure to meet RI targets, in part, can be explained by variability in timing of migration and the influence of flow on sampling efficiency. For instance, the annual RI value for common galaxias is calculated for the period of October–December (typical peak migration period). In 2016–17, peak abundance of upstream migrants was observed in January, most likely due to the influence of decreasing barrage discharge on sampling efficiency. This resulted in a low RI value for common galaxias and failure to meet the target value, yet inclusion of January in RI calculation would have resulted in the target being met (Bice & Zampatti 2017a). Therefore, since the adoption of the Basin Plan, the annual recruitment of congolli and common galaxias are considered to have surpassed their recruitment index target values in each year of this assessment until 2021–22 and 2022–23 (see section 10.5.3 Unanticipated outcomes).

The delivery of water for the environment recovered through the Basin Plan has contributed to improved connectivity by maintaining open barrage gates in winter, and increased volumes of water reaching the Coorong in spring and summer, supported by the operation of fishways and provided flow cues for upstream movement (see section 10.5.1). Additionally, in years when high (unregulated) flows did not occur during winter months (i.e. 2015, 2017, 2018 and 2019), the coordinated delivery of water for the environment, with contributions from upstream catchments (particularly the Goulburn) to winter flow pulses in the SA River Murray, likely supported diadromous fish movement and recruitment. The lack of freshwater inflows and loss of connectivity due to closure of the barrages (see Figure 3-5) and fishways during the Millennium Drought, resulted in negligible recruitment of diadromous fish and subsequently a depleted population of reproductively mature adults (Bice et al. 2019). Thus, the low abundance of reproductively mature adults likely also negatively influenced diadromous fish recruitment, delaying observed recovery post flood (Bice et al. 2019).

10.5.1 System connectivity

Barrage flows, including water for the environment, has contributed to the improved recruitment of diadromous fish in the CLLMM by maintaining system connectivity. The delivery of water to maintain open barrage gates in winter and operable fishways in spring/summer has improved diadromous fish recruitment, however, the abundance of juveniles were likely limited by the low population of reproductively mature adults until 2014–15 (Bice et al. 2021) (Figure 10-7; Figure 10-8). From 2014–15 to 2020–21, the abundance of juvenile congolli and common galaxias were strongly associated with the percentage of days when at least one barrage gate was open in winter to support downstream spawning migrations (referred to as open days). However, this association between diadromous fish recruitment and open days in winter did not occur in 2021–22 and 2022–23, likely due to dilution effects influencing sampling efficacy during high flow years (Chris Bice, personal communication, August 2023) (see section 10.5.3).

The Millennium Drought reduced flows and connectivity, resulting in negligible recruitment of diadromous fish and a depletion of the population of reproductively mature adults. When flows returned in late 2010, connectivity was restored through barrage gates and fishways (Bice et al. 2021). Since 2019, all 11 barrage fishways have remained open, except for the closure for maintenance on the northern and southern fishways of the Goolwa Barrage in 2020. During 2020, only one of three fishways was closed, so connectivity was maintained through the Goolwa Barrage (Figure 10-8). In 2021–22 and 2022–23, high flows from the River Murray resulted in increased connectivity between the river and Murray Estuary, however these flows did not translate into an improvement in recruitment index (see unanticipated outcomes section 10.5.3 below for explanation).

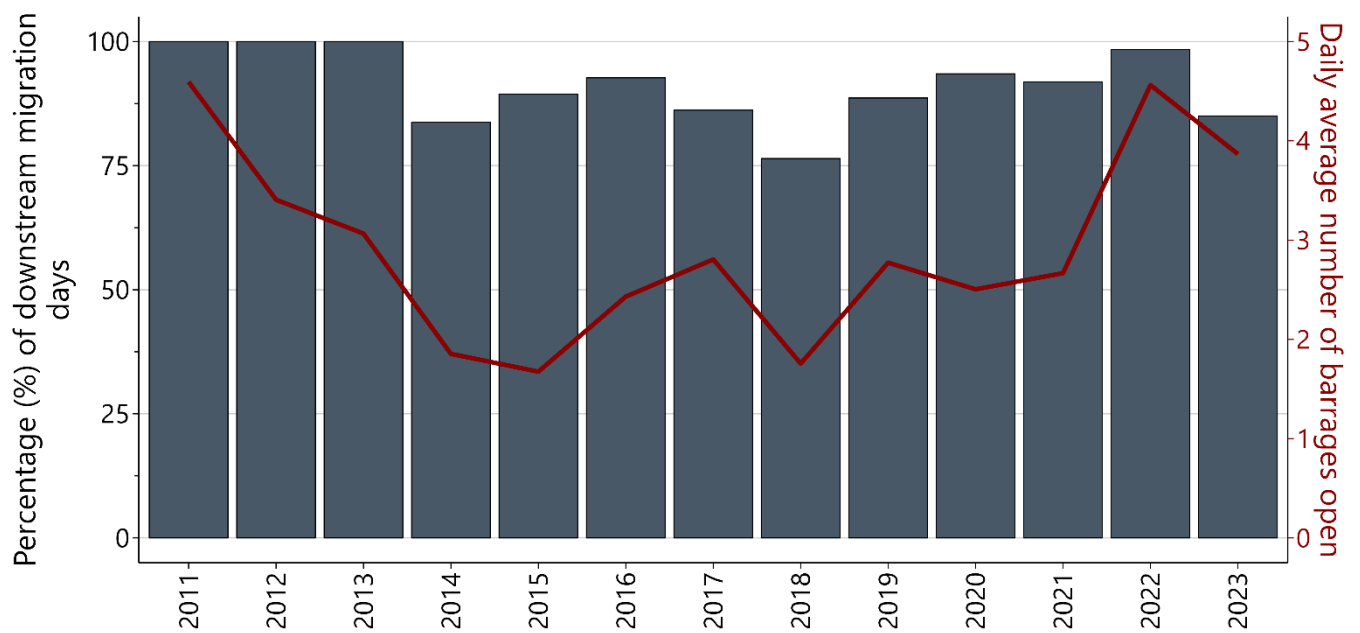


Figure 10-7. The proportion of downstream migration days (May to August) per year with at least one gate open on any barrage (grey bars), and the daily mean number barrages open during those same months (red line). Note: this graph does not include operational fishway data (see Figure 10-8 for fishway data).

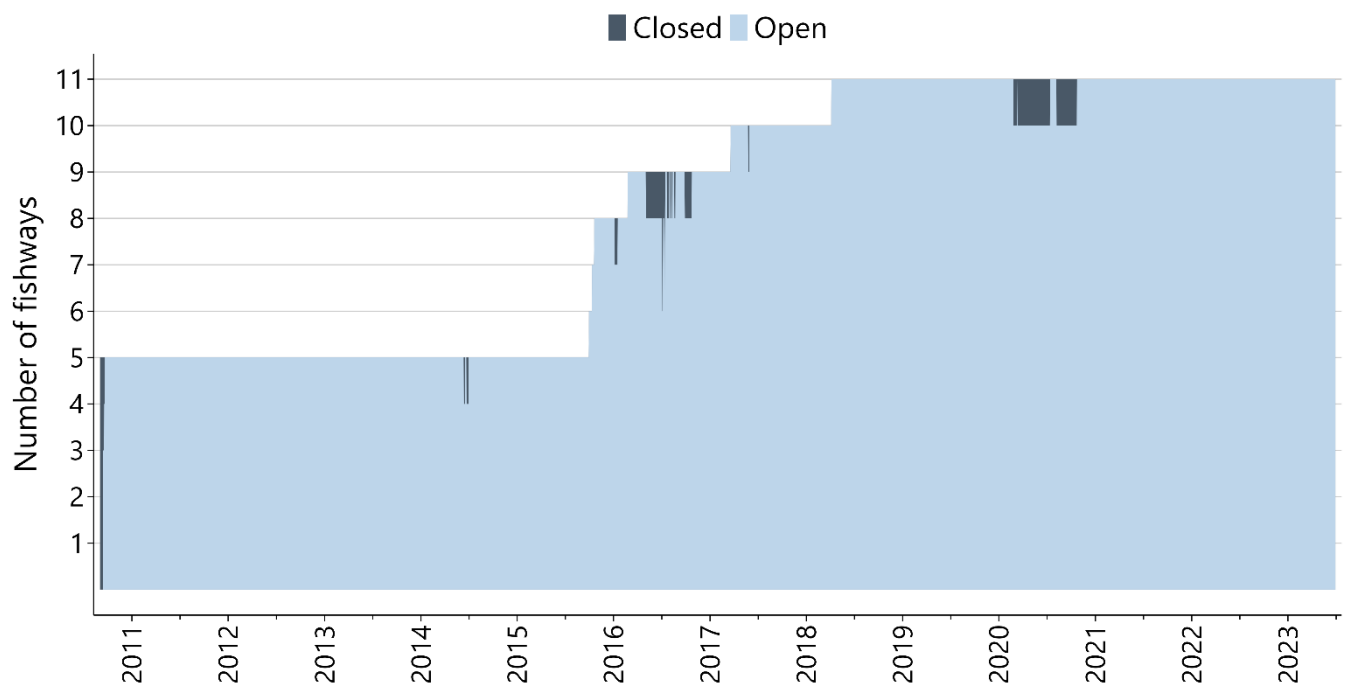


Figure 10-8. The number of constructed, and open (blue shaded) or closed (black shaded) status, of fishways through time.

10.5.2 Open Murray Mouth

A permanently open Murray Mouth is critical to the recruitment of congolli and common galaxias (Bice et al. 2018a; Bice et al. 2018b). Adult congolli complete their downstream migration by passing through the Murray Mouth, prior to spawning, while juveniles must make a similar, but upstream migration through the Murray Mouth (Bice & Zampatti 2017a; Bice et al. 2018b). While common galaxias spawn in the Coorong, larvae are typically flushed to the ocean and undertake a marine larval phase (although some intra-estuarine development likely occurs in the Coorong), before migrating upstream (Bice et al. 2018a).

Freshwater flows alone have been inadequate to maintain an open Murray Mouth over the entire assessment period, with dredging required from 2006–07 to 2022–23 during periods of low flows and constriction. Since adoption of the Basin Plan, dredging has been in operation 67% of years, only ceasing during and immediately following periods of high barrage flow (2010–11 and 2011–12, 2016–17 and 2022–23), as these events ($>60 \text{ GL day}^{-1}$) naturally scour the Murray Mouth (Figure 10-9). Despite contributing to improvements in system connectivity, it is not considered a primary factor that has influenced the recruitment of congolli and common galaxias in the CLLMM.

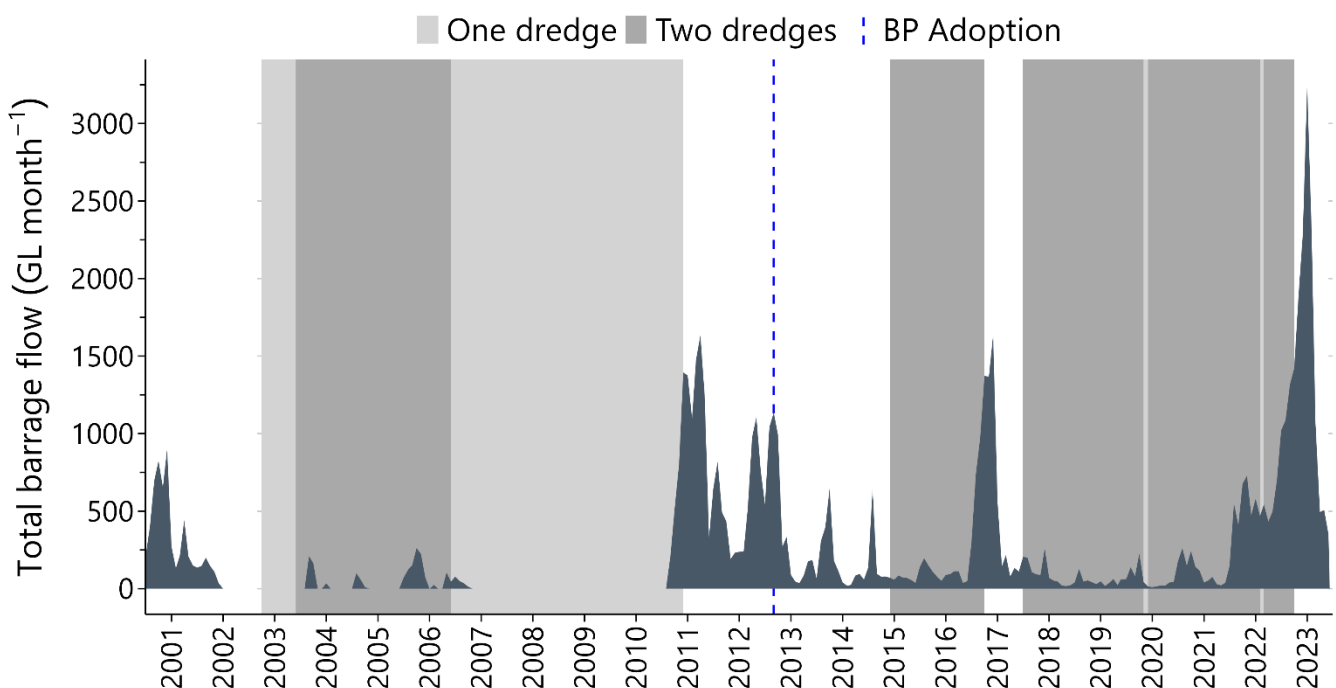


Figure 10-9. Dredging operations at the Murray Mouth from 2000 to 2023, with respect monthly barrage discharge (ML month⁻¹) and adoption of the Basin Plan (blue dashed line). White = no dredges, light grey = 1 dredge in operation and dark grey = 2 dredges in operation.

10.5.3 Unanticipated outcomes

The high flow events of 2016–17, 2021–22 and 2022–23 were expected to result in high RI values given the increased connectivity between freshwater, estuarine and marine habitats, however, observed recruitment in these years were particularly low. In 2021–22 and 2022–23, the relationship between open barrage gates and recruitment indices for congolli and common galaxias was not correlated like all other sampling years since 2014–15. The reasons behind the lower-than-expected recruitment indices for congolli and common galaxias remain a knowledge gap, however, it may have been influenced by (Chris Bice, personal communication, August 2023):

- YOY bypassing fishways and instead passing through open barrage bays when migrating upstream due to a high number of open gates and higher frequency of similar water levels (low head differential)

between the Lakes and Murray Estuary. Low head differential means flow velocities through barrage gates are minimised and passage may be directly facilitated via barrage gates.

- the timing of fish sampling at the Murray barrages. The change in timing may have influenced the congolli recruitment index as the vertical slot fishway that traditionally has higher captures was not accessible in January and instead was surveyed in February, which may have missed the month of peak upstream migration, and
- changes in physico-chemical water conditions leading to decreased motivation for migration, i.e. high flows and open barrage gates reducing the difference in salinity between estuary and lake, which is typically accepted as a primary cue for migration.

During high (unregulated) flows there are an increased number of open barrage gates and low head loss between the Lakes and Murray Estuary (Figure 10-10). This provides YOY diadromous fish with greater opportunity to bypass fishways and migrate upstream from the Murray Estuary to the Lakes through open barrage gates. While fishways remain open during these flow conditions, their efficacy may be reduced as discharge is more widespread across the barrage network. In contrast, during low flow years, water is regularly discharged from gates adjacent to fishways, in what is referred to as 'attractant flow', which provides physicochemical cues that guide migrating fish to fishway entrances and maximises their efficacy.

With increased connectivity through an increased number of open barrage gates, and generally elevated water levels in the Murray Estuary, head loss between the Lakes and Murray Estuary are also reduced, which in turn decreases the attractant flow and likelihood of fish utilising the fishways for migration (Zampatti et al. 2012). In 2016–17, 2021–22 and 2022–23 (higher flow years), the lower RI values coincided with decreased head differential between the Lakes and the Murray Estuary/Coorong (Figure 10-10) (Bice et al. 2023; Zampatti et al. 2012).

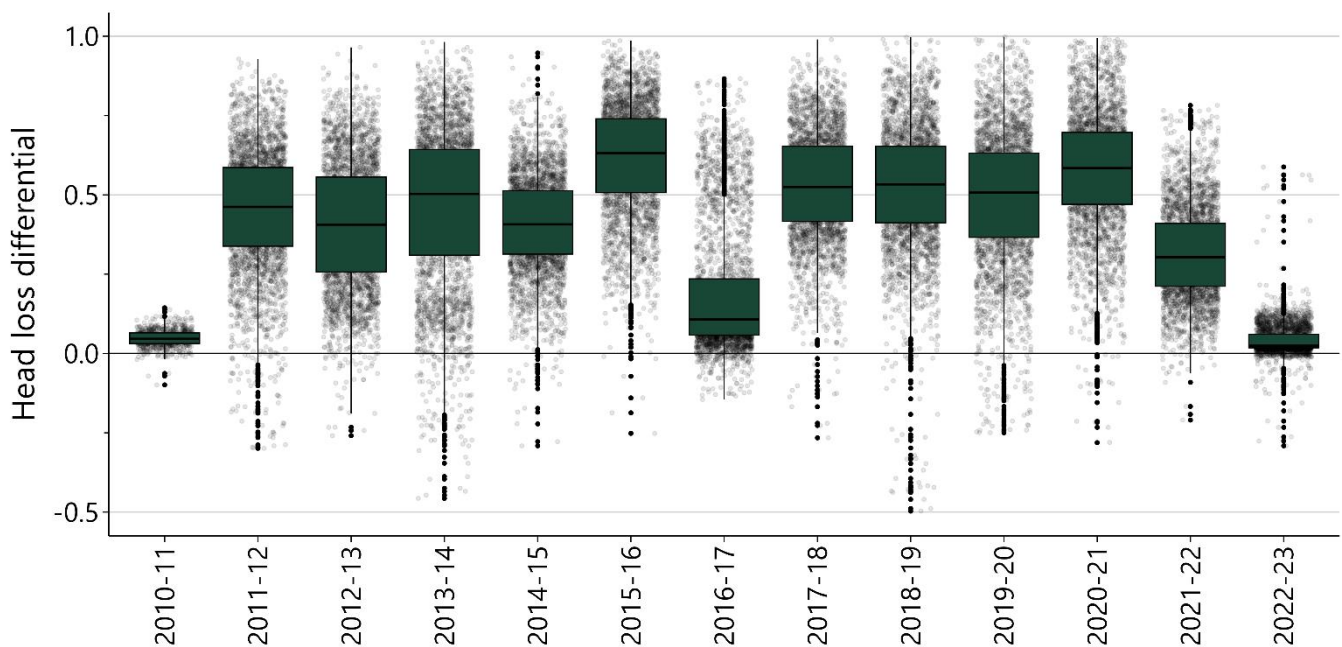


Figure 10-10. Boxplot of head loss differential between the Lakes and the Murray Estuary from 2010–11 to 2022–23 using hourly data. Solid black dots are outliers ($>1.5 \times \text{IQR}$).

The low RI values during years of high (unregulated) flows (e.g., 2016–17, 2021–22 and 2022–23) are not considered to be reflective of declining populations of congolli and common galaxias. Long-term data collected in other fish monitoring programs in the Lakes and Coorong found that the CPUE of both species varied from 2009–10 to 2022–23, and was even observed to have increased in high flow years in the Murray Estuary for both species, and in the South Lagoon and Lakes for congolli (Figure 10-11; Figure 10-12).

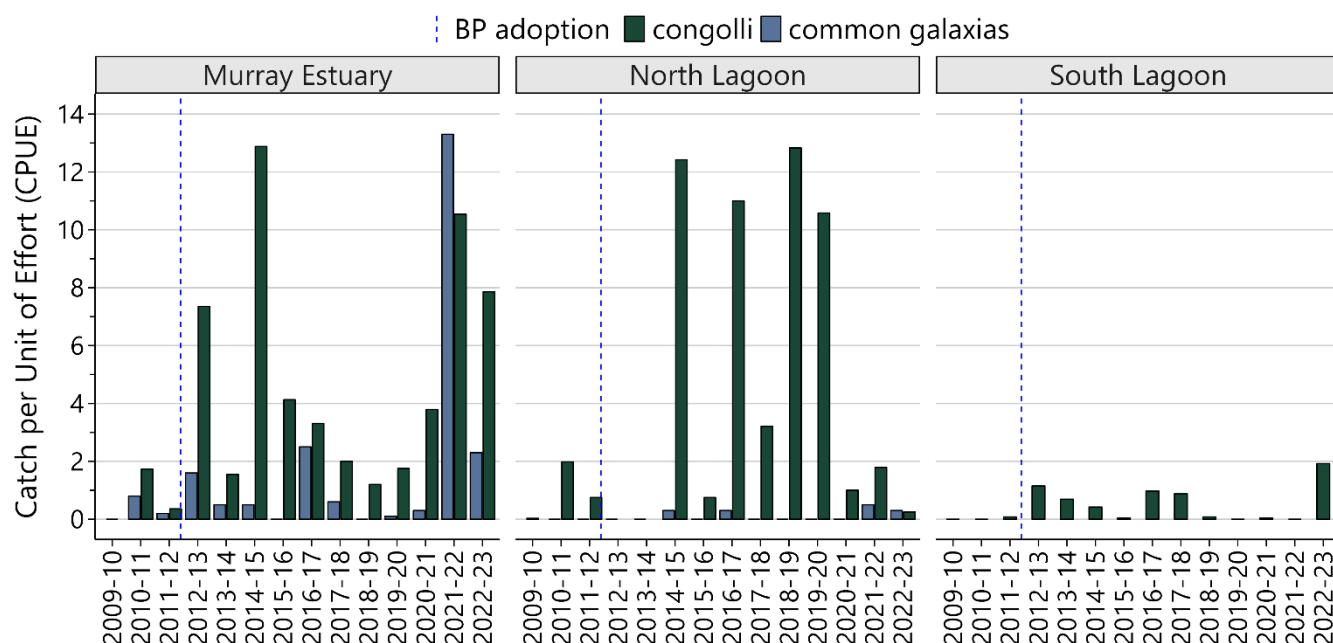


Figure 10-11. Catch per unit effort (CPUE) of common galaxias and congolli from sampling in the Murray Estuary, Coorong North Lagoon and South Lagoon from 2009–10 and 2022–23. Data source: Qifeng Ye, SARDI.

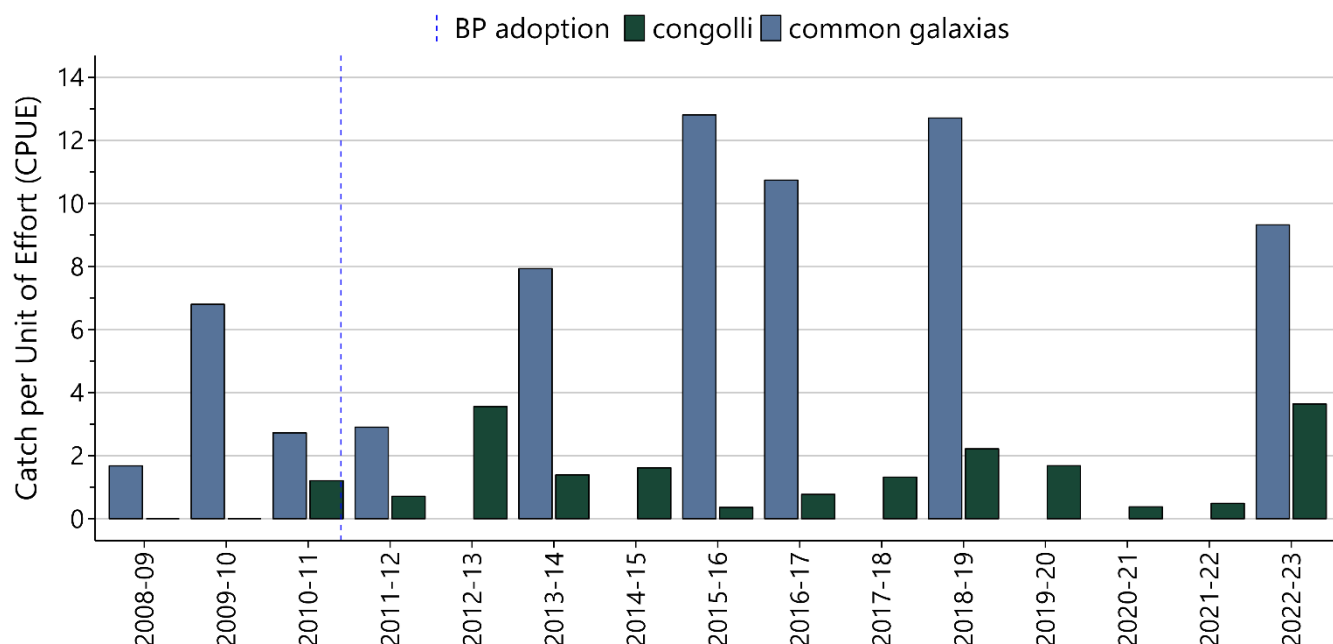


Figure 10-12. Mean annual catch per unit effort (CPUE) of common galaxias and congolli in the Lakes from 2009 to 2023. Data source: Scottie Wedderburn, The University of Adelaide.

10.5.4 Actions to achieve environmental outcomes

River Murray discharge through open barrage gates in winter and open fishways in spring/summer provides connectivity between freshwater, estuarine and marine environments, which enables downstream migration of adults for spawning in winter and upstream migration of juveniles from their spawning grounds to freshwater environments in spring/summer (Bice et al. 2021; Bice et al. 2018b). Flow may also contribute to greater attraction and ingress of juvenile congolli from the ocean and productivity pulses that improve recruitment (Bice et al. 2018b). Populations of congolli and common galaxias collapsed during the Millennium Drought when there was no barrage flow for three consecutive years, resulting in the closure of barrage gates and fishways (Bice et al. 2021; Bice et al. 2018b).

To ensure successful recruitment of congolli and common galaxias in future years, it is critical that bi-directional migration can occur. To support downstream spawning migration of congolli and common galaxias, winter flow pulses, supported by water for the environment, can be delivered to ensure water is available for discharge through open barrage gates. Upstream migration of juvenile congolli and common galaxias can be supported by the delivery of water, including water for the environment, in spring and summer to enable operation of fishways and contribute to 'attractant flow' through open barrage gates adjacent to fishways to guide migration and maximise their performance. Delivery of water for the environment is also used to maintain water levels in the Lakes above critical thresholds, which helps fishways to function properly.

There is potential to further promote upstream passage of congolli and common galaxias by opening barrage gates when water levels in Lake Alexandrina and the Murray Estuary are similar and the risk of saltwater ingress to Lake Alexandrina is low (i.e. under high flow conditions).

10.6 Conclusion

Recruitment of diadromous fish has improved due to increased system connectivity between freshwater, estuarine and marine habitats. Delivery of water for the environment to maintain open barrage gates in winter and operable fishways with attractant flow in spring and summer, enables congolli and common galaxias to migrate downstream and upstream, and complete their lifecycles. The expected environmental outcome for congolli and common galaxias in 2029 is likely on-track to be achieved, and recruitment levels for both species are expected to be maintained into the future.

11 Small-mouthed hardyhead



Trend
Improved



Reliability
Very good

Key findings and messages:

- Small-mouthed hardyhead recruitment has improved from 2008–09 to 2022–23, with increased barrage flows including from recent high (unregulated) flow events, contributing to improvements in suitable Coorong habitat conditions.
- Recent improvements in the population condition of small-mouthed hardyhead, including maintained extent of recruitment, indicate progress towards the 2029 expected outcome.
- Adoption of the Basin Plan, including the delivery of water for the environment, has supported the management of barrage flows that have contributed to increased spatial and temporal extent of suitable salinity conditions for small-mouthed hardyhead.
- An open Murray Mouth is critical to the Coorong and maintenance of small-mouthed hardyhead habitat, providing system connectivity, enhancing productivity and enabling improvements in salinity conditions and recruitment of small-mouthed hardyhead.
- Flows from Salt Creek are important for maintaining localised habitat within the Coorong South Lagoon and provide refugia habitat, particularly during years of low flows.
- High (unregulated) flow events are important for maintaining and restoring water levels and salinities as well as enhancing productivity, improving the distribution and recruitment of small-mouthed hardyhead.
- Full implementation of the Basin Plan, particularly the recovery and delivery of the 450 GL of additional water for the environment and addressing current water delivery constraints, will ensure that water is able to be delivered to the Murray Estuary and Coorong during critical times supporting small-mouthed hardyhead.

11.1 Introduction

Small-mouthed hardyhead (*Atherinosoma micostoma*) are a small-bodied (<100 mm) fish that are native to south-eastern Australia (Lintermans 2007). Small-mouthed hardyhead inhabit the lower end of freshwater rivers, brackish lakes and wetlands, estuaries and hypersaline lagoons (Lintermans 2007). In the SA River Murray, the species occurs in the lowermost 100 km of the river and are in their greatest abundance within the Coorong (Wedderburn et al. 2008). The lifespan of small-mouthed hardyhead is short, completing their lifespan in one year and dying after spawning (Molsher et al. 1994).

Healthy populations of small-mouthed hardyhead are critical for the Coorong's food web, particularly in the South Lagoon (Giatas & Ye 2016; Goldsworthy et al. 2022; Ye et al. 2017). These fish are highly abundant in the North and South Lagoons of the Coorong (Dittmann et al. 2022) and are a major food resource for piscivorous fish and waterbirds (Giatas & Ye 2016; Paton 2010; Ye et al. 2023a). Given their ecological significance, the maintenance or

improvement of small-mouthed hardyhead abundance and distribution is an essential part of managing the ecological health of the Coorong (Ye et al. 2020c).

The abundance of small-mouthed hardyhead in the Coorong is driven by flows from the River Murray to the Coorong via the barrages. Freshwater flows help to maintain salinity within the preferred range ($<100 \text{ g L}^{-1}$), increases longitudinal and lateral connectivity (Ye et al. 2022b), and enhances productivity and food resource availability (Ye et al. 2020c). Zooplankton are a food resource for small-mouthed hardyhead (Hossain et al. 2017), and their transport via flows from the River Murray to the estuary likely promote recruitment (Ye et al. 2021). Seasonal reductions in salinity, influenced by freshwater flows, are likely a partial cue for spawning (Molsher et al. 1994). Furthermore, freshwater flows influence the condition of aquatic macrophytes that provide habitat and a substrate for egg adhesion for small-mouthed hardyhead, improving egg survival and recruitment (Molsher et al. 1994).

Salinity plays a significant role in supporting the health of small-mouthed hardyhead populations (Dittmann et al. 2022; Wedderburn et al. 2016; Ye et al. 2021). Small-mouthed hardyhead can tolerate a wide range of salinities and were recorded in salinities up to 130 g L^{-1} during the Millennium Drought in the Coorong (Noell et al. 2009). Salinities favoured by small-mouthed hardyhead are $35\text{--}100 \text{ g L}^{-1}$ (Dittmann et al. 2022; Noell et al. 2009), with abundances usually highest at approximately 80 g L^{-1} (Ye et al. 2020c), although high abundances have been observed up to 117 g L^{-1} (Dittmann et al. 2022). In hypersaline waters, small-mouthed hardyhead have an osmoregulatory advantage over other estuarine fish species (McNeil et al. 2013; Noell et al. 2009), likely reducing competition with, and predation by other fish species (Ye et al. 2020a). However, as waters become extremely hypersaline ($>100 \text{ g L}^{-1}$), approaching the osmoregulatory threshold of small-mouthed hardyhead ($\text{LD}_{50} 108 \text{ g L}^{-1}$) (Lui 1969), they can become physiologically stressed (Dittmann et al. 2022), and distribution and recruitment may become limited (Ye et al. 2011).

Connectivity, both longitudinally and laterally, is important to small-mouthed hardyhead. Longitudinal connectivity between the Coorong lagoons may allow the species to escape unfavourable water quality, such as when high salinities occur in the South Lagoon (Qifeng Ye, personal communication, December 2021). In addition, longitudinal connectivity can facilitate fish movement between North and South Lagoons, which may enable them access to favourable habitat with abundant aquatic macrophytes. Lateral connectivity between the Coorong and south east may also be important as Salt Creek likely provides low salinity refuge when salinity in the South Lagoon increases substantially. Fish monitoring at Salt Creek and Morella fishways having observed large numbers of small-mouthed hardyhead utilising fishways (Ye et al. 2022b).

Small-mouthed hardyhead were impacted during the Millennium Drought (1996–2010), particularly during the period of no barrage flows between 2007 and 2010 (Wedderburn et al. 2016). During this period, salinities in much of the Coorong exceeded the osmoregulatory limit of small-mouthed hardyhead and led to the $>50\%$ reduction in its distribution (Wedderburn et al. 2016). The population was confined to the Murray Estuary, North Lagoon and fresher waters within and near Salt Creek (Ye et al. 2022a). This impact had flow-on effects for higher trophic levels, including the nationally vulnerable Fairy Tern (*Sternula nereis nereis*) (Paton 2010), which rely on small-bodied prey fish as food resources.

11.2 Ecological objective, target and environmental outcomes

The ecological objective for the fish community and target for small-mouthed hardyhead in the CLLMM, as described in the [South Australian River Murray Long-term Watering Plan](#) (LTWP) (DEW 2020a), are presented in Table 11–1.

Sites with $>60\%$ proportional abundance of juveniles are considered to have supported significant recruitment. Therefore, any mention of the percentage of sites with significant recruitment will be based on the criterion of $>60\%$ proportional abundance.

Table 11-1. Ecological objective and target for small-mouthed hardyhead.

Ecological objective	Ecological target
Maintain a spatiotemporally diverse fish community and resilient populations of key native fish species in the Lower Lakes and Coorong.	Maintain the proportional abundance of small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM.

The expected environmental outcomes for small-mouthed hardyhead recruitment 2019, 2029 and 2042 were determined by elicitation with key experts. It is expected that the percentage of sites with significant recruitment will be maintained, however, the confidence in future predictions varies over time (Table 11-2; Figure 11-1).

Table 11-2. Expected outcomes for small-mouthed hardyhead in 2019, 2029 and 2042.

Species	Expected outcome	Year		
		2019	2029	2042
Small-mouthed hardyhead	Percentage of sites where the proportional abundance of juvenile small-mouthed hardyhead exceeds 60%.	63% of sites have a proportional abundance >60% (80% confidence interval of 34-93% sites).	74% of sites have a proportional abundance >60% (80% confidence interval of 48-92% sites).	63% of sites have a proportional abundance >60% (80% confidence interval of 38-88% sites).

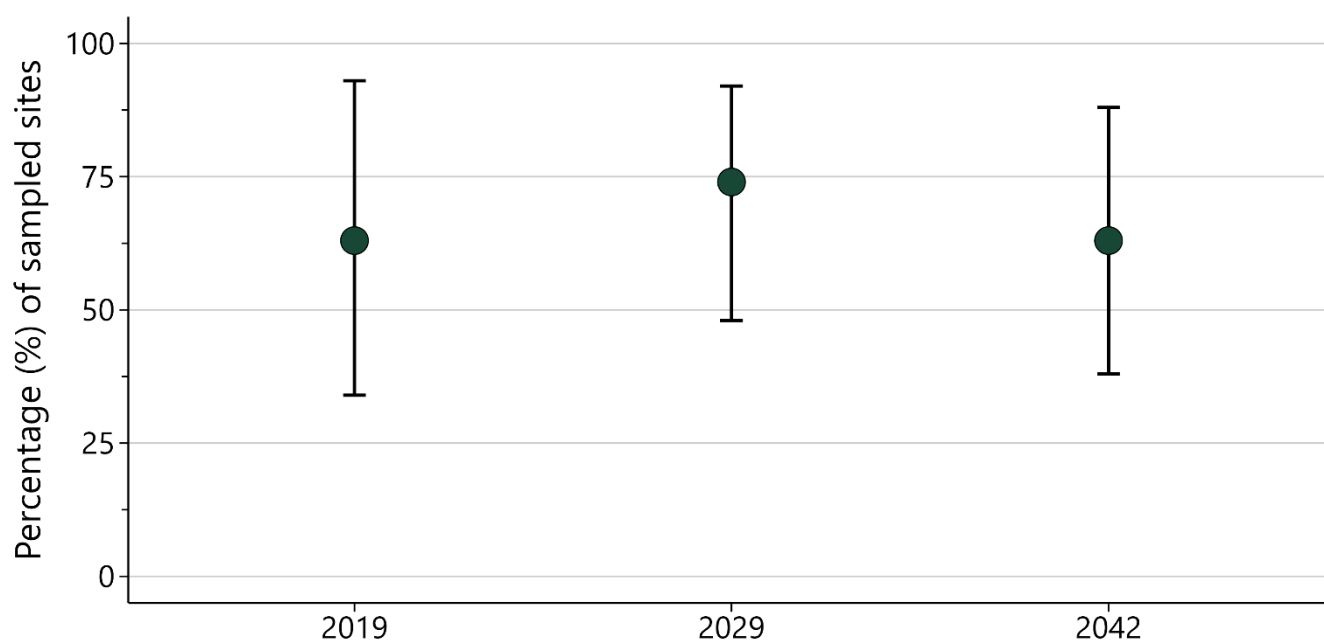


Figure 11-1. Expected percentage of monitoring sites with >60% juvenile small-mouthed hardyhead ($\pm$ 80% confidence limits) in 2019, 2029 and 2042.

11.3 Method

11.3.1 Data sources

Data used in this reporting were collected as a part of TLM program for the Lower Lakes, Coorong and Murray Mouth Icon Site, a joint initiative funded by the Australian Government and Government of South Australia, coordinated by the MDBA. The methodology for small-mouthed hardyhead monitoring followed the 'small-mouthed hardyhead' chapter (Ye et al. 2017) of the [LLCMM Icon Site Condition Monitoring Plan](#) (DEWNR 2017) and is summarised below.

Sampling independent of fishery catches was conducted annually between spring and early autumn to quantify the abundance and distribution of small-mouthed hardyhead to assess annual recruitment of juveniles. Small-mouthed hardyhead were sampled at eight regular sites along the Coorong using a standardised seine net methodology (combined large seine net and small seine net). Large (61 m long) seine nets swept an area of approximately 592 m² and small seine nets (8 m long) swept an area of approximately 100 m². Large and small seine net sweeps were replicated three times (shots) at each site.

The number of small-mouthed hardyhead from each net were counted and a random subsample of up to 50 individuals per net measured for total length (TL) (mm). Fish ≥ 40 mm TL sampled in spring/early summer (some years were only sampled once due to logistical constraints) were classified as adults; whereas fish < 40 mm TL sampled in late summer/early autumn were classified as juveniles (new recruits). The proportional abundance of juvenile small-mouthed hardyhead was calculated as the number of juveniles divided by the total number of juveniles and adults.

11.3.2 Trend assessment

Trend analyses for small-mouthed hardyhead was undertaken as per section 4.2.2. A logistic generalised linear model was used to assess trends in the number of sites with $> 60\%$ the sampled population as juvenile fish. Years were treated as independent data points and time step was used as a fixed effect. Sites were treated as a random effect (both intercept and slope), with a 1 allocated to sites in each year where the target of proportional juvenile abundance was met, or a 0 allocated otherwise.

11.3.3 Information reliability

The information reliability assessment for small-mouthed hardyhead in the Coorong was conducted as per section 4.2.3.

11.4 Limitations and assumptions

The small-mouthed hardyhead population in the Coorong shows a distinct temporal response to environmental change (i.e. increased flows and decreased salinities). Typically, the overall population condition score of small-mouthed hardyhead experiences a lag of one to two years following such changes, whereas recruitment reacts almost immediately (Ye et al. 2022a).

When analysing long-term trends, particularly with data from 2014–15, 2015–16, 2018–19 and 2019–20, it is important to exercise caution due to variations in the methods and timing of sampling. In 2014–15, only large seine nets were used for sampling, potentially leading to an under-representation of juvenile fish, where smaller seine nets are more effective for small-mouthed hardyhead juvenile sampling (Ye et al. 2018). Furthermore, the recruitment rates for 2015–16, 2018–19 and 2019–20 might have been underestimated, because data on adult fish from late summer/autumn were used, instead of data from late spring/early summer as in other years (Ye et al. 2020a). Given that small-mouthed hardyhead typically spawn in spring/early summer (Molsher et al. 1994), sampling in late summer/autumn may have biased the results towards capturing larger fish, over 40 mm in size, potentially leading to an underestimation of proportional juvenile abundance (Ye et al. 2020a).

This assessment and analysis presumed that predatory fish and waterbirds do not exhibit size preference when preying on small-mouthed hardyhead, treating the likelihood of preying on fish smaller than 40 mm and those 40 mm or larger as equal.

11.5 Results

11.5.1 Environmental outcome assessment

The environmental outcome assessment in 2019 found that the expected outcome for small-mouthed hardyhead recruitment was met, with >63% of monitoring sites having recorded significant recruitment in all years following the adoption of the Basin Plan (Figure 11-2). Currently 75% of sites have significant recruitment and this indicates that we are likely on-track to achieve the 2029 expected percentage of sites with significant small-mouthed hardyhead recruitment (expected 74% of sites).

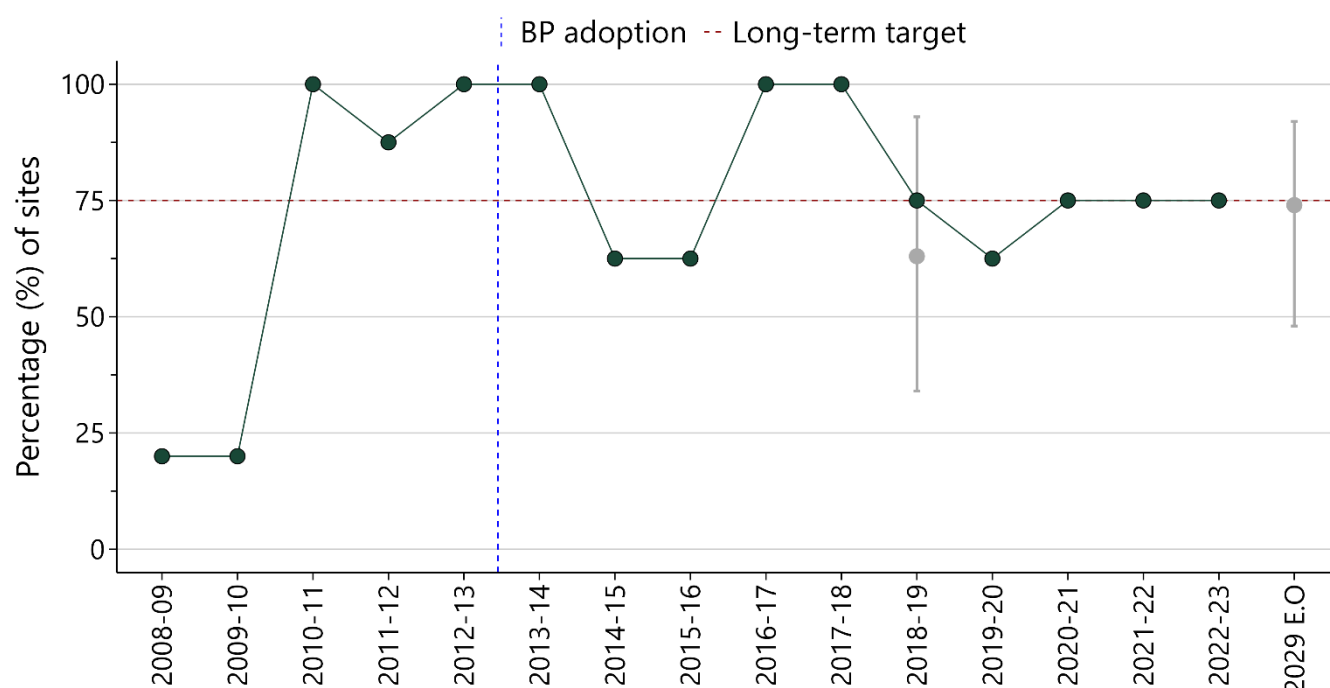


Figure 11-2. Percentage of monitoring sites with significant recruitment (>60% juvenile fish) of small-mouthed hardyhead from 2008-09 to 2022-23. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the grey point and associated error bars. Data source: SARDI.

11.5.2 Trend

The trend indicating the percentage of monitoring sites with significant recruitment of small-mouthed hardyhead was likely (89% probability) to have **improved** over the assessment period (2008-09 to 2022-23), as shown by posterior slope values >0 (Figure 11-3).

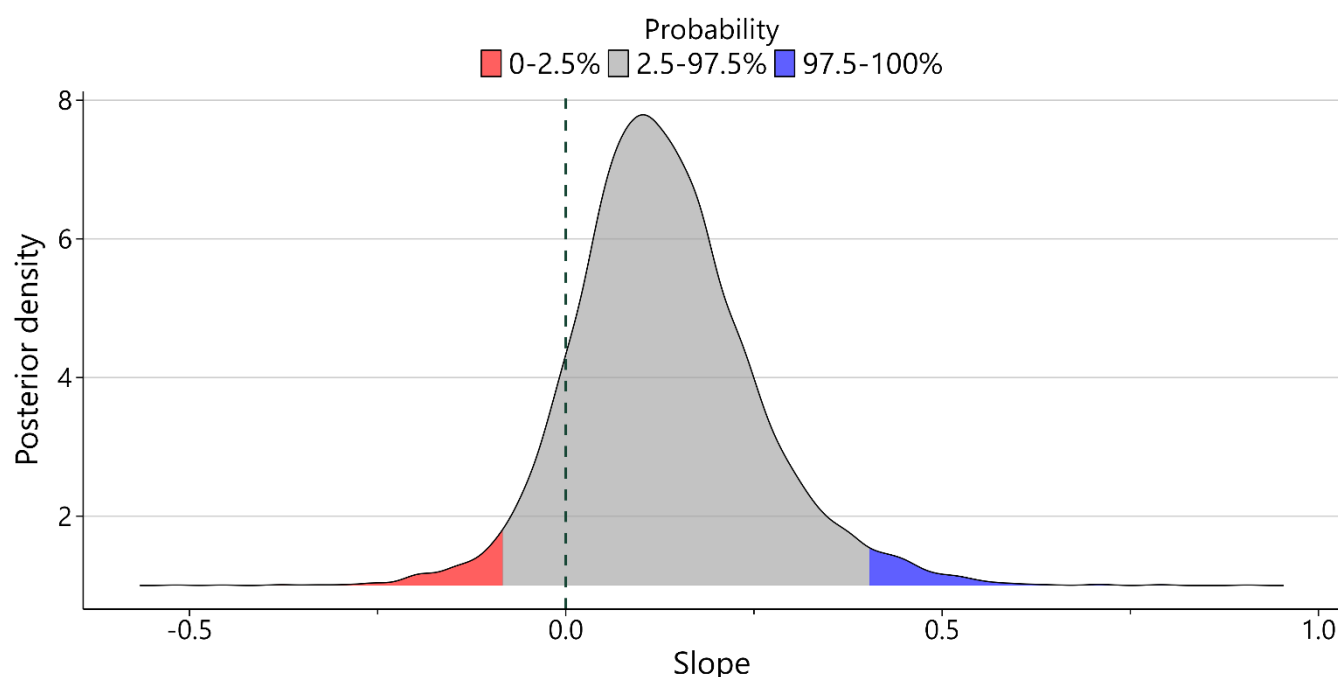


Figure 11-3. Estimated values for the slope generated from Bayesian modelling for the percentage of monitoring sites with proportional abundance of juvenile small-mouthed hardyhead >60%. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

11.5.3 Information reliability

The information reliability rating for small-mouthed hardyhead was **very good** (final score of 11). Justification for the scoring for small-mouthed hardyhead information reliability is provided in Table 11-3.

Table 11-3. Reliability of data to assess outcomes of small-mouthed hardyhead. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Partially, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Yes. The sampling methods as described in the Condition Monitoring Plan was used each year. One exception was the sampling undertaken in 2014–15 when only large seine nets were used.	2
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Coorong with equal effort?	Yes. Eight sampling sites were evenly spread across the North and South Lagoons.	2
Time	Has the duration of sampling been sufficient to represent	Yes. Sampling was conducted from 2008-09 to 2022–23, and therefore, includes years of	2

Methods	Question	Answer and justification	Score
	change over the assessment period?	monitoring pre- and post-Basin Plan adoption years and a range of hydrological conditions.	
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. The same sampling sites were revisited each year of the monitoring program. It should be noted that five sampling sites were established in 2008–09 and a further three sites were established in 2010–11.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Partially. Sampling was conducted annually from 2008–09 to 2022–23. The extent of recruitment may have been underestimated in 2015–16, 2018–19 and 2019–20 as adult fish were sampled in late summer/autumn rather than late spring/early summer, which occurred in other years of monitoring.	1
Final score			11
Information reliability			Very good

11.6 Evaluation

The condition score of small-mouthed hardyhead populations in the Coorong and Murray Estuary is strongly influenced by freshwater flows, which affects salinity, productivity, and habitat availability (Ye et al. 2023a). The Millennium Drought led to high salinities in the Coorong, restricting species distribution to the Murray Estuary and North Lagoon and in proximity of Salt Creek (Wedderburn et al. 2016; Ye et al. 2011). The return of flows post-drought and delivery of water for the environment has reduced salinity and boosted productivity (Furst et al. 2014) in the Coorong and Murray Estuary, enhancing fish population condition (Furst et al. 2014; Ye et al. 2011). Dredging has also been crucial in keeping the Murray Mouth open, promoting salt export, and maintaining habitats (DEW 2020b). The re-establishment of the aquatic plant community (dominated by *Ruppia tuberosa*) in the South Lagoon following its disappearance during the Millennium Drought has led to an expansion in favourable habitat for small-mouthed hardyhead (Paton & Bailey 2012).

Increased freshwater flows, including several unregulated high flow events, have improved small-mouthed hardyhead population condition (Wedderburn et al. 2016; Ye et al. 2011). Fluctuations in recruitment patterns have been observed, with some declines during prolonged low flow periods; however, the overall recruitment trend has been positive, linked to improved barrage outflows and delivery of water for the environment (Ye et al. 2022a).

Recruitment of small-mouthed hardyhead in the Coorong and Murray Estuary has increased since the Millennium Drought, however, has fluctuated over the assessment period (2008–09 to 2022–23) with most targets only met after periods of high flow. Since the 2019 assessment, the percentage of sites with significant recruitment has been maintained. At present, the trend toward the 2029 expected outcome is on track.

11.6.1 Barrage flows

High (unregulated) flows

High flow events elevate water levels, reduce salinity and boost pelagic productivity in the Coorong (Mosley et al. 2019). This enhancement increases the spatial and temporal extent of favourable conditions for small-mouthed hardyhead. High flow events during 2010–11, 2011–12, 2016–17, 2021–22, 2022–23 led to a reduction in salinity in the South Lagoon to below 100 g L⁻¹. The reduced salinity levels (<100 g L⁻¹), and general improvement in habitat

(aquatic plant coverage) and productivity may have contributed to the broader distribution and recruitment of small-mouthed hardyhead in the Coorong (Ye et al. 2020b).

Ye et al. (2023a) reported improvements in the overall population condition and increased percentage of sites with over 60% juvenile abundance. These outcomes can be largely attributed to the influence of high flows on salinity levels and the improvement in both food resources and habitat in the Coorong and Murray Estuary (Ye et al. 2023a).

Increased water levels during high flow periods increase the extent of the habitat for small-mouthed hardyhead. The connectivity between populations of small-mouthed hardyhead is also improved through utilisation of fishways and promoting increased dispersion and colonisation of new areas, which in-turn improves the resilience of the population (DEW 2020b).

Contribution of water for the environment

Water for the environment has substantially enhanced barrage flows, in dry years, often providing for most of the barrage discharge (Ye et al. 2023b). Water for the environment enhances estuarine productivity by transporting nutrients and zooplankton from the River Murray and Lakes to the Murray Estuary (Bice et al. 2016). Additionally, it has expanded habitat for small-mouthed hardyhead by reducing the salinity in the southern Coorong. The effects of water for the environment accumulate over time, significantly increasing the extent of preferred habitat for small-mouthed hardyhead. Typically, there is a one- to two-year delay in the overall condition score of the small-mouthed hardyhead responding to these changes, although observed recruitment is usually immediate (Ye et al. 2022a).

The effect of water for the environment is more significant during low flow years, supporting barrage flows (Stewardson & Guarino 2019). Water for the environment had the most impact on Coorong salinities during low flow years, such as 2015–16, 2018–19 and 2019–20 when Commonwealth Environmental Water constituted 100% of annual barrage flows (Stewardson & Guarino 2019) and was crucial in maintaining salinities below 100 g L⁻¹. Salinities over 100 g L⁻¹ are suboptimal for small-mouthed hardyhead and may limit recruitment (Noell et al. 2009; Ye et al. 2011; Ye et al. 2015a; Ye et al. 2020a). The delivery of water for the environment likely played a key role in sustaining the distribution and recruitment of this species across the Murray Estuary and North Lagoon during low flow years.

Salt Creek flows

At the height of the Millennium Drought, Salt Creek and its surrounding discharge area served as crucial refugia for small-mouthed hardyhead survival and reproduction (Wedderburn et al. 2016; Ye et al. 2011). This was particularly important as salinity levels in other parts of the South Lagoon reached up to 166 g L⁻¹, surpassing the species' physiological ability to regulate salt (Wedderburn et al. 2016; Ye et al. 2011). Since the break of the Millennium Drought, South Lagoon salinity levels are less extreme, reducing dependency on Salt Creek. This change is also demonstrated by the enhanced recruitment observed throughout the Coorong since 2010 (Figure 11-2). Salt Creek provides localised habitat, particularly near the outlet, during and following flow events and when salinities at the southern end of the South Lagoon exceed 100 g L⁻¹ (Wedderburn et al. 2016; Ye et al. 2011). Additionally, TLM program has observed enhancements in habitat and salinity conditions at the northern end of the South Lagoon, partly attributable to the influence of Salt Creek (Qifeng Ye, Personal Communication, March 2024).

Open Murray Mouth

Maintaining an open Murray Mouth has been critical in preserving habitat and salinity levels suitable for small-mouthed hardyhead in the Coorong and Murray Estuary. An open Murray Mouth regulates water and salinity levels, particularly during periods of low flow (Brookes et al. 2009; Higham 2012; Kingsford et al. 2009; Webster 2005). It performs these functions through tidal influence, as well as serving as a mechanism for the export of salt and nutrients (Brookes et al. 2009; Higham 2012; Kingsford et al. 2009; Webster 2005).

Post-2012, barrage flows have been insufficient to maintain an open Murray Mouth, necessitating dredging. The dredges at the Murray Mouth were active for 67% of months following 2012, ceasing operation only during and after high (unregulated) flow periods.

11.6.2 Unanticipated outcomes

The lack of significant recruitment (>75% sites) of small-mouthed hardyhead in 2021–22 and 2022–23 was unanticipated. Like previous high (unregulated) flows (e.g. 2010–11 and 2016–17) we would have expected the percentage of sites to be greater, but this could have been influenced by reduced catchability of recent recruits and/or the high flows increased fish growth rates and underestimated the abundance of YOY (i.e. those <40 mm total length) (Ye et al. 2015b).

11.6.3 Actions to achieve environmental outcomes

Actions to achieve environmental outcomes for small-mouthed hardyhead include:

- managing barrage flows and other inflows into the southern Coorong to maintain the extent of suitable habitat conditions
- maintaining an open Murray Mouth to enhance system connectivity, productivity, and salinity conditions
- that support small-mouthed hardyhead recruitment.

Although outside of current management influence, periodic high flow events are required more frequently to increase pelagic productivity and the extent of suitable habitat conditions in the Murray Estuary and Coorong, particularly following low flow years, for the species.

Management of salinities within the Coorong through barrage flows is critical to maintain and improve habitat and facilitate recruitment of small-mouthed hardyhead (Ye et al. 2023a). The increase in barrage flows through the delivery of water for the environment will continue to be important in maintaining productive estuarine habitat within the Murray Estuary and North Lagoon, particularly during drier years. This can include timing the delivery of upstream flow pulses with the recession of managed floodplain inundations, surcharging and then discharging water from the Lower Lakes, to transport freshwater derived nutrients, phytoplankton and zooplankton to the Murray Estuary.

An open Murray Mouth is essential to maintaining appropriate estuarine conditions in the Murray Estuary. Should another large-scale drought occur, maintaining an open Murray Mouth will be necessary to assist with water quality management in the Coorong. An improved understanding of ecological requirements for flows from the south east to the Coorong South Lagoon is required to support operational decision-making to benefit the ecological health of the Coorong. Current research on fish assemblages and fish movement in the South East Drainage Network, Morella Basin and Salt Creek are helping to improve understanding and inform the management of flow in these systems (Bice et al. in review; Ye et al. 2022b).

Complementary restoration initiatives such as those being investigated in the HCHB program are expected to have a positive impact on the ecological health of the Coorong, particularly aquatic plant communities and associated habitat conditions that support small-mouthed hardyhead.

11.7 Conclusion

The delivery of water for the environment, has led to some improvement in the population condition score of small-mouthed hardyhead in the Murray Estuary and Coorong, particularly through improved water quality during low flow years. However, trends since the break of the Millennium Drought, suggest that an overall improvement in hydro-climatic conditions across the Basin since 2010, was the predominant driver of positive outcomes for the species. Water for the environment was important in increasing productivity and habitat for small-mouthed hardyhead in lower flow years, while periodic high flows increased their habitat quality and extent. Currently 75% of sites have significant recruitment, indicating that we are likely on-track to achieve the 2029 expected outcome.

12 Waterbirds

Lakes



Trend
Improved



Reliability
Very good

Key findings and messages:

- Abundances of selected waterbird species utilising the Lakes have improved from 2009 to 2023.
- Trends in the abundance of species differed between waterbird guilds, with generalists and herbivores having likely improved, while piscivores have remained stable.
- Despite the overall improvement in trend, the abundance, area of occupancy and extent of occurrence for some waterbird species has predominantly declined since 2019 and are not on track towards the 2029 expected outcomes.
- Wetland availability across inland Australia may have influenced outcomes during wet climate phases (i.e. 2022–23 River Murray flood event), with some species potentially taking advantage of the increased expanses of productive wetland habitat.
- Implementation of the Basin Plan has enabled lake levels to be managed within normal operating ranges and with seasonal variations, which has likely been important in protecting island-nesting birds from terrestrial predators and increasing primary productivity and subsequent resource availability.

Coorong



Trend
Declined



Reliability
Very good

Key findings and messages:

- The Millennium Drought (1996–2010, specifically from 2001 onwards) had severe impacts on the Coorong ecosystem and waterbird populations. The abundance of Coorong waterbirds was expected to improve following the return of freshwater flows to the system from 2010 onwards.
- Despite improved hydrological conditions in recent years, abundance only improved for herbivorous waterbirds. Abundances of generalist waterbirds remained stable, while piscivores and both resident and migratory shorebirds declined.
- With only two guilds currently meeting their abundance targets (herbivores and piscivores) we are not anticipating achievement of the 2029 expected outcomes for Coorong waterbird populations.
- The decline of migratory shorebird abundances is likely in response to the deterioration of habitat quality in the Coorong, as well as the loss and degradation of habitat in the East Asian Australasian flyway.
- Implementation of the Basin Plan has played an important role in maintaining salinities in the Coorong that are tolerable to key food resources for waterbirds, but the southern Coorong remains in a

degraded state, impacting the availability and quality of habitat and resources for waterbirds in the Coorong.

12.1 Introduction

The CLLMM PEA supports nationally and internationally significant populations of waterbird species (Paton et al. 2009), which is one of the main reasons for its listing as a Wetland of International Importance under the Ramsar Convention in 1985 (Paton et al. 2018). The wetland system supports large numbers of resident (e.g. Stilts, Avocet, Plovers) and migratory shorebirds (e.g. Stints, Sandpipers), piscivores (e.g. Cormorants, Australian pelicans, Hoary-headed Grebes, Terns), herbivores (e.g. Swans, Ducks, Swampheens) and generalists (e.g. Gulls and Ibis) (Paton et al. 2018), with numbers greatest during summer and in drought (Paton 2010; Paton et al. 2018). During summer, the Coorong supports twice the number of waterbirds than the Lakes (Paton et al. 2018).

The waterbird communities supported in the Lakes and Coorong differ based on the abiotic (e.g. water level and salinity) and biotic (e.g. vegetation and food resources) characteristics of their habitats (Paton et al. 2015; Paton et al. 2018). The Lakes are characterised by freshwater lakes and adjoining wetlands with variable but generally steep shorelines and reed beds around their margins, while the Coorong is characterised by estuarine to hypersaline waters that cover vast areas of shallow, gently sloping shorelines where emergent vegetation is absent (Paton et al. 2015). The key difference between the waterbird communities is that large numbers of resident and migratory shorebirds are supported by shallow mudflat habitats in the Coorong, whereas relatively small numbers are supported in the Lakes peripheral wetlands and backwaters (Paton et al. 2015; Paton et al. 2018). The Lakes and Coorong both support large numbers of piscivores, herbivores and generalists, however, the species composition of these guilds differ between the Lakes and Coorong (Paton et al. 2018). For example, far greater numbers of Great Cormorants, Pied Cormorants and Pacific Black Duck use the Lakes, whereas Hoary-headed Grebes and Chestnut Teal are more numerous in the Coorong (Paton et al. 2018). However, certain species such as Australian Pelicans and Black Swan are prominent across both wetlands (Paton et al. 2018).

The condition of waterbird populations in the CLLMM are assessed each summer, with annual counts having occurred in the Coorong since 2000 and in the Lakes since 2009 (Paton et al. 2023). Three key parameters are used to evaluate the condition of waterbird populations in the Lakes and Coorong: abundance, area of occupation (AOO) and extent of occurrence (EOO) (Paton et al. 2017a). The factors affecting these waterbird population condition measures differ between guilds and species based upon their life histories and ecologies (Jackson et al. 2022; Prowse et al. 2022). However, these factors likely include freshwater flows, water levels, salinity and other water quality factors (i.e. nutrients and excessive growth of filamentous algae) that affect the quantity, quality and accessibility of waterbird food and habitat (Paton 2010; Giatas and Ye 2016; Paton et al. 2018; Jackson et al. 2022; Paton et al. 2023).

Numerous waterbird species that use the Lakes and Coorong are either highly mobile, nomadic or migratory, meaning that their population dynamics are impacted by factors outside of the Coorong and Lakes (Paton et al. 2018; Mott et al. 2022). Therefore, the availability and condition of wetlands at regional (Mott et al. 2022; Sanchez-Gomez et al. 2022), national (Clemens et al. 2016; Porter et al. 2022; Mott et al. 2022; Prowse et al. 2022) and international (for migratory species) (Clemens et al. 2016) scales also contribute to the variance in the abundance of certain waterbird species between years (Paton et al. 2018). The breeding success of waterbirds within the Coorong and at greater spatial scales (i.e. nationally and internationally) is also likely to influence waterbird numbers in the CLLMM (Minton et al. 2014; Paton et al. 2018; Porter et al. 2022).

Water resource development and over-extraction has adversely impacted waterbirds in the MDB (Kingsford et al. 2017). These impacts are most acutely felt at the end of system, where the hydrology and environmental conditions of the CLLMM have changed, particularly in the Coorong (Mosley et al. 2023). Such hydrological and environmental change in the Coorong has been associated with a long-term decline in waterbird populations, with many species that characterise the wetland's waterbird community having significantly declined in abundance since the 1980s (Paton 2010). Population declines have been particularly severe for migratory shorebird species, and these species are declining more rapidly in the Coorong compared to elsewhere in Australia (Clemens et al. 2016).

12.2 Ecological objective, target and environmental outcomes

The ecological objective for Lakes and Coorong waterbirds from the [South Australian River Murray Long-term Watering Plan](#) (LTWP) (DEW 2020) is presented in Table 12–1. The [Lower Lakes Coorong and Murray Mouth \(LLCMM\) Icon Site Condition Monitoring Plan](#) (CMP) (DEWNR 2017) defines a set of ecological targets (CMP targets) for waterbirds, which are presented in Table 12–1. Target values include assessment of waterbird abundance, AOO and EOO.

Table 12–1. Ecological objectives (DEW 2020) and CMP targets (DEWNR 2017) for waterbirds in the Lakes and Coorong.

Ecological objective	Area	CMP targets
Maintain or improve waterbird populations in the Coorong and Lakes	Lakes	Exceed the recent (2013–2015) median value for abundance of each of 25 selected waterbird species in the Lower Lakes in two of the last three years.
		Exceed the 75% threshold for the recent (2013–2015) AOO for each of 25 selected waterbird species in the Lower Lakes.
		Exceed the 75% threshold for the recent (2013–2015) EOO for each of 25 selected waterbird species in the Lower Lakes.
	Coorong	Exceed the long-term (2000–2015) median value for abundance of each of 40 selected waterbird species in the Coorong in two of the last three years.
		Exceed the 75% threshold for the long-term (2000–2015) AOO for each of 40 selected waterbird species in the Coorong.
		Exceed the 75% threshold for the long-term (2000–2015) EOO for each of 40 selected waterbird species in the Coorong.

To track the progression towards the CMP target for Lakes and Coorong waterbirds, expected outcomes were established based upon the proportion of waterbird species within each guild that exceeded their CMP target (Figure 12-1). Based on expert advice, only a subset of species listed in the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) were used in the assessment of expected outcomes, listed in Table 12–2 and Table 12–3. These expected outcomes form the basis of the assessment of waterbird environmental outcomes.

Table 12–2. Selected species grouped by guild that were used to assess outcomes in the Lakes waterbird community.

Scientific name	Common name	Guild
<i>Phalacrocorax varius</i>	Pied Cormorant	Piscivores
<i>Phalacrocorax carbo</i>	Great Cormorant	
<i>Pelecanus conspicillatus</i>	Australian Pelican	
<i>Chlidonias hybrida</i>	Whiskered Tern	
<i>Cygnus atratus</i>	Black Swan	Herbivores
<i>Anas superciliosa</i>	Pacific Black Duck	
<i>Porphyrio porphyrio</i>	Purple Swampphen	
<i>Threskiornis spinicollis</i>	Straw-necked Ibis	Generalists
<i>Threskiornis moluccus</i>	White Ibis	
<i>Platalea regia</i>	Royal Spoonbill	

Table 12–3. Selected species grouped by guild that were used to assess outcomes in the Coorong waterbird community.

Scientific name	Common name	Guild
<i>Pelecanus conspicillatus</i>	Australian Pelican	Piscivores
<i>Sternula nereis</i>	Fairy Tern	
<i>Poliiocephalus poliocephalus</i>	Hoary-headed Grebe	
<i>Hydroprogne caspia</i>	Caspian Tern	
<i>Tringa nebularia</i> *	Common Greenshank*	
<i>Anas castanea</i>	Chestnut Teal	Herbivores
<i>Cygnus atratus</i>	Black Swan	
<i>Tadorna tadornoides</i>	Australian Shelduck	
<i>Numenius madagascariensis</i>	Eastern Curlew	Migratory Shorebirds
<i>Tringa nebularia</i> *	Common Greenshank*	
<i>Calidris acuminata</i>	Sharp-tailed Sandpiper	
<i>Caliris ferruginea</i>	Curlew Sandpiper	
<i>Calidris ruficollis</i>	Red-necked Stint	
<i>Cladorhynchus leucocephalus</i>	Banded Stilt	Resident shorebirds
<i>Recurvirostra novaehollandiae</i>	Red-necked Avocet	
<i>Charadrius ruficapillus</i>	Red-capped Plover	
<i>Haematopus longirostris</i>	Pied Oystercatcher	
<i>Chroicocephalus novaehollandiae</i>	Silver Gull	Generalists
<i>Egretta novaehollandiae</i>	White-Faced Heron	
<i>Ardea alba modesta</i>	Great Egret	

*Captured in both the piscivore and migratory shorebird guilds

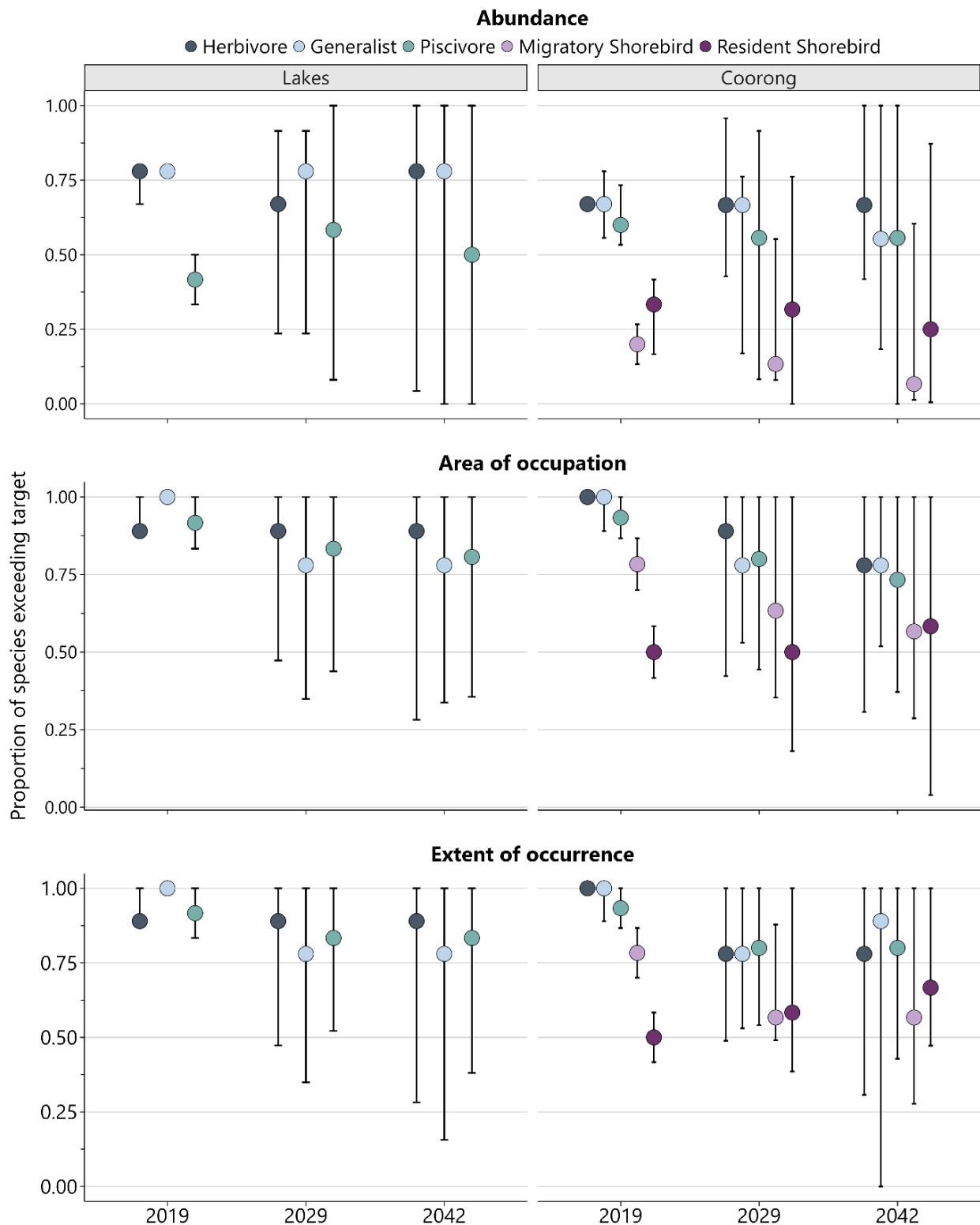


Figure 12-1. The expected environmental outcomes for waterbirds in the Lakes and Coorong based on the expected proportion of selected species in each guild that exceed their target values. If the target value is met for all species in the subset of the waterbird community, then the proportion of species exceeding their respective targets would be 1. Expected outcomes were derived through expert elicitation and informed by the Basin Plan water recovery scenarios and best available data and information.

12.3 Method

Annual waterbird censuses of the Lakes and Coorong were conducted by The University of Adelaide and BioR (Associate Professor David Paton). The censuses in the Coorong (2000 onwards) and Lakes (2009 onwards) are conducted in January and late January/early February, respectively. The methodology of the annual waterbird census of the Lakes and Coorong are detailed in the [Lower Lakes Coorong and Murray Mouth \(LLCMM\) Icon Site Condition Monitoring Plan](#) (CMP) (DEWNR 2017), Paton et al. (2017) and summarised below.

The data collected during monitoring activities is made available in the Australian National Data repository (<https://data.gov.au/data/dataset/coorong-and-lower-lakes-waterbird-census-data>).

Data has been collected for the DEW primarily through TLM's condition monitoring program and other funding sources of the MDBA. Data is used to inform the delivery of water for the environment to the Coorong and Lower Lakes.

12.3.1 Lakes

The shoreline of Lake Alexandrina, Lake Albert and Goolwa Channel were divided into 1 km × 1 km cells. Within each 1 km² cell, waterbirds were counted and identified by surveyors on foot or by boat.

12.3.2 Coorong

The Coorong and the Murray estuary was divided into 1 km sections that run perpendicular to the wetland direction. Within each 1 km section, waterbirds were counted and identified on the eastern and western shorelines, around islands and over open water in the centre of the wetland. Waterbird counts in each 1 km section were conducted by a minimum of two surveyors on foot or by boat.

12.3.3 Trend assessment

Trend analysis was undertaken using the approach detailed in section 4.2.2. Two models using a negative binomial distribution assessed the probability of trend (positive or negative) in the abundances of selected waterbird species in the Lakes and Coorong. The first model assessed trend in the total abundance across selected waterbird species, including time step (years since the commencement of the assessment period) as a fixed effect and waterbird species as a random effect (allowing trends for species to have varying slopes and intercepts). The second model assessed differences in the trends of abundance between guilds by including an interaction effect between time step and guild (fixed effects), and species as a random effect (allowing species to have varying slopes and intercepts).

12.3.4 Information reliability

The information reliability assessments for the waterbird communities of the Lakes and Coorong were conducted as per section 4.2.3.

12.3.5 Limitations and assumptions

The Lakes and Coorong waterbird environmental outcome assessment is limited to a subset of selected species listed in the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017). As guild-specific outcomes were assessed in this report, species selected were assumed to be representative of the suite of species that comprise each guild in the Lakes and Coorong waterbird communities. It is also noted that targets for both AOO and EOO were originally set at low levels in order to provide a threshold so that a detection of failure may trigger management actions. However, a limitation with this assessment is that expected outcomes were set with confidence intervals, meaning that they allow for variability in the metrics that are below these set thresholds.

12.4 Results

12.4.1 Lakes outcome assessment: Abundance

The environmental outcome assessment in 2019 (DEW 2020b) found that the proportion of piscivore and herbivore species that met their respective abundance outcomes was lower than expected (Figure 12-2).

In 2023, 67% of generalist species met their target abundances, slightly below what is expected by 2029, but likely on-track to achieve the 2029 expected percentage. Although only 33% of herbivore species exceeded target abundances, this remains within the expected range for 2029. No piscivore species met target abundances in 2023, and they are considered not on-track to achieve the 2029 expected percentage (Figure 12-2). This decline in piscivore waterbirds during the high flow conditions of 2022 and 2023 was unexpected, possibly due to changes in prey-sized fish availability and the availability of other wetland habitats in inland Australia due to wetter climate conditions.

For generalists and herbivores, the proportions of species that met their abundance target values in 2023 remained within the confidence intervals of the 2029 expected outcome. However, as no species within the piscivore guild met their abundance target values in 2023, the lower confidence bound of the 2029 expected outcome has not been reached. Therefore, 2029 expected outcomes for abundance are on-track for generalists and herbivores, however, it is not on-track for piscivores.

Annual abundances of selected waterbird species in the generalist, herbivore and piscivore guilds in the Lakes are presented in Figure 12-3, with reference to their (2013–2015) median abundance that needs to be exceeded in two of the last three years to meet their abundance target.

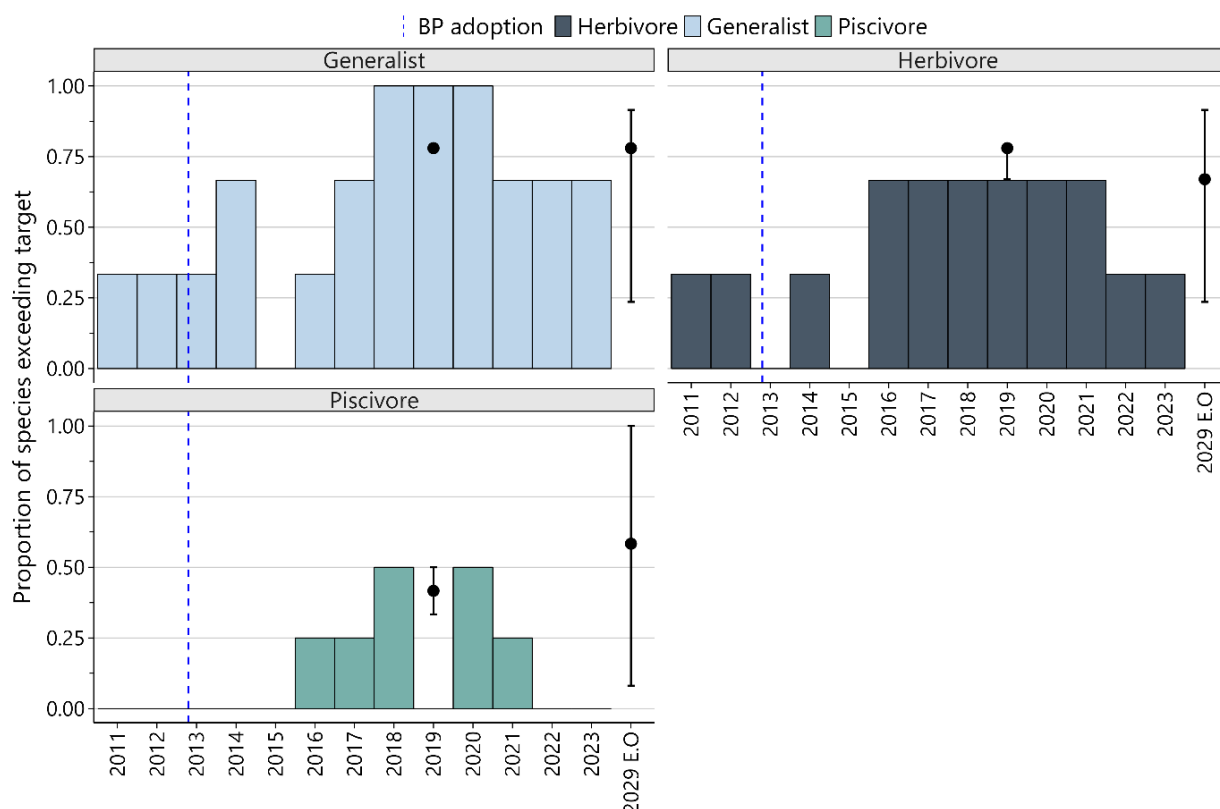


Figure 12-2. The proportion of selected species within each Lakes waterbird guild that exceeded their abundance target value in two of the last three years between 2011 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars. Note: only data from 2011 is presented due to insufficient data to assess interval expected outcomes before this period.

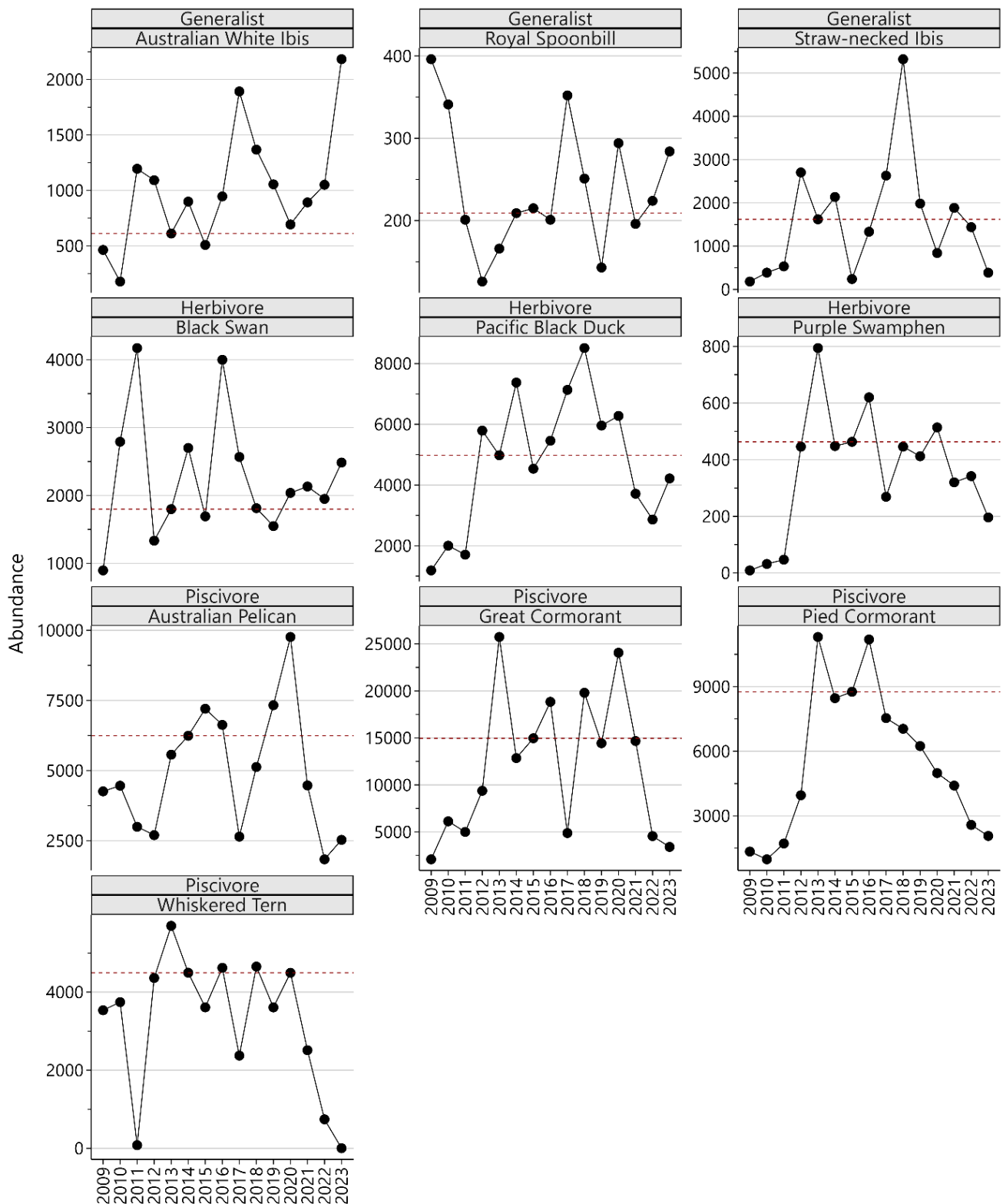


Figure 12-3. The abundances of selected waterbird species during annual late January/early February censuses for the Lakes from 2009 to 2023. Each species is referenced to their (2013–2015) median abundance (horizontal red dashed line) that needs to be exceeded in two of the last three years to meet their abundance target. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.2 Trend: Abundance

The abundances of selected species in the Lakes waterbird community were likely (84% probability) to have **improved** over the assessment period (2009–2023) (Table 12–4; Figure 12-4). The estimated median slope (0.036) of the model using data from 2009–2023 is lower than that reported using data from 2009–2019, and therefore, a greater proportion (16%) of the posterior distribution now crosses zero (95% CI [-0.06, 0.12]). This indicates that the probability of an improvement in the abundances of selected species has reduced since the last assessment in 2019.

Trend analysis on guild-specific slopes (Table 12–4; Figure 12-5) indicates that it is likely that the abundances of generalists (81% probability) and herbivores (70% probability) has **improved**. Slope estimates for the abundance of piscivores are as likely as not to have declined, and therefore trend is **stable**.

Table 12–4. Outcomes from Bayesian modelling assessing trends in the abundance of all selected species and selected species within the generalist, herbivore, and piscivore guilds in the Lakes between 2009 and 2023.

Guild/group	Outcome	Median estimate	Probability	Trend category
All selected species	Likely	0.019	84.4%	Improved
Generalist	Likely	0.036	80.7%	Improved
Herbivore	Likely	0.022	69.7%	Improved
Piscivore	About likely as not	-0.00483	55%	Stable

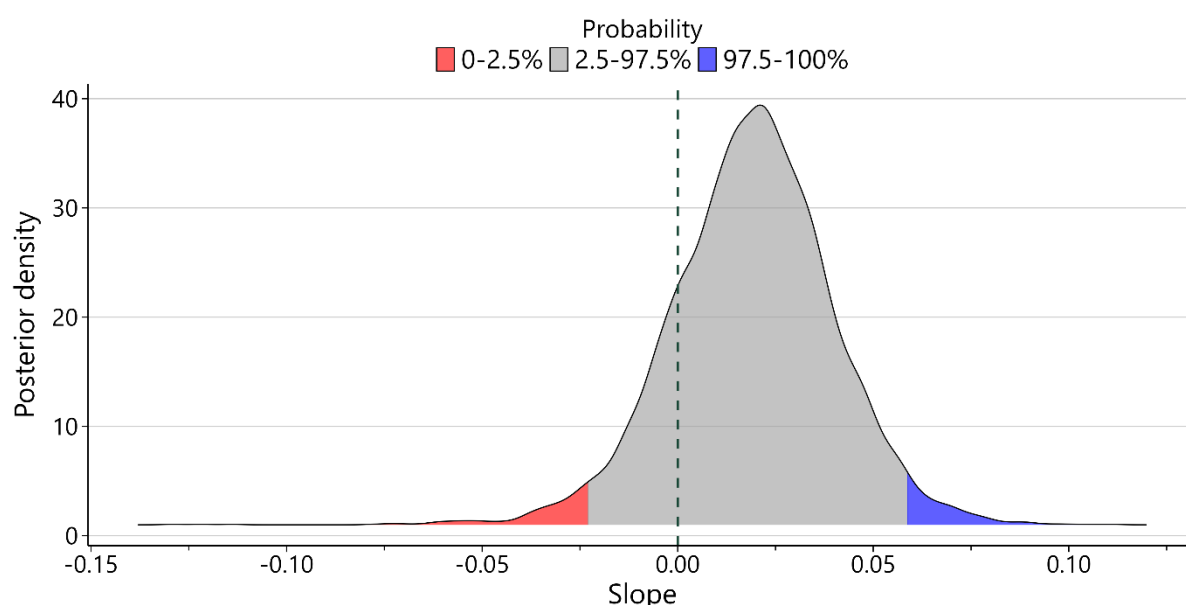


Figure 12-4. Estimated values for the slope from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species in the Lakes from 2009 to 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

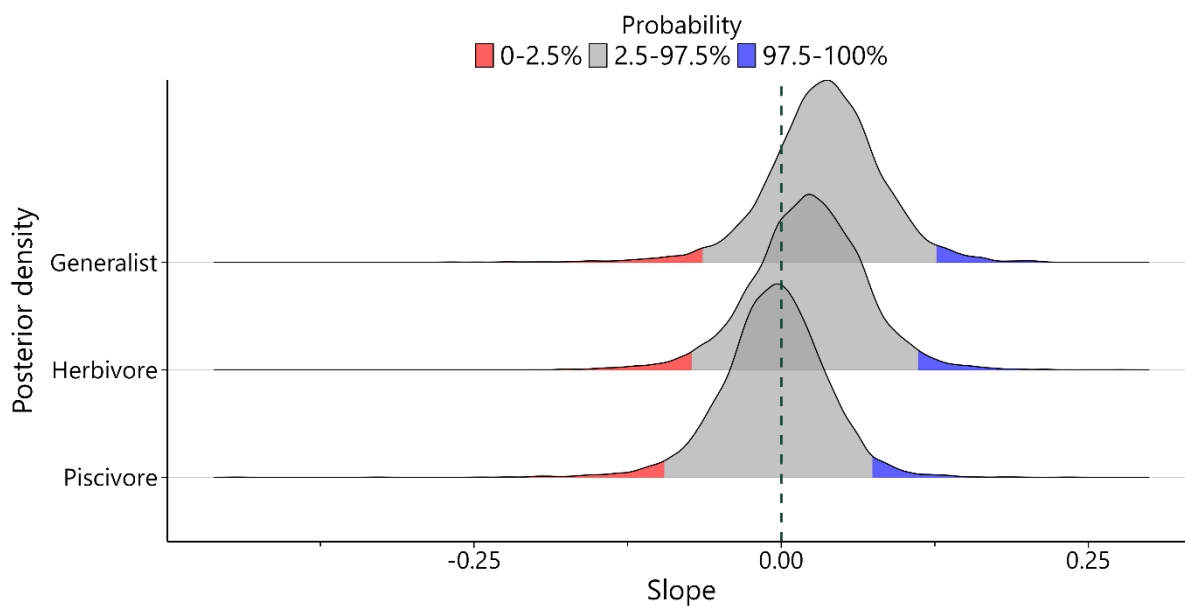


Figure 12-5. Estimated values for the slope from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species from the piscivore, generalist and herbivore guilds in the Lakes from 2009 to 2023. Posterior slope values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

12.4.3 Lakes Outcome Assessment: Area of Occupation (AOO)

The last assessment in 2019 found that the proportion of selected species in each guild that met their respective AOO target values aligned with expectations (Figure 12-6). All species within each guild achieved their AOO target values in six of seven years from the adoption of the Basin Plan (in 2012) and 2019. The exceptions were that generalists in 2015, and piscivores and herbivores in 2017, failed to meet their AOO target values for those years.

Since 2019, all generalist species met their AOO target value in all years other than 2023. The proportion of herbivore and piscivore species that met their abundance target value has reduced since 2019. This reduction was particularly evident for piscivores (Figure 12-6).

The proportion of species in the generalist and herbivore guilds that have exceeded their AOO target value in 2023 is within the confidence bounds of their respective 2029 expected outcomes (Figure 12-6). In contrast, no species in the piscivore guild exceeded their AOO target values in 2023. Therefore, 2029 expected outcomes for AOO are on-track for generalists and herbivores, however, it is not on-track for piscivores.

The annual AOO of selected waterbird species in the generalist, herbivore and piscivore guilds in the Lakes are presented in Figure 12-7, with reference to their AOO target.

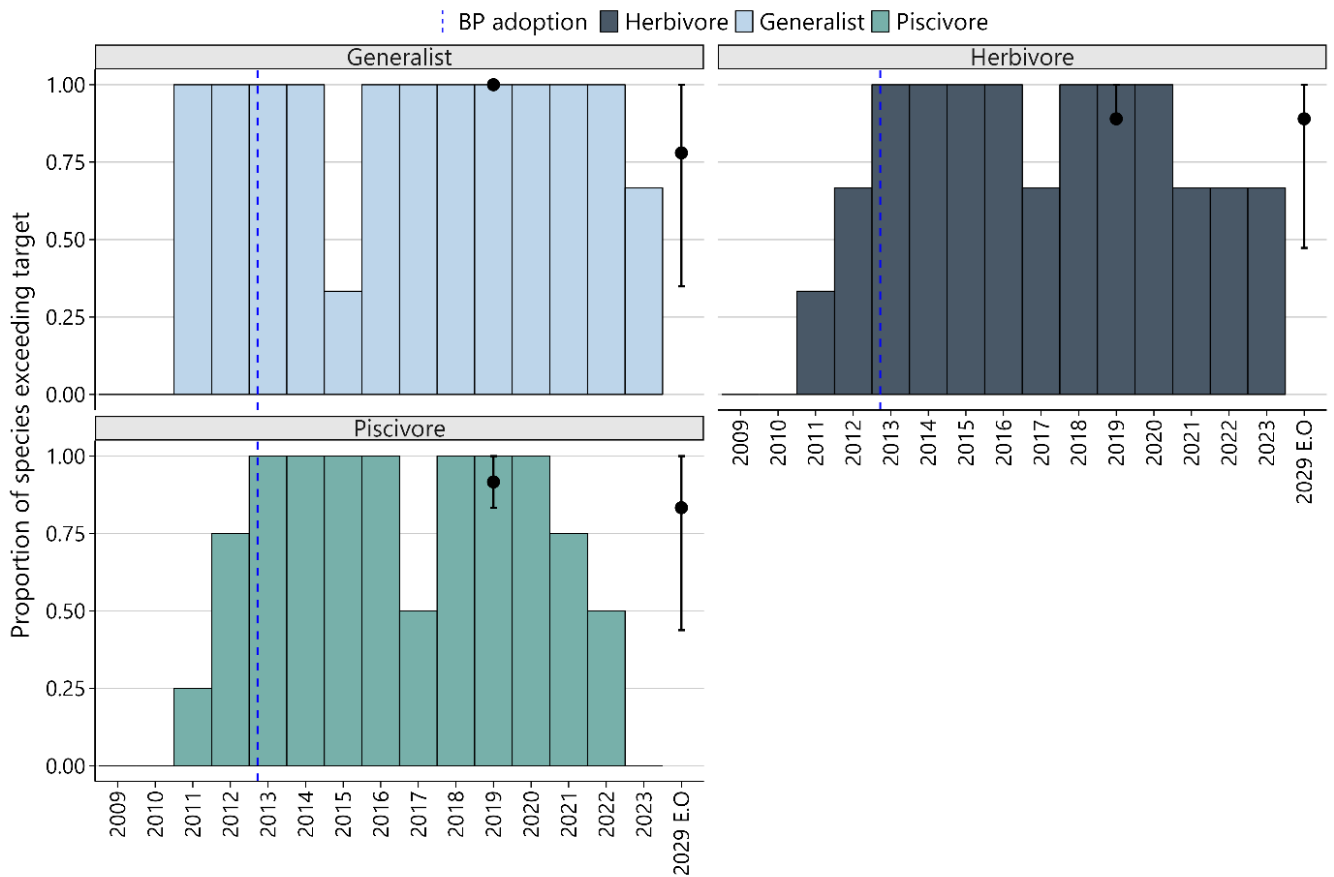


Figure 12-6. The proportion of selected species within each Lakes waterbird guild that achieved their AOO target values between 2009 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.

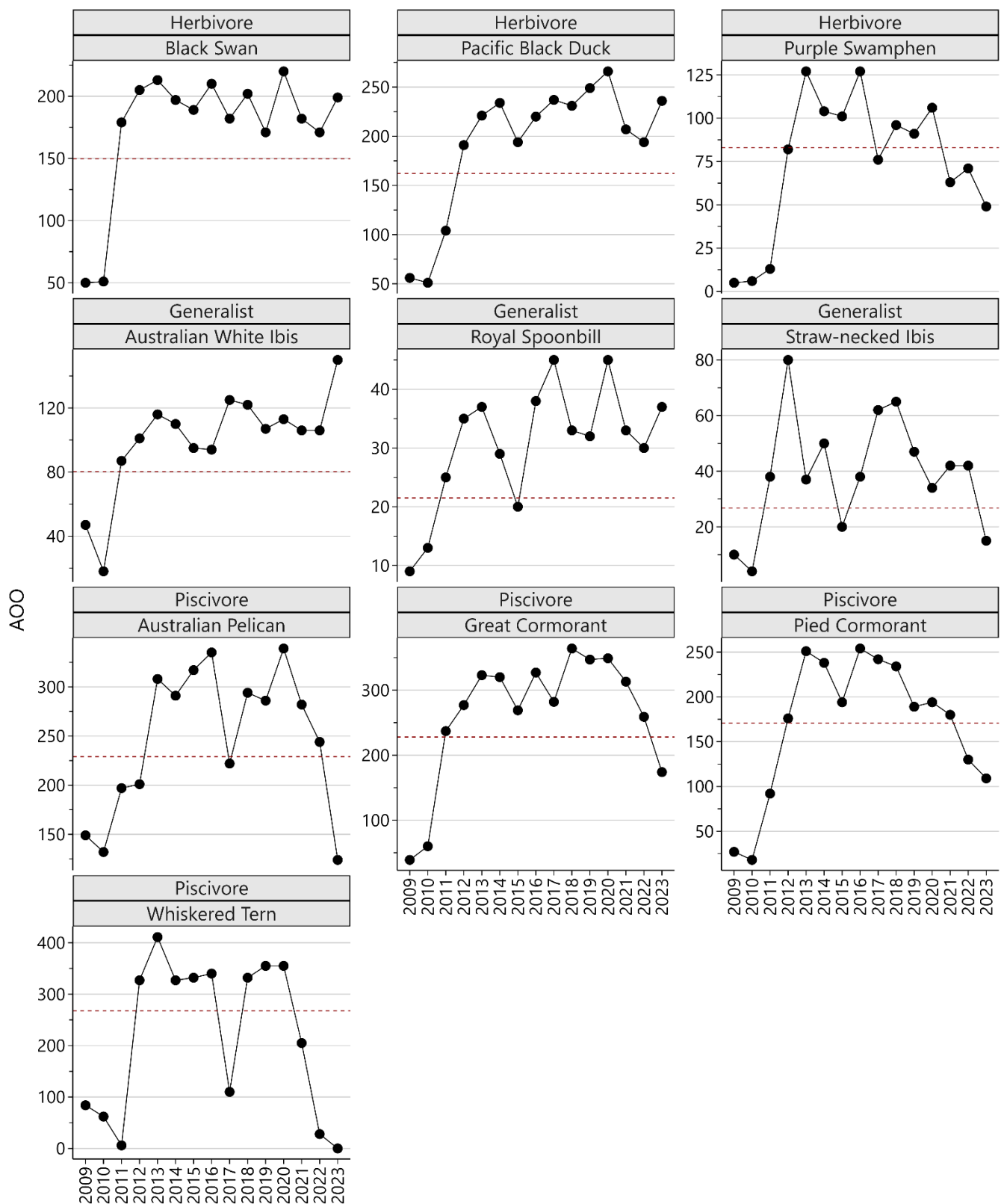


Figure 12-7. Area of occupation (AOO) of selected waterbird species during the late January/early February censuses over the Lakes from 2009 to 2023. Each species is referenced to its target value (75% of the mean AOO between 2013 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.4 Lakes Outcome Assessment: Extent of Occupation (EOO)

The assessment of environmental outcomes in 2019 found that the proportion of selected species in each guild that met their respective EOO outcome aligned with expectations (Figure 12-8). All species within the herbivore guild exceeded their EOO expected outcome between adoption of the Basin Plan and 2019, while at least one species within the generalist and piscivore guilds failed to achieve their EOO expected outcome in one of seven years.

Since 2019, all species in the herbivore guild have met their EOO target values on an annual basis (Figure 12-8). All generalist species met their EOO target values between 2020 and 2022, however, Straw-necked Ibis failed to achieve its EOO target values in 2023. All piscivore species met their EOO target values in 2020 and 2021, however, one (Whiskered Tern) and two species (Whiskered Tern and Pied Cormorant) failed to reach their expected outcome in 2022 and 2023, respectively.

For generalists and herbivores, the proportions of species meeting their EOO target values remained within the confidence intervals of the 2029 expected outcome. However, for piscivores, the lower confidence bound of their 2029 expected outcome was not reached. Therefore, 2029 expected outcomes for EOO are on-track for generalists and herbivores, however, it is not on-track for piscivores.

Annual EOO of selected waterbird species in the generalist, herbivore and piscivore guilds in the Lakes are presented in Figure 12-9, with reference to their EOO target.

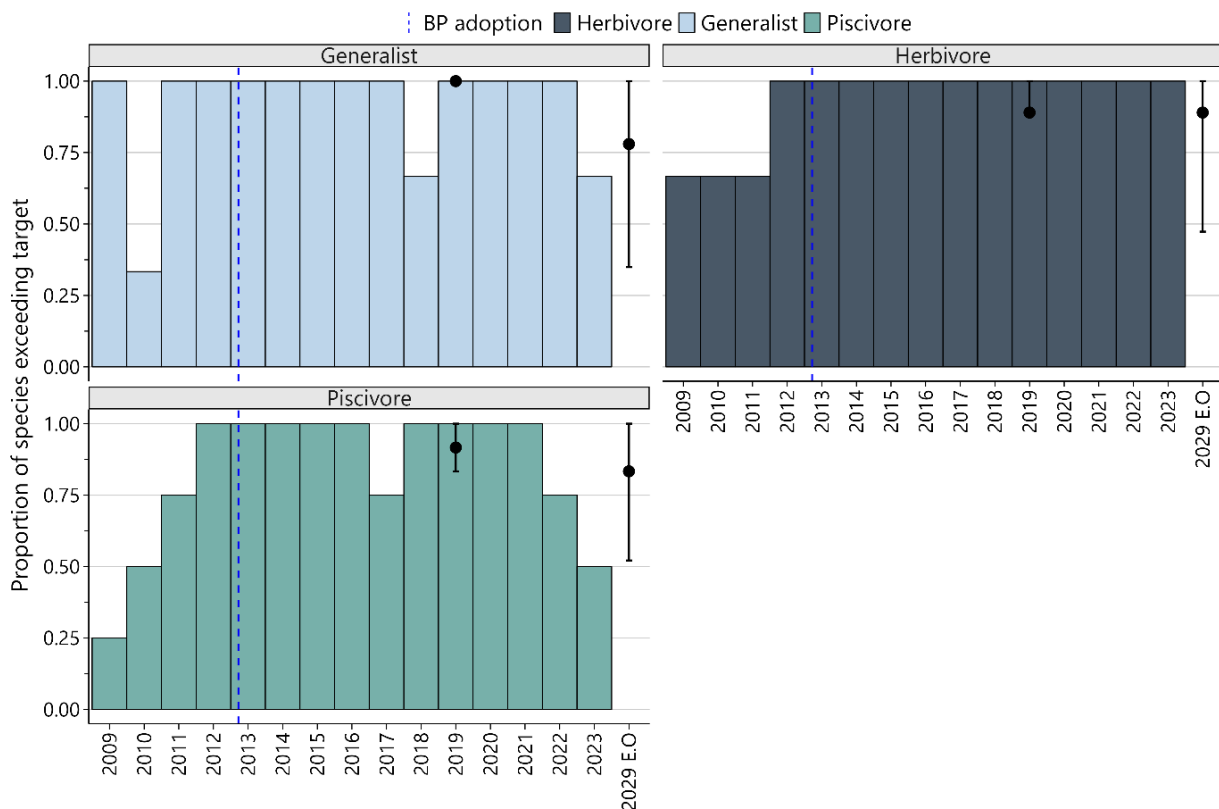


Figure 12-8. The proportion of selected species within each Lakes waterbird guild that achieved their EOO target value between 2009 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.

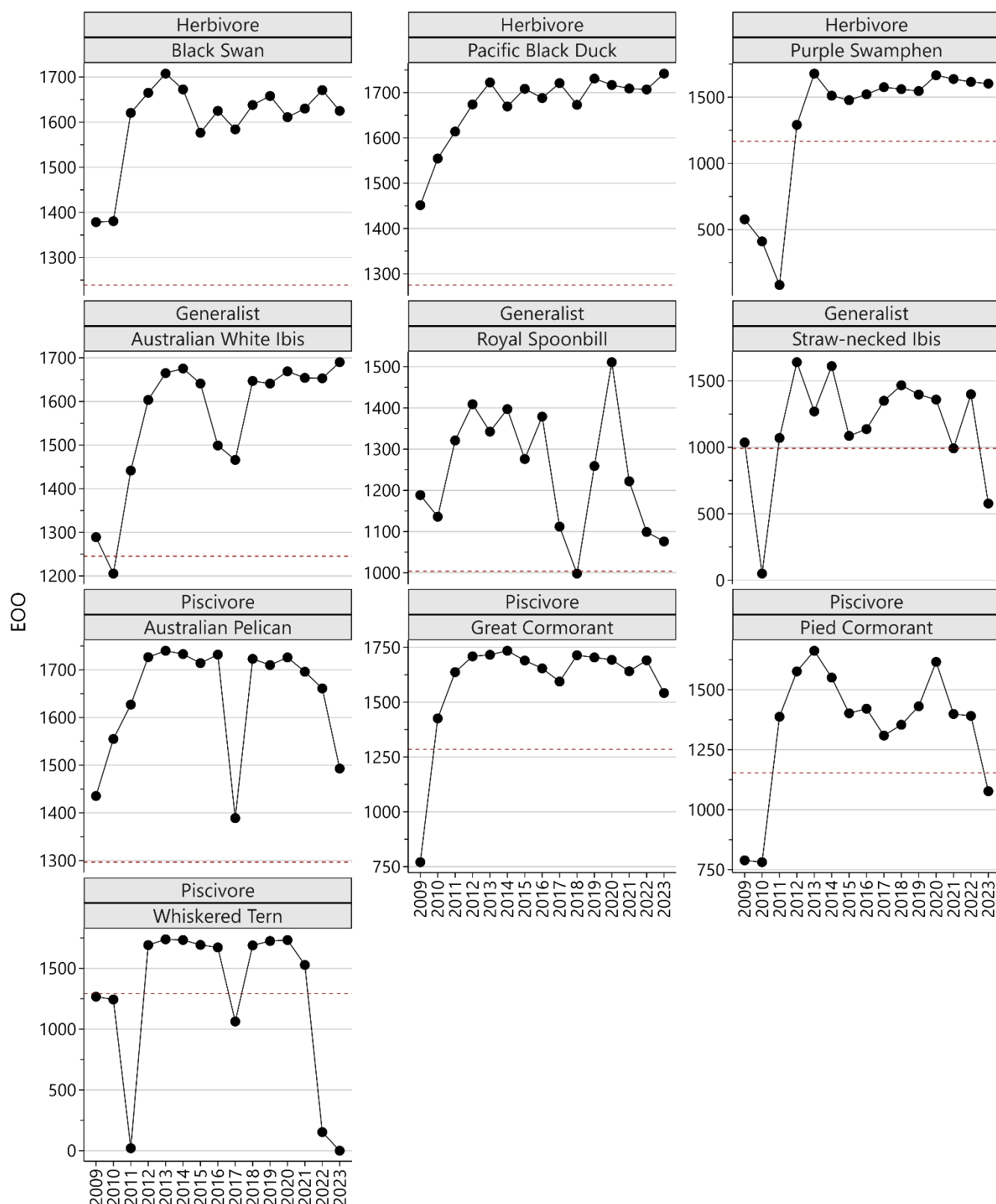


Figure 12-9. Extent of occupation (EOO) of selected waterbird species during the late January/early February censuses for the Lakes from 2009 to 2023. Each species is referenced to its target value (75% of the mean EOO between 2013 and 2015) by the horizontal red dashed line. Data source: University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.5 Coorong Outcome Assessment: Abundance

The environmental outcome assessment in 2019 found that the proportion of migratory and resident shorebird species that met their respective target values was lower than expected (Figure 12-10). Therefore, abundance outcomes for the Coorong waterbird community in 2019 did not align with expectations.

Since 2019, the proportion of generalist and piscivore species that met their abundance target values has reduced, while the proportion of herbivore, migratory and resident shorebird species that met their abundance expected outcome has not changed. However, the annual proportion of migratory and resident shorebird species that met their abundance target values over this period has remained very low (maximum of 0.5).

The proportion of species within all guilds, except migratory shorebirds, that met their abundance target values in 2023 is within the confidence intervals of the 2029 expected outcome. In 2023, no migratory shorebird species met their abundance target values, and therefore, the 2029 expected outcome for Coorong waterbird abundance is not on track to be met. However, there is uncertainty regarding this, as there is variability between years in the annual proportion of species meeting their abundance target values.

Annual abundances of selected waterbird species in the Coorong are presented in Figure 12-11, with reference to their (2000–2015) median abundance that needs to be exceeded in two of the last three years to meet their abundance target.

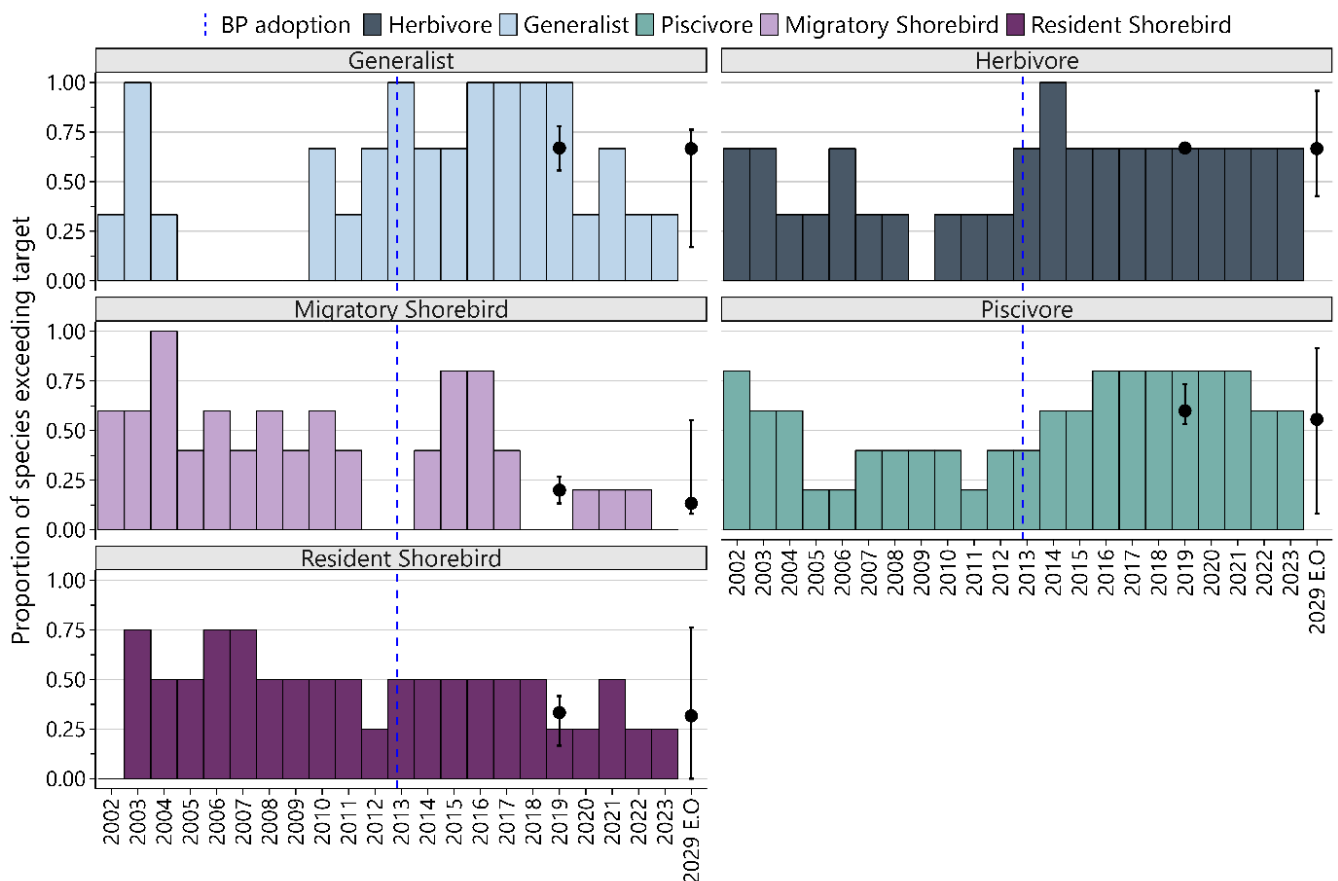


Figure 12-10. The proportion of selected species within each Coorong waterbird guild that exceeded their abundance expected outcome in two of the last three years between 2002 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars. Note: only data from 2002 is presented due to insufficient data to assess interval expected outcome before this period.

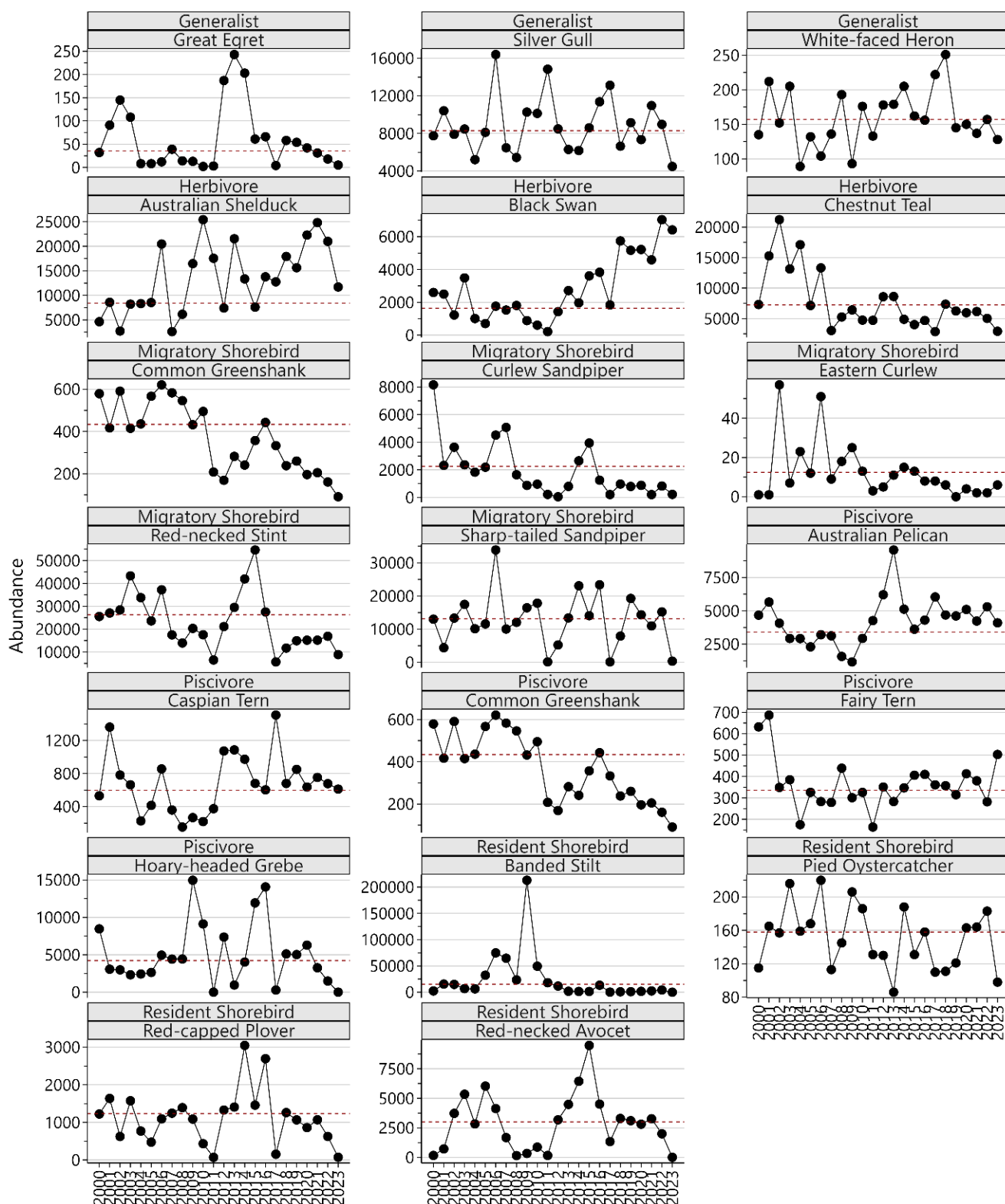


Figure 12-11. Abundances of selected waterbird species during annual January censuses over the Coorong from 2000 to 2023. Each species is referenced to their (2000–2015) median abundance (horizontal red dashed line) that needs to be exceeded in two of the last three years to meet their abundance target. Note different y-axis ranges across panels. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.6 Trend: Abundance

The abundance of selected species in the Coorong waterbird community were likely (95% probability) to have **declined** over the assessment period (2000–2023) (Table 12–5; Figure 12-12). The estimated median slope (-0.022) for this model is lower than that reported using data from 2000–2019, and therefore, the probability of abundance decline is higher (95% CI [-0.05, 0.00]).

Trend analysis on guild-specific slopes (Table 12–5; Figure 12-13) indicate that it is extremely likely (96%) and very likely (94%) that the abundance of resident shorebirds and migratory shorebirds have **declined**, respectively. The abundance of the piscivore guild was likely (78% probability) to have **declined**. The generalist guild was about as likely as not (58% probability) to have a minor declining trend and therefore is considered **stable**. Herbivores were the only guild to have an increasing trend in abundance and were likely (71% probability) to have **improved**.

Table 12–5. Outcomes from Bayesian modelling of trend for all selected species and selected species within the generalist, herbivore, migratory shorebird, piscivore and resident shorebird guilds in the Coorong between 2000 and 2023.

Guild/group	Outcome	Median estimate	Probability	Trend category
All selected species	Very likely	-0.022	94.7%	Declined
Generalist	About as likely as not	-0.006	57.8%	Stable
Herbivore	Likely	0.017	71.1%	Improved
Migratory Shorebird	Extremely likely	-0.044	96.1%	Declined
Piscivore	Likely	-0.018	78.1%	Declined
Resident Shorebird	Very likely	-0.047	93.8%	Declined

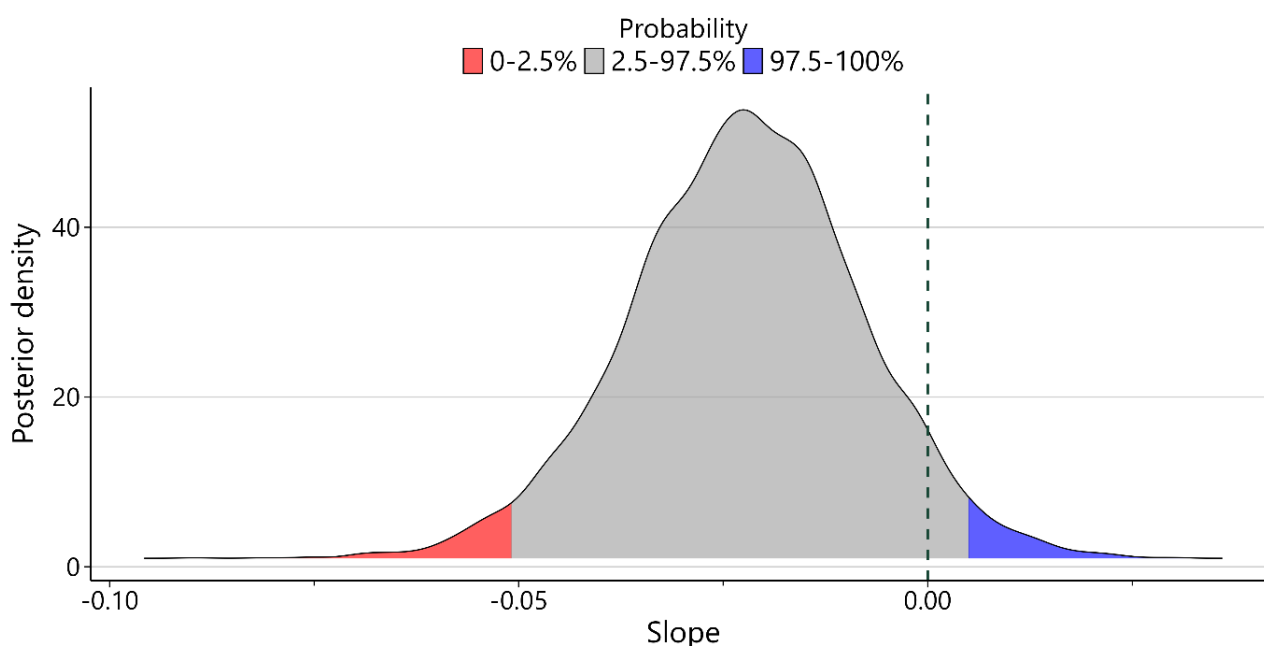


Figure 12-12. Estimated values for the slope from Bayesian modelling for the annual January census of selected waterbird species in the Coorong from 2000 to 2023. Posterior values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

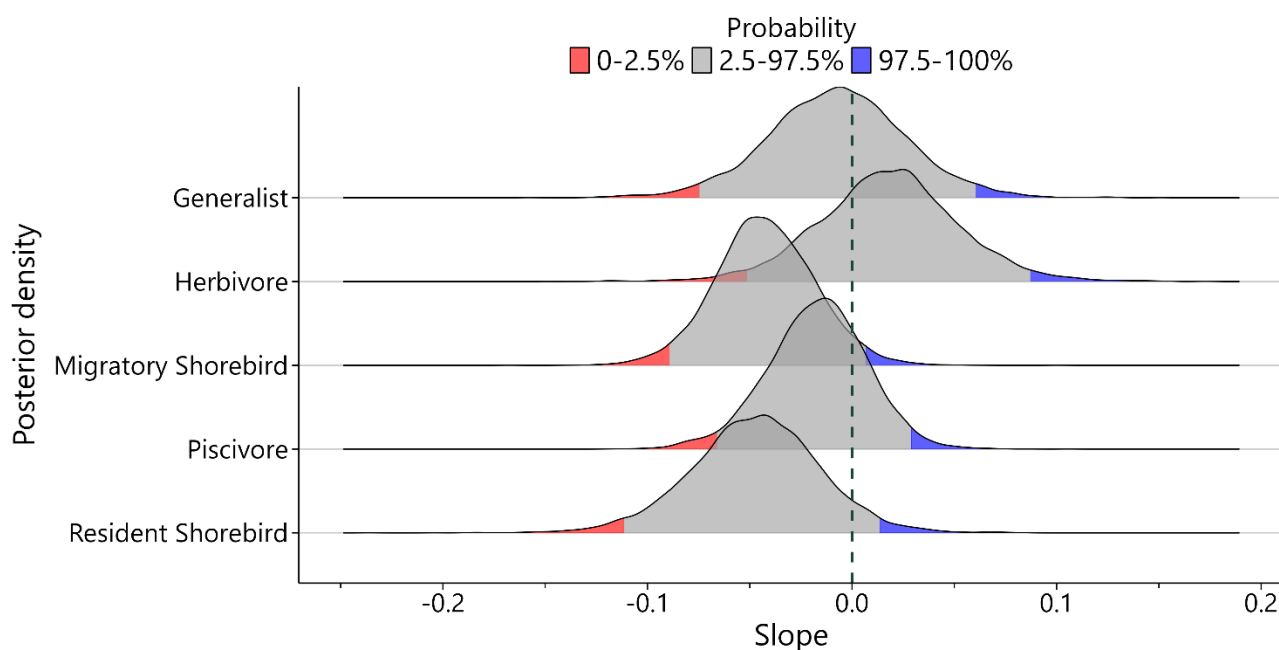


Figure 12-13. Estimated values for the slope from Bayesian modelling for the annual January census of selected waterbird species from the generalist, herbivore, migratory shorebird, piscivore and resident shorebird guilds in the Coorong from 2000 to 2023. Posterior values >0 infer a positive trend (improved) and values <0 infer a negative trend (declined).

12.4.7 Coorong Outcome Assessment: Area of Occupation (AOO)

The environmental outcome assessment in 2019 found that the proportion of selected species in each guild that met their respective AOO target values aligned with expectations for that year (Figure 12-14).

Since 2019, all species in the herbivore guild have met their AOO target values in each year, however, the proportions of generalists, piscivores, and migratory and resident shorebird species that met their AOO target values on an annual basis has declined over this period.

The proportion of species within the herbivore guild that met their AOO target value in 2023 exceeded the 2029 expected outcome. For the generalist, piscivore and migratory and resident shorebird guilds, the proportions of species that met their AOO target values is below the lower confidence bound of the 2029 expected outcomes. Therefore, at present, the 2029 expected outcome for Coorong waterbird AOO is not on track to be met. However, the 2029 expected outcome has been reached for all guilds, except for generalists and migratory shorebirds, in at least one of the past four years.

Annual AOO of selected waterbird species in the Coorong are presented in Figure 12-15, with reference to their AOO target.

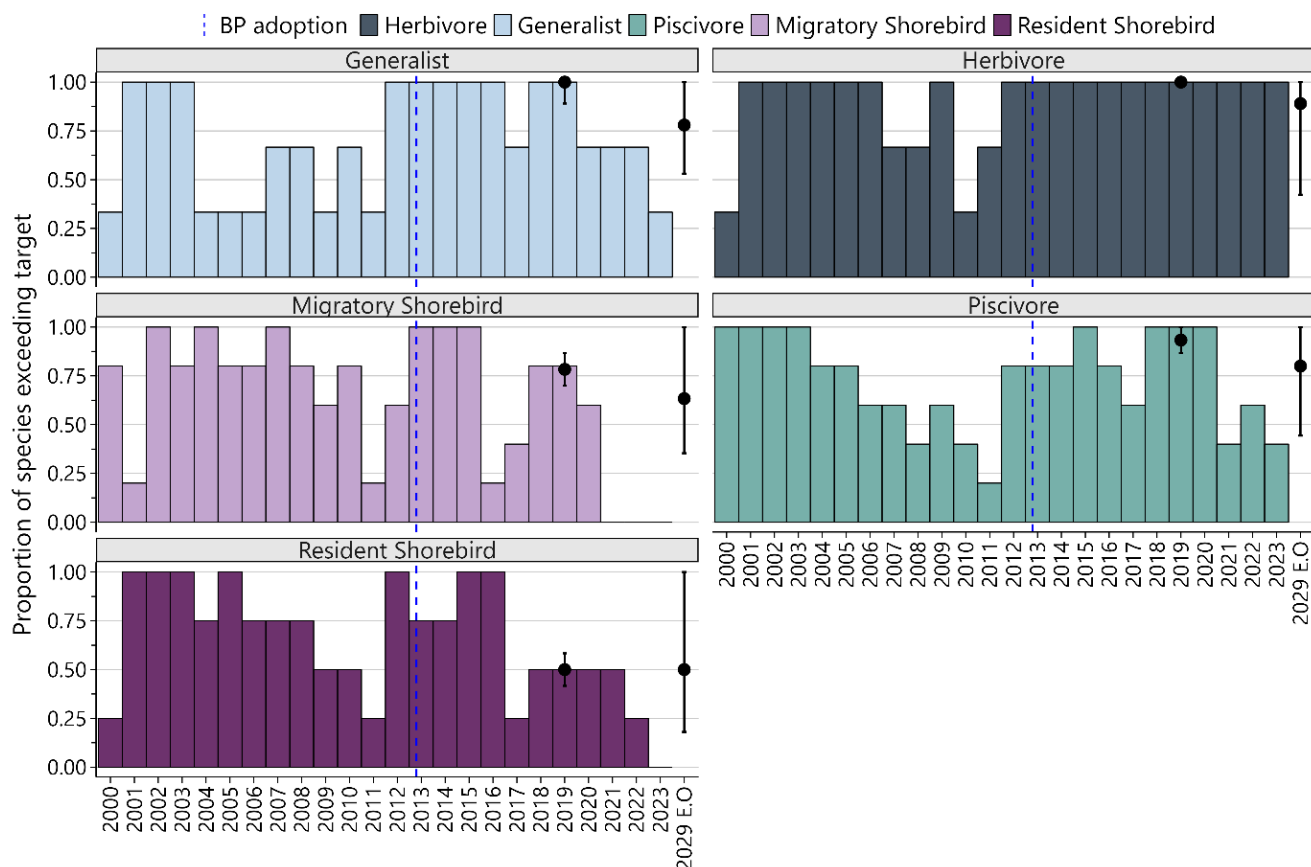


Figure 12-14. The proportion of selected species within each Coorong waterbird guild that achieved their AOO target values between 2000 and 2023. The 2019 and 2029 expected outcomes (±80% confidence interval) are referenced by the black point and associated error bars.

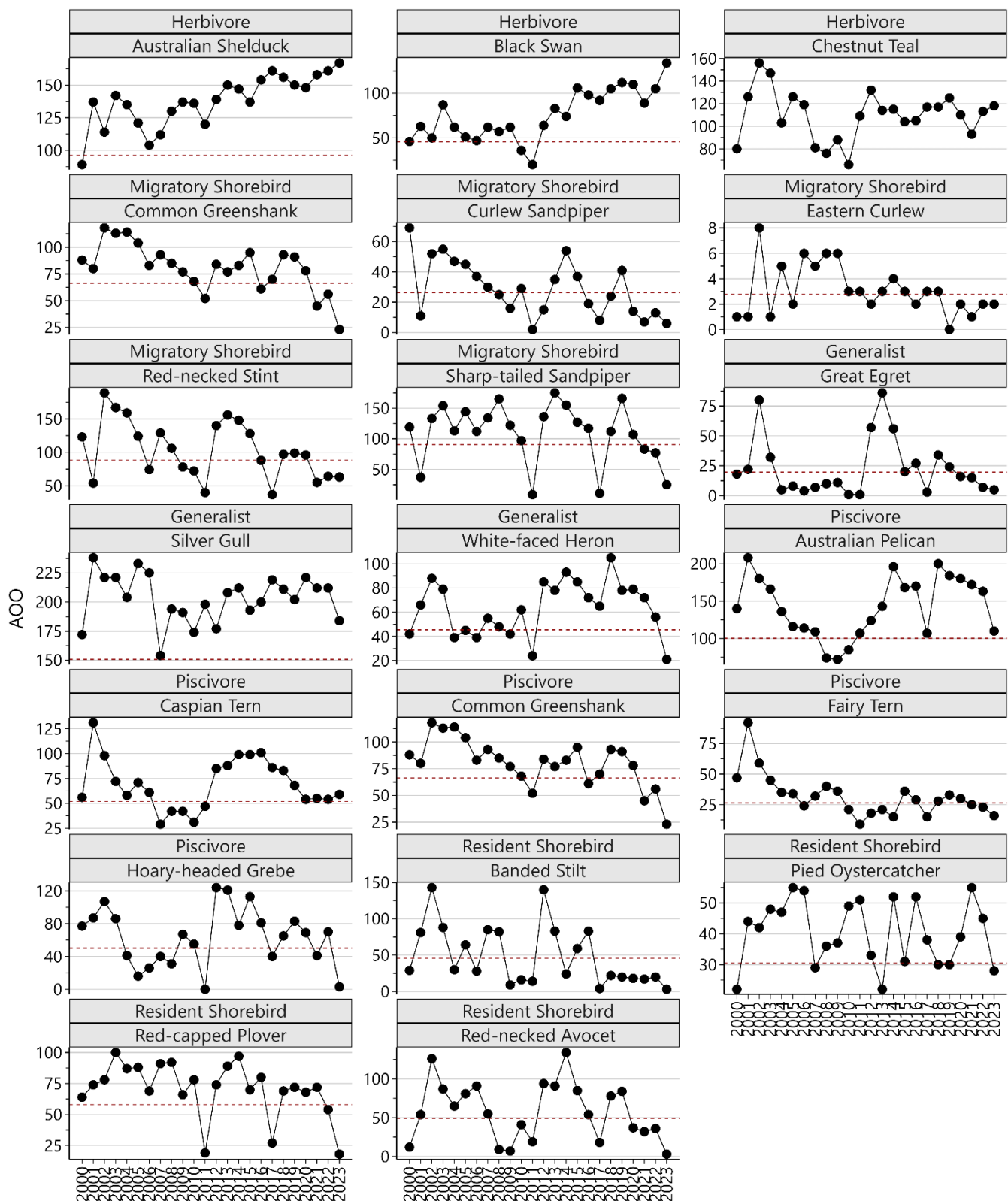


Figure 12-15. Area of occupation (AOO) of selected waterbird species during the January census over the Coorong from 2000 to 2023. Each species is referenced to its target value (75% of the mean AOO between 2000 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.8 Coorong Outcome Assessment: Extent of Occurrence (EOO)

The environmental outcome assessment in 2019 found that the proportion of selected species in each guild that met their respective EOO target values aligned with expectations for that year (Figure 12-16).

Since 2019, the proportion of species in the herbivore and piscivore guilds that met their EOO target values has largely remained unchanged, while the number of species in the generalist and migratory and resident shorebird guilds are less compared to the last assessment.

The proportion of species within the herbivore, piscivore and migratory shorebird guilds that met their EOO target values in 2023 is at or above their expected outcome for 2029. For generalists and resident shorebirds, the proportion of species that met their EOO target values was within the confidence bounds of the 2029 expected outcomes. All waterbird guilds have exceeded their 2029 expected outcome in a minimum of two of the past four years. Therefore, the 2029 expected outcome for Coorong waterbird EOO is on track to be met.

Annual EOO of selected waterbird species in the Coorong are presented in Figure 12-17, with reference to their EOO target.

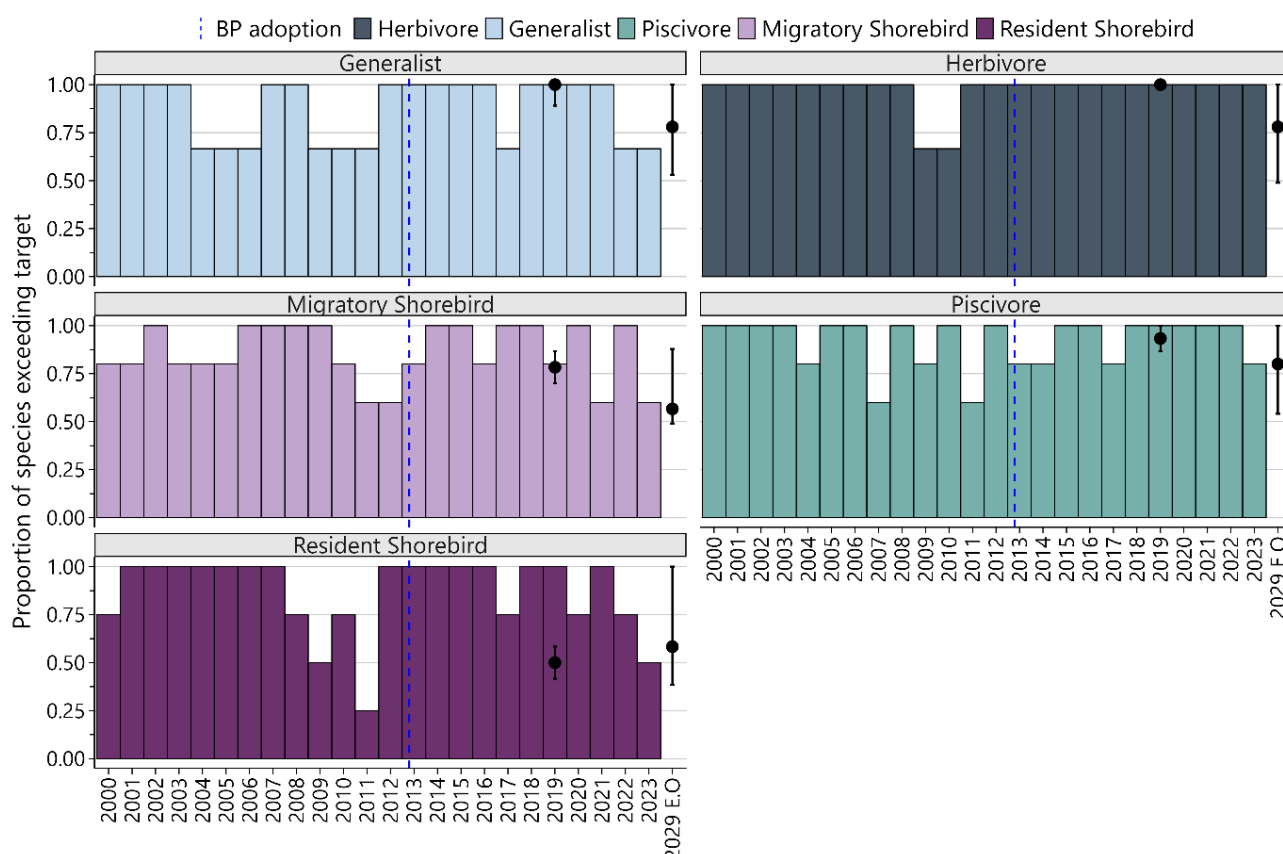


Figure 12-16. The proportion of selected species within each Coorong waterbird guild that achieved their EOO target values between 2000 and 2023. The 2019 and 2029 expected outcomes ($\pm 80\%$ confidence interval) are referenced by the black point and associated error bars.

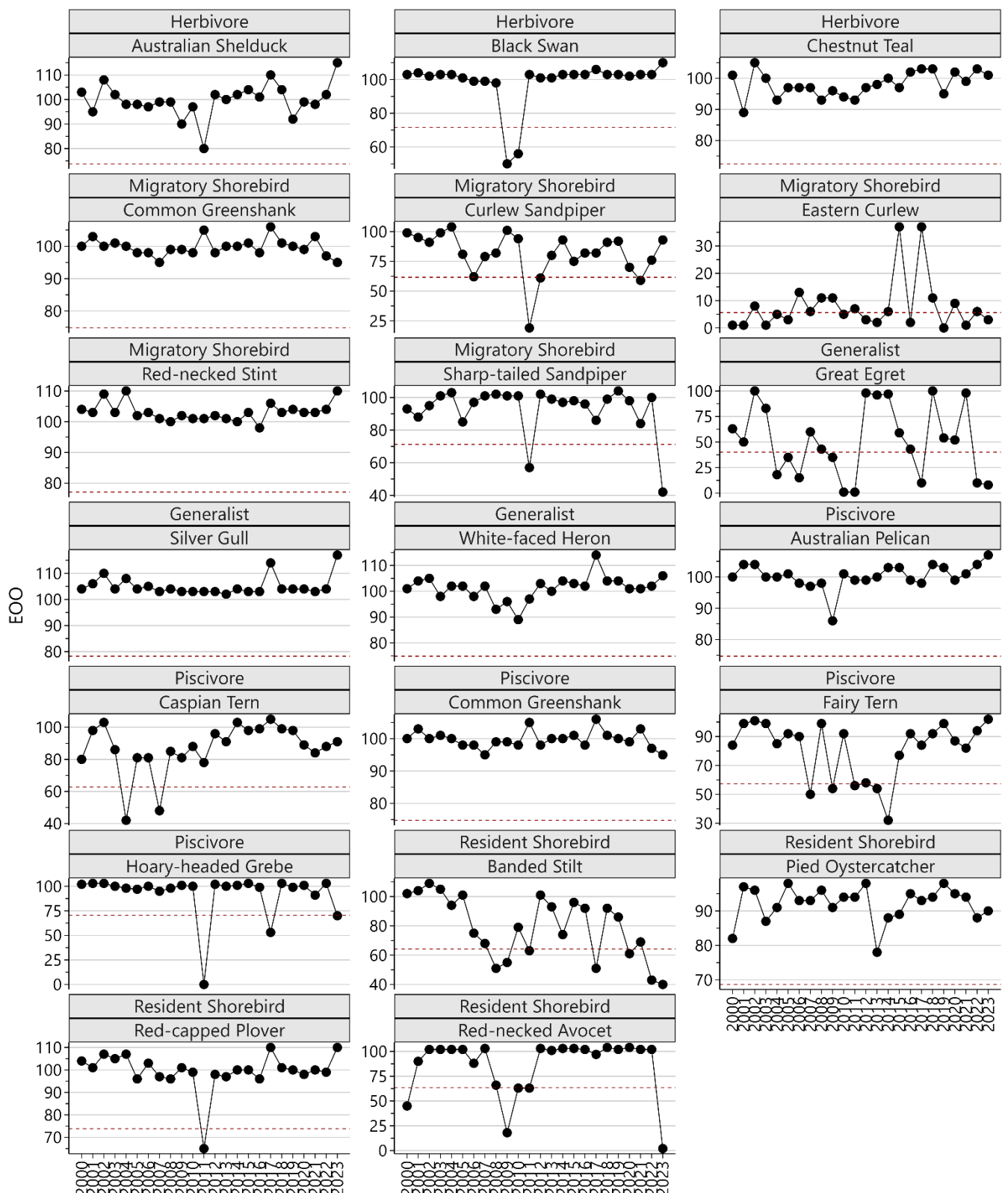


Figure 12-17. Extent of occupation (EOO) of selected waterbird species during the January census over the Coorong from 2000 to 2023. Each species is referenced to its target value (75% of the mean EOO between 2000 and 2015) by the horizontal red dashed line. Data source: The University of Adelaide/BioR (Assoc. Prof. David Paton).

12.4.9 Information reliability

The information reliability rating for waterbird censuses of the Lakes and Coorong was **very good** (final score of 11). Justification for the scoring for waterbird information reliability is provided in Table 12–6.

Table 12–6. Reliability of data from the waterbird censuses of the Lakes and Coorong to assess expected environmental outcomes and trend in the abundance of selected species. The methods used in data collection as well as the representativeness and repetition of data were scored based on the answered to questions regarding each facet of data collection. Answers to questions on the method, representativeness and repetition of data collected were scored 2 points – Yes, 1 point – Partially and 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	Yes. Methods were peer reviewed as part of the Condition Monitoring Plan (DEWNR 2017).	2
Standard methods	Has the same method been used over the sampling program?	Yes. Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary and each 1 km × 1 km cell of the Lakes and Goolwa Channel by surveyors on foot or by boat.	2
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Murray estuary with equal effort?	Yes. Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary and each 1 km × 1 km cell of the Lakes and Goolwa Channel	2
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	Yes. Censuses have been conducted in the Coorong from 2000 to 2023 and in the Lakes from 2009 to 2023. Therefore, monitoring has occurred pre- and post-adoption of the Basin Plan and over a range of hydrological conditions.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	Yes. The same spatial extent of the Coorong and Lakes are counted for waterbirds each year of the respective monitoring programs.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	Partially. Annual census data of waterbirds in the Coorong in January and the Lakes in late January/early February has largely been sufficient to represent change of the waterbird community over the assessment period. However, as these wetland systems are important habitat for waterbirds over autumn, spring and summer, the absence of both autumn and spring data is considered a weakness.	1
Final score			11
Information reliability			Very good

12.5 Evaluation

12.5.1 Lakes

The abundance of the selected species (Table 12–2) in the Lakes waterbird community were likely to have improved over the assessment period (2009–2023). Trends in the abundance of selected species differ between guilds, with generalists and herbivores having likely improved, while piscivores are stable. As very low abundances of selected species were recorded in the first two annual censuses (2009 and 2010) that were associated with the late Millennium Drought, an improvement in trend for each guild should have been achievable.

Since 2019, the proportion of selected waterbird species within each guild that met their respective abundance, AOO and EOO target values have predominantly reduced. At present, the 2029 expected environmental outcome for Lakes waterbird abundance, AOO and EOO are considered on-track for the generalist and herbivore guilds, but are not on-track for piscivores.

The environmental outcomes of selected species in the Lakes waterbird community over the assessment period (2009–2023) was influenced by water regime, salinity and inland wetland availability.

Water regime

Water regimes of freshwater lake systems influence ecological processes and the diversity of waterbirds (Kingsford et al. 2004). For the past decade, water levels in the Lakes under normal conditions have been managed between +0.5 m AHD and +0.85 m AHD on an annual basis (Figure 12-18). The margins of freshwater lake systems that experience wet and dry cycles enhance productivity through the accumulation and resuspension of nutrient-rich organic matter (Gownaris et al. 2018). Although a knowledge gap, the variable water regime of the Lakes is also expected to somewhat increase primary and biological productivity, and potentially increase aquatic food resources for waterbirds. For example, the January–February 2023 census occurred when lake levels had exceeded +1 m AHD for the first time in over 20 years. These high lake levels created backwaters that were scattered around the lake margins, and supported high densities of aquatic invertebrates, small fish and frogs, and provided good foraging habitats for generalist species, including Royal Spoonbill, White-faced Herons and Australian White Ibis (Paton et al. 2023).

Maintaining lake levels that connect with fringing vegetation around the margins of the Lakes is important for establishing a food resource base for waterbirds and protecting active nesting sites from land-based predators, such as foxes. During the Millennium Drought, water levels receded below sea level for over two years, and disconnected the waterline from fringing vegetation, which had adverse impacts on the macroinvertebrates (Giglio 2011), submergent plants (Nicol et al. 2023), frogs (Mason and Durbridge 2015) and small-bodied fish (Wedderburn et al. 2012). The importance of inundated fringing vegetation was demonstrated by the waterbird responses to the operation of the Goolwa regulator during the Millennium Drought. The regulator re-inundated fringing vegetation in the Goolwa weir pool (section managed by the regulator) and provided habitat for frogs that was highly limited elsewhere around the Lakes (Mason and Durbridge 2015), promoted the recolonisation of submergent plants (Gehrig and Nicol 2010), and increased the abundance of fish, albeit primarily through the mass recruitment of common carp (*Cyprinus carpio*) (Bice and Zampatti 2011). These changes to food resource availability and habitat, while limited to areas of re-inundated fringing vegetation, likely contributed to the marked increase in the abundances of piscivores (e.g., Australian Pelican, Great Cormorant and Little Black Cormorant) and herbivores (e.g., Black Swan), and provided an opportunity for herbivores (e.g., Pacific Black Duck and Black Swan) to breed that was unavailable elsewhere in the Lakes (Paton et al. 2011).

Water for the environment delivery is expected to have contributed to waterbird breeding in the Lakes. Since adoption of the Basin Plan, water for the environment has been critical in supporting lakes levels above +0.4 m AHD (Guarino and Sengupta 2023). At these lake levels, fringing vegetation is inundated and waterbirds nesting on islands or clumps of reeds are protected from land-based predators. Without water for the environment, lake levels in 2018–19 and 2019–20 would dropped below +0.4 m AHD, and in 2019–20 may have approached sea level, disconnecting fringing vegetation from the water line. When such conditions were experienced during the late Millennium

Drought, Cormorant breeding was prevented (Paton et al. 2018). Therefore, in dry years, it is likely that water for the environment has contributed to the breeding of colonial nesting species (e.g., Cormorants, Ibis, and Royal Spoonbill) and other species that nest in isolated pairs or small colonies (e.g., Purple Swamphen and Black Swan).

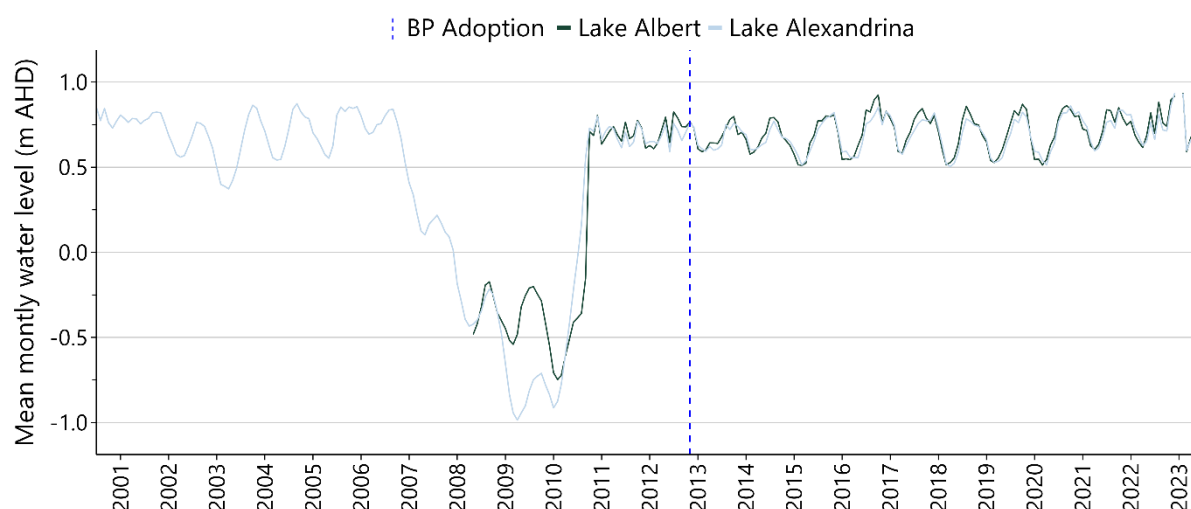


Figure 12-18. Mean monthly lake levels (m AHD) at Lake Albert (DEW water quality stations: A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (DEW water quality stations: A4260574, A4260524, A4261156, A4261133) from 2001 to 2023 with respect to Basin Plan adoption (2012) as shown by the dashed blue line.

Salinity

Salinity is known to affect the diversity of food resources for waterbirds in wetland systems (Takekawa et al. 2009). In the Lakes, the extremely elevated salinities that occurred during the late Millennium Drought changed the species composition of the macroinvertebrate (Giglio 2011), aquatic plant (Gehrig and Nicol 2010), frog (Mason and Durbridge 2015) and fish communities (Ye et al. 2016). The impact of elevated salinities on waterbirds in the Lakes during the late Millennium Drought is a knowledge gap, and unable to be discerned from the associated impacts of unprecedentedly low lake levels.

Since adoption of the Basin Plan, salinities in Lake Alexandrina have largely been maintained below $1,000 \mu\text{S cm}^{-1}$ and those in Lake Albert have declined from approximately $4,000 \mu\text{S cm}^{-1}$ to around $1,000 \mu\text{S cm}^{-1}$ through lake level cycling events, seasonal lake level management, high (unregulated) flow events and the enhancement of barrage flows with delivery of water for the environment (Figure 12-19). The magnitude of change in Lake Albert salinity is not expected to be biologically significant for waterbirds in the Lakes as many Australian species have plasticity in their diets, meaning they can switch between prey items depending upon environmental conditions (Kingsford and Norman 2002).

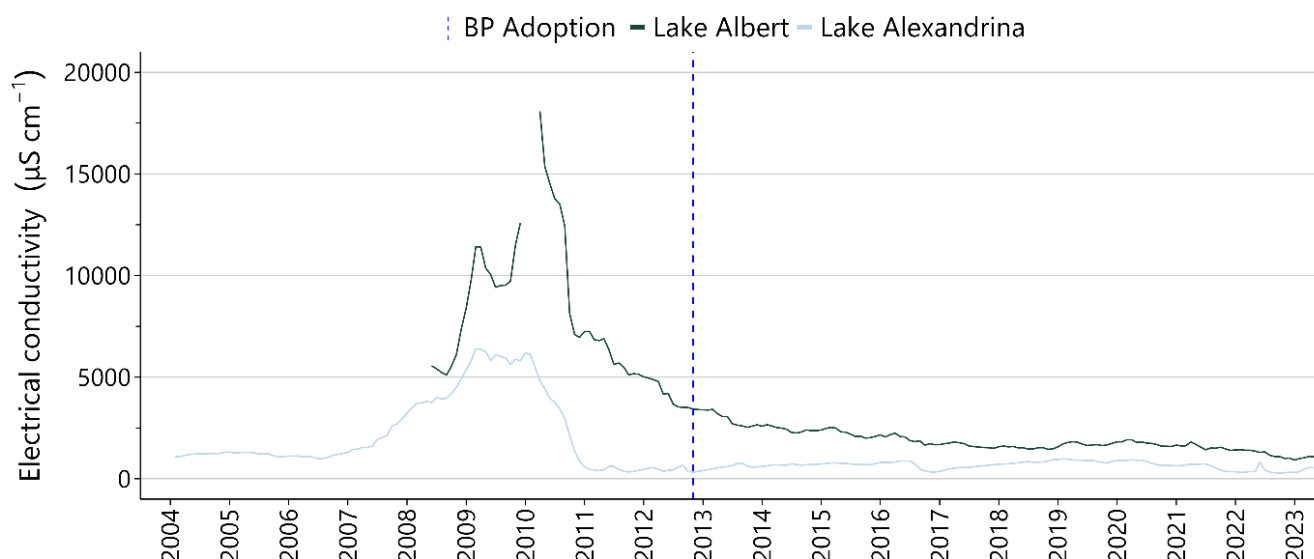


Figure 12-19. Mean monthly electrical conductivity ($\mu\text{S cm}^{-1}$) in Lake Albert (DEW water quality stations: A4261155, A4260630, A4261153) and Lake Alexandrina (DEW water quality stations: A4260574, A4260524, A4261156, A4261133) from 2004 to 2023 with respect to Basin Plan adoption (2012) as shown by the dashed blue line.

Inland wetland availability

Nomadic waterbird species in Australia respond to broad-scale resource availability (Kingsford et al. 2010). During dry climate phases, waterbirds become largely confined to more permanent waterbodies, such as the Lakes, which provide habitat and food resources (Kingsford et al. 2010; Wen et al. 2016). As temporary wetlands and floodplains, when wet, are more productive than permanent waterbodies, waterbirds can have rapid movements to inland areas that support these habitats. A suite of waterbird species, including Great Cormorant and Whiskered Tern, that use the Lakes consistently had lower abundances in years (e.g., 2010–11, 2016–17 and 2022–23) of increased wetland availability in inland Australia (Figure 12-20). The exodus of waterbirds during years of increased wetland habitat in the inland areas of Australia was also observed at wetlands in south-eastern South Australia, with the presence of a range of waterfowl (e.g., Grey Teal, Pink-Eared Duck), piscivores (Australian Pelican, Hoary-headed Grebe, Whiskered Tern) and generalists (Straw-necked Ibis) found to be lower in such years (Sanchez-Gomez et al. 2022). Although it is recognised that certain waterbird species depart the Lakes during wet climate phases, there is negligible information where they have moved and whether factors internal to the Lakes (e.g., availability and accessibility of food resources) associated with high water levels (unregulated flows) drove changes in abundance (Paton et al. 2023).

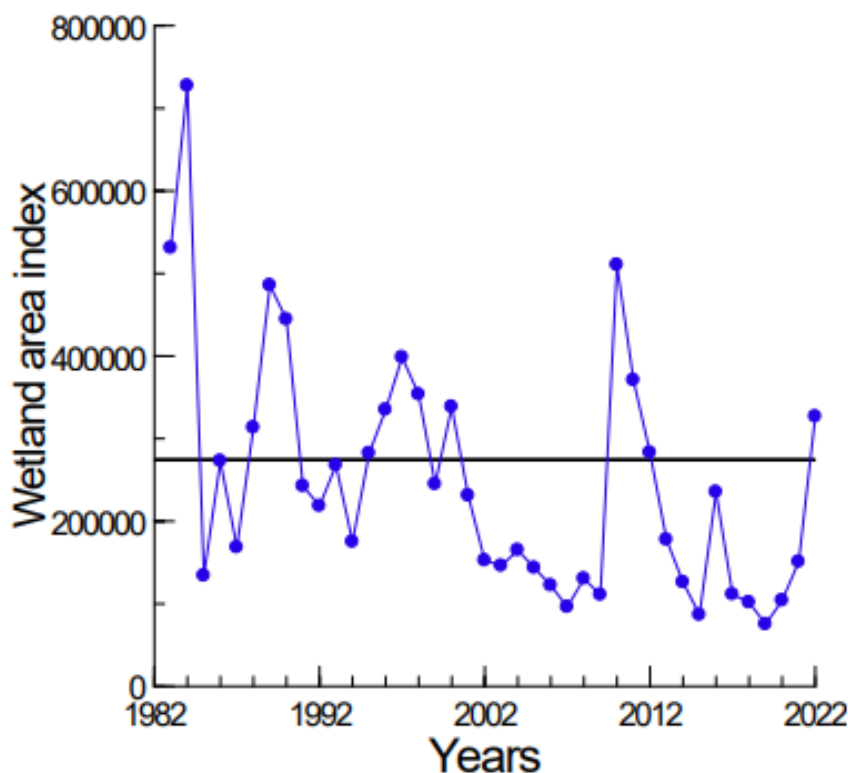


Figure 12-20. Changes in wetland area index during the Eastern Australian Waterbird Aerial Survey from 1983–2022. The black horizontal line shows the long-term average. Source: Porter et al. (2022), see [Eastern Australian waterbird survey | Centre for Ecosystem Science - UNSW Sydney](#) for further information.

Unanticipated outcomes

It was unanticipated that piscivorous waterbirds, inclusive of species with different foraging techniques (diving, swimming and striking), declined in abundance from 2020 to 2023. The factors behind this decline are currently unclear or unknown, but they may be due to changes in the availability or accessibility of prey sized fish and/or the use of other wetlands in inland Australia that became available over this period with three consecutive La Niña years (see *Inland wetland availability*).

Actions to achieve outcomes

The continued delivery of water for the environment through full implementation of the Basin Plan is critical to maintaining water levels in the Lakes that support waterbird breeding and enabling seasonal fluctuations in levels that are likely to enhance the extent and quality foraging habitat.

The permanent waterbodies of the Lakes are important drought refuges for waterbirds at a national scale, however, are expected to be less productive habitats than temporary or ephemeral wetlands. To improve the extent of productive wetland habitat for waterbirds around the Lakes, the HCHB program's On-Ground Works project has received Commonwealth and State funding to priority infrastructure upgrades at Tolderol Game Reserve and Teringie Wetland Complex. These infrastructure upgrades will improve the ability to manage water delivery to these sites to increase the quality and availability of waterbird habitat. Although management of these wetlands aims to provide alternative wetland habitats for migratory and resident shorebirds to the Coorong, waterbirds from other guilds (i.e., herbivores, generalists and certain piscivores) are also expected to benefit, however given the small spatial scale of these wetlands, they cannot be considered as substitutes for the Lakes or Coorong.

The Murraylands and Riverland Landscape Board also manage the provision of water for the environment to several wetlands around the Lakes through operation of infrastructure and pumping. These include Narrung, Waltowa, Jenny's Lagoon and Milang Snipe Sanctuary, aiming to enhance habitat for waterbirds through maintaining water levels and wetting/drying cycles. Management of these wetlands should continue and where possible, be optimised through adaptive management based on current hydro-climatic conditions, aiming to provide suitable habitat for target waterbird species.

Conclusion

The abundances of selected species in the Lakes waterbird community have improved since the Millennium Drought. However, this improvement was not consistent across all guilds, with abundances of selected species of herbivores and generalists having improved, while those of piscivores have remained stable over the assessment period (2009–2023). The delivery of water under the Basin Plan has allowed periodic inundation of fringing vegetation through the seasonal fluctuation of water levels. This water regime is expected to have benefited food resources for waterbirds and provided nesting sites that are protected from land-based predators. Since 2019, the proportion of selected waterbird species within each guild meeting their respective abundance, AOO and EOO target values has predominantly reduced. This was particularly evident for piscivores, which may have responded to changes in food resource availability and accessibility in the Lakes or departed the system to take advantage of the increased extent of productive wetland habitat in inland Australia. Given this, the 2029 expected environmental outcomes for Lakes waterbird abundance, AOO and EOO are currently not on track.

12.5.2 Coorong

The abundance of selected species in the Coorong waterbird community were very likely to have declined over the assessment period (2000–2023). Trends in abundance differ between guilds in the waterbird community, with herbivores having improved, generalists remaining stable, and piscivores and both resident and migratory shorebirds having declined. These trends are of particular concern as the assessment period (2000–2023) includes the Millennium Drought (1996–2010), a period of severe impacts on the Coorong ecosystem and waterbird populations (Paton 2010), and therefore, improvement in abundance should have been achievable.

Since 2019, the proportion of selected waterbird species within each guild that met their respective abundance, AOO and EOO target values has either been stable or declined depending upon the guild. At present, the 2029 expected environmental outcomes for Coorong waterbird abundance and AOO are not on track, however, the outcome for EOO remains on track.

The environmental outcomes of selected waterbird species in the Coorong over the assessment period (2000–2023) were influenced by water level, salinity, filamentous algae, and factors external to the Coorong at national and international scales.

Water level

Water level is a primary driver of waterbird abundance in the Coorong (Prowse et al. 2022). It influences the availability and accessibility of food resources (Jackson et al. 2022) and the level of protection from predators for colonies of island nesting waterbirds (Paton et al. 2017b). While water level is a key driver of abundance for waterbirds in the Coorong, favourable water levels can vary greatly between guilds and species (Prowse et al. 2022).

Adequate Coorong water levels in spring and early summer (preceding the January waterbird census), are important for priming habitat conditions that are conducive to supporting waterbirds. *Ruppia tuberosa* is a key food resource for herbivores and shorebirds (resident and migratory) (Paton 2010; Ye et al. 2020; Giatas et al. 2022), and its growth is strongly influenced by spring and summer water levels (Lewis et al. 2022). As most aquatic plants, including *R. tuberosa*, are found at elevations of ± 0.2 m AHD in 2020–21 (Lewis et al. 2022), maintaining water levels at a minimum of +0.2 m AHD in spring and into summer is desirable to protect a majority of the plant community from desiccation and provide an opportunity to produce seed and turions. Water for the environment has limited capacity

to influence water levels, particularly in the South Lagoon, however, in dry years elevated spring flows can be delivered to limit the rate of water level recession in spring–summer to the benefit of *R. tuberosa*.

Another food resource at the margins of the Coorong are benthic macroinvertebrates, which are consumed by shorebirds and certain generalist and herbivore species. As with *R. tuberosa*, benthic macroinvertebrates can also be impacted by low water levels as mudflats become uninhabitable if exposed for long time periods (Dittmann et al. 2015). While food resources are undoubtedly a key feature of habitat quality for shorebirds, Jackson et al. (2022) was unable to establish a clear relationship between shorebird abundance and the density of preferred macroinvertebrate prey taken at the waterline immediately following waterbird counts.

Accessibility of waterbird foraging habitat at lagoon margins becomes reduced with increasing water levels in the southern Coorong, affecting selected species from all guilds except for piscivores. The guilds most sensitive to shoreline water levels are resident and migratory shorebirds, which forage in wet mud and shallow water habitats. For example, two of the most common shorebird species in the Coorong, the Red-necked Stint and Sharp-tailed Sandpiper are only able to forage to depths of 4 cm and 7 cm, respectively, due to their short leg and beak lengths. Therefore, even a small increase in water depth can cause a decline in foraging performance (Rogers and Paton 2009). Shorebirds also generally avoid areas of mudflat that are in proximity to tall vegetation to avoid predators (Jackson and Straw 2021). This means that they are unlikely to use sites in the Coorong where the waterline is too close to terrestrial vegetation. Therefore, high water levels associated with high (unregulated) flow events in 2010–11, 2016–17 and 2022–23 (Figure 12-21) largely caused shoreline foraging habitat to become too flooded and inaccessible for shorebirds and other species (e.g., Great Egret and Chestnut Teal). Lack of accessible shoreline foraging habitat likely contributed to the low abundances of these species in such years (Paton and Bailey 2011; Paton et al. 2017b; Paton et al. 2023).

Piscivorous waterbirds that form breeding colonies on islands in the southern Coorong require water levels that prevent connection to other land masses but also do not inundate breeding areas. The sensitivity of water level changes on island nesting piscivores varies between species. For example, the larger islands that support Australian Pelican breeding remained isolated from the mainland even under very low water levels experienced during the Millennium Drought (DENR 2010). In contrast, the small islets that support Fairy Tern breeding colonies are more susceptible to water level changes. In 2016–17, high (unregulated) flows inundated islets that historically supported breeding and led to the colony establishing on an islet close to the eastern shore of the South Lagoon that remained exposed (Paton et al. 2017b). During that breeding season, water levels in the South Lagoon suddenly receded by 60 cm and re-connected the islet with the mainland, and subsequently led to the decimation of chicks within the colony by foxes (Paton et al. 2017b). The flood in 2022–23 also impacted Fairy Tern nesting colonies as it caused inundation of the only islet supporting breeding in the South Lagoon (Paton et al. 2023). Therefore, changes to water level can have severe consequences on the breeding success of Fairy Terns.

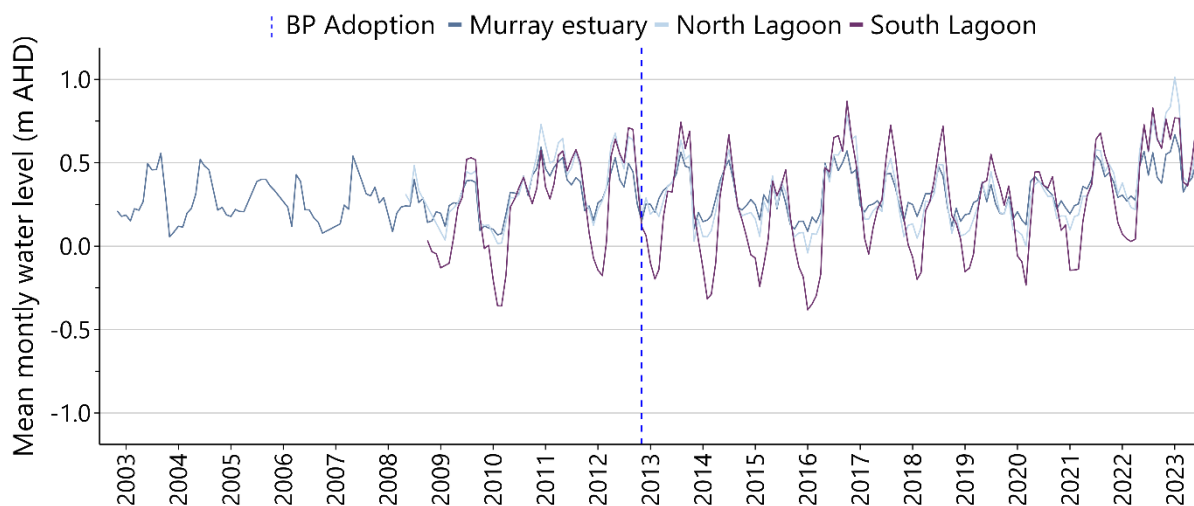


Figure 12-21. Water levels (m AHD) in the Coorong between 2003 and 2023. Data are from the Murray Estuary (DEW water quality station A4261036, A4261039, A4261043, A4261128), North Lagoon (DEW water quality stations: A4261134, A4261135, A426057) and South Lagoon (DEW water quality stations: A4261209, A4261165).

Salinity

Salinity, like water level, is a primary driver of waterbird abundance in the Coorong (Paton et al. 2018; Prowse et al. 2022). Habitat quality for waterbirds is impacted by salinity through its influence on the density and distribution of aquatic food resources and aspects of physical habitat, such as aquatic plant meadows and filamentous algae biomass (Dittmann et al. 2022b; Waycott et al. 2022). As the location of sites that support waterbird species in their highest abundances in the Coorong is species-specific (Jackson et al. 2022), a salinity gradient that increases with distance south from the Murray Mouth is important in maintaining conditions that support a diverse waterbird assemblage (Paton et al. 2018).

Waterbirds were severely affected by the extreme salinities that prevailed during the Millennium Drought, and particularly from 2007–08 to 2009–10 when flow through the barrages ceased. During this time, salinities in the Murray estuary were equal to seawater (35 g L^{-1}) and those in the south lagoon reached 150 g L^{-1} (Figure 12-22). These salinities were often above the tolerable or favourable salinities of key food resources in the Coorong, which contributed to adverse effects on the food web (Paton 2010). This ultimately resulted in low abundances of selected waterbird species and a contraction in their distribution (Paton 2010).

Water for the environment plays an important role in regulating the salinity environments of the Coorong (Brookes et al. 2023; Ye et al. 2023). Barrage flows, which are comprised largely or entirely of water for the environment in dry years (Guarino and Sengupta 2023; Ye et al. 2023), reduces the amount of salt that enters the Murray Mouth and moves into the Coorong (Brookes et al. 2023). Delivery of water for the environment had a cumulative impact on salinity in the Coorong. If no water for the environment had been delivered in the five years preceding 2020–21, salinities in the south lagoon would have been reminiscent of the Millennium Drought (Ye et al. 2023). With the contribution of water for the environment, salinities in the south lagoon were less than 100 g L^{-1} between 2017–2019, which are suitable for key salt-tolerant food resources for waterbirds (e.g., *R. tuberosa*, chironomid larvae and smallmouth hardyhead) (Lui 1969; Kokkinn 1986; Collier et al. 2017).

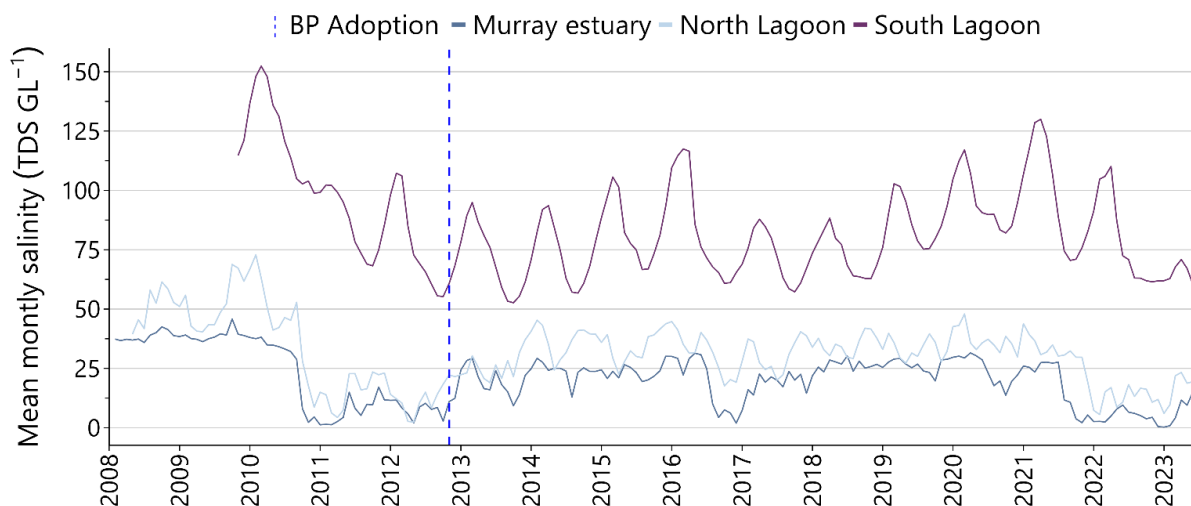


Figure 12-22. Salinity (TDS GL⁻¹) in the Coorong between 2008 and 2023. Data are from the Murray Estuary (A4261036, A4261039, A4261128, A4261043), North Lagoon (DEW water quality stations: A4261134, A4261135, A426057) and South Lagoon (DEW water quality stations: A4261209, A4261165).

Filamentous algae

Hyper-eutrophic conditions have led to very high loads of filamentous algae in the Coorong (Priestley et al. 2022; Mosley et al. 2023). Filamentous algal blooms are frequently observed during spring and summer in the Coorong and can form widespread mats on the water's surface (Lewis et al. 2022). When salinities exceed 80 g L⁻¹, the growth rates of filamentous algae are reduced and can result in lower biomass or mortality (Collier et al. 2017). This means that filamentous algae can potentially proliferate in the high nutrient environments of the Coorong when salinities freshen below 80 g L⁻¹, as is commonly observed in years of high (unregulated) flows (e.g., 2016–17 and 2022–23) (Figure 12-22).

Filamentous algae proliferation has a direct effect on key food resources for waterbirds and may influence the ability of waterbirds to forage (Paton et al. 2023). *Ruppia* taxa are a key food resource for herbivores and shorebirds (resident and migratory) in the Coorong (Delroy 1974; Paton 1982; Giatas et al. 2022). The ability of *Ruppia* to produce food resources for waterbirds, which include foliage, turions and seed, is hampered by filamentous algae. Filamentous algae attach to *Ruppia* beds and can reduce the growth rates of plants through shading and interference with their sexual reproduction (Waycott et al. 2022). While filamentous algae are consumed by herbivores in the Coorong, it comprises a far smaller proportion of their diet than *Ruppia* (Giatas et al. 2022) and is less nutritious (Moore 2014).

Mats of filamentous algae that cover mudflats negatively impact benthic macroinvertebrates (Sutula et al. 2014), which are a key food resource for many waterbird species in the Coorong (Ye et al. 2020; Giatas et al. 2022). The impacts of filamentous algae on benthic macroinvertebrates were demonstrated at Ewe Island, in 2020–21, filamentous algae covered the mudflats adjacent to the barrage and were associated with a decline in macroinvertebrate abundance (Dittmann et al. 2021). This decline was reversed in 2021–22, with high (unregulated) barrage flows dislodging mats from the island that facilitated a recovery of macroinvertebrates (Dittmann et al. 2022a).

The physical structure of filamentous algae during its growth and decay phases may impede the foraging of waterbirds. Mats of decaying filamentous algae are thought to adversely impact shorebirds in the Coorong by restricting access to mudflats for foraging (e.g., Paton et al. 2017b). This is partially supported by Green et al. (2015) who found that algal mats in a eutrophic lagoon in the USA impacted the ability of migratory shorebirds to forage. This result was species-specific, with some species unaffected by the macroalgae and others altering their foraging behaviour or avoiding areas with macroalgae (Green et al. 2015).

Inland wetland availability

Habitat availability for waterbirds in the MDB can vary significantly between wet and dry climate phases (Wen et al. 2016). The Coorong is recognised as the most valuable drought refuge in the MDB and supported approximately 90% of the waterbirds in the Basin when the Millennium Drought was at its most severe (Brookes et al. 2021). Modelling by Prowse et al. (2022) sought to determine the effect of wet inland conditions on the probability of presence in key waterbird species in the Coorong, and found some evidence that Sharp-tailed Sandpipers, Black Swan and Red-necked Avocet use the Coorong as a drought refuge. This modelling approach was also undertaken by Sanchez-Gomez et al. (2022) for the entire waterbird community present at wetlands in south-eastern South Australia and identified that these wetland sites may provide drought refugia for Great Crested Grebe, Hoary-headed Grebe, Whiskered Tern, Australian Pelican, Black-winged Stilt, Red-capped Plover, and Sharp-tailed Sandpiper. Therefore, increased abundance of waterbirds in the Coorong could reflect a lack of inland wetland habitat rather than an improvement in the habitat quality of the Coorong (Jackson et al. 2022).

During wet climate phases when there is high wetland availability in inland Australia, the numbers of waterbirds in the Coorong are reduced. This reduction is expected to be driven by; the departure of species that rarely, if ever, breed in the Coorong in search of breeding opportunities; and the high water levels (Figure 12-21) that may eventuate in the Coorong when there is prolonged, widespread high rainfall in the MDB.

Species that rarely or do not breed in the Coorong (e.g., Banded Stilt, Red-necked Avocet, Hoary-headed Grebes, Whiskered Terns, Black-winged Stilts, and Eurasian Coots) can show dramatic reductions in abundance when the availability of inland wetlands increases (Paton et al. 2018). The largest breeding events of waterbirds over eastern Australia has occurred in years where there has been a significant increase in the wetland area index, i.e., 2010, 2016 and 2022 (Porter et al. 2022) (Figure 12-20). These water years (2010–11, 2016–17 and 2022–23) have coincided with an exodus of waterbirds that breed inland from the CLLMM; however, the extent to which these species use alternate wetland habitats largely remains a knowledge gap. One exception is the study by Mott et al. (2022) who tracked 12 Red-necked Avocets from their capture sites in the Coorong. This study found that all tracked individuals departed the Coorong within 21 days of high inland rainfall across the continent, and that central place foraging movements consistent with breeding at inland sites was detected for six individuals. In the absence of complete tracking data for key waterbird species in the Coorong, a precautionary principal is adopted when interpreting waterbird outcomes during wet climate phases as the coincident high-water levels in the Coorong can limit access to habitat and food resources for waterbirds, as discussed in the *water level* section above.

International factors

Migratory shorebird abundances are declining more rapidly in the Coorong than elsewhere in Australia (Clemens et al. 2016). Despite this, declines in migratory shorebird populations in the East Asian-Australasian Flyway are largely being driven by factors outside of Australia (Clemens et al. 2016), especially habitat loss and degradation of key staging sites in the Yellow Sea (Szabo et al. 2016; Studds et al. 2017). Yellow Sea tidal mudflats are important foraging grounds for migratory shorebirds and provide an opportunity to re-fuel during their migrations between overwintering sites and breeding grounds (Barter 2002). Migratory shorebird species that are most reliant on Yellow Sea staging sites were found to have the greatest long-term population declines (Studds et al. 2017). Therefore, it is likely that the loss and degradation of these tidal mudflats meant that the species were unable to meet their energy demands for migration leading to their reduced survival (Studds et al. 2017).

Migratory shorebird species that overwinter in the Coorong vary in their reliance on staging sites in the Yellow Sea. For example, Eastern Curlews and Curlew Sandpipers are dependent on Yellow Sea staging sites and are estimated to have an annual flyway population decline of 5.8% and 7.5%, respectively (Studds et al. 2017; Lisovski et al. 2021). In contrast, Red-necked Stints have lower reliance on Yellow Sea staging sites, have a more stable population, with an estimated annual flyway population decline of 1.6% (Studds et al. 2017; Lisovski et al. 2021). As counts of each of these species have declined in the Coorong, it is evident that even species (i.e., Red-necked Stint) with low reliance on Yellow Sea staging sites and stable flyway populations have declined in the Coorong, meaning local impacts could be having significant impacts on the population.

The response of common greenshank, a migratory shorebird, may have influenced the results in this report for the piscivore guild in this assessment, considering this species was assigned to both guilds.

Unanticipated outcomes

The 2022–23 flood was an unanticipated event that impacted waterbirds in the Coorong, as discussed in the *water level* and *filamentous algae* sections above. This flood event was widespread over the MDB and led to increases in the number of waterbird species breeding, numbers of nests and brood sizes (Porter et al. 2022). How these breeding events will change the numbers of waterbirds utilising the Coorong into the future will be determined through the continuation of the annual census.

It is noted that the selection of some bird species in the piscivore guild may be more generalist species or are known migratory birds (common greenshank). This means that because of the nature of some species in the piscivore guild, and that many waterbirds are highly mobile, the assessment of this guild may be more susceptible to other external influences rather than just the availability of fish prey in the Coorong.

Actions to achieve outcomes

The conservation of waterbird populations in the Coorong relies on a variable water regime. This variability is important because optimal water level and salinity conditions not only differ among waterbird species (Paton et al. 2009; Mott et al. 2022; Prowse et al. 2022) but also between these species and their respective food resources. For instance, while higher water levels are beneficial to the production of shorebird food resources, such as *R. tuberosa* seed and turions, they simultaneously reduce the extent of shorebird foraging habitat to acquire food (Jackson et al. 2022). The salinity gradient, that increases with distance south from the Murray Mouth, is a key feature of the Coorong and structures the distribution of food resources (Dittmann et al. 2022b). The Coorong supporting these favourable salinities will vary longitudinally based on volumes of freshwater inflow and antecedent conditions.

Full implementation of the Basin Plan would improve the resilience of the Coorong ecosystem to future droughts when it acts as a refuge for waterbirds across the MDB. The lifting of constraints and achievement of water recovery requirements under full implementation of the Basin Plan would ensure that salinities in the Coorong remain within favourable to tolerable ranges for key food resources.

The HCHB program has commenced regional wetland restoration activities to ensure that habitats for key Coorong South Lagoon waterbird species exist within the broader regional landscape at critical times. These activities aim to improve the availability and quality of habitat for migratory and non-migratory shorebirds outside of the Coorong in the short-to medium-term, while broader restoration of the Coorong is underway. Small-scale wetland management infrastructure will be constructed at priority wetland sites within proximity to the Coorong to manage water at levels that improves the extent, quality and duration of inundation. This infrastructure will increase the extent of productive mudflats for migratory and resident shorebirds by improving water delivery and water level management to provide complementary habitat for migratory and resident shorebirds that have declined in the Coorong.

The integrated management of water regimes in the regional wetland network, inclusive of the wetlands with infrastructure upgrades, will be necessary to ensure that habitats for resident and migratory shorebirds exist in the region at critical times (Hunt et al. 2019). The need for such integrated management was demonstrated by Mott et al. (2022) who found that tracked Red-necked Avocets and Sharp-tailed Sandpipers used both the Coorong and regional wetlands. As counts of migratory shorebird species at regional wetlands (e.g., Tolderol Game Reserve) have been regionally and internationally significant (Hartvigsen-Power et al. 2019), the improved and integrated management of regional wetlands will be important to their conservation. This management is in addition to the continued management of existing wetlands in the Lakes including Waltowa, Narrung and Jenny's Lagoon.

Conclusion

The abundance of selected species in the Coorong waterbird community have very likely declined over the assessment period (2000–2023). Trends in abundance differ between guilds, with herbivores improved, generalists remaining stable, and piscivores and both resident and migratory shorebirds declining. Differences in trend between guilds reflect their different responses to key factors that have influenced outcomes, including water level, salinity, filamentous algae, and factors external to the Coorong at national and international scales. The delivery of water for the environment under the Basin Plan has been important in regulating salinity environments within the Coorong to be tolerable to key waterbird food resources. However, volumes of water for the environment have been inadequate to provide the water levels required by *R. tuberosa* to produce high quantities of seed and turions during dry years, which is a key driver for certain waterbird guilds. Since 2019, the proportion of selected waterbird species within each guild meeting their respective abundance, AOO and EOO targets have either been stable or declined depending upon the guild. This was evident for all guilds, except herbivores. As such, only the 2029 expected outcome for EOO is considered on-track to be achieved.

13 Abbreviations and Glossary

13.1 Abbreviations

AHD	Australian Height Datum
AOO	Area of occupation
CDM	Coorong Dynamics Model
CEW	Commonwealth Environmental Water
CEWH	Commonwealth Environmental Water Holder
CLLMM	Coorong, Lower Lakes Murray Mouth
CMP	Condition Monitoring Plan
CPUE	Catch per unit effort
DEW	Department for Environment and Water (South Australia)
DTR	Diurnal Tidal Ratio
EOO	Extent of occurrence
EWRs	Environmental watering requirements
GL	Gigalitre
HCHB	<i>Healthy Coorong, Healthy Basin</i>
HSI	Habitat Suitability Index
PEA	Priority Environmental Asset
RAP	Rapid Assessment Protocol
RI	Recruitment Index
SARDI	South Australian Research and Development Institute
TL	Total Length (mm)
TLM	<i>The Living Murray</i>
LCF	Lakes and Coorong Fishery
LLCMM	Lower Lakes Coorong Murray Mouth
LTIM	Long Term Intervention Monitoring
LTWP	Long-term Watering Plan
MDB	Murray–Darling Basin
MDBA	Murray–Darling Basin Authority
ML	Megalitre
PEW	Planned Environmental Water
QSA	Flow at the South Australian border
YOY	Young-of-year

13.2 Glossary

Algae	Photosynthetic organisms that lack true stems, roots, leaves and vascular tissue.
Amphipod	Any of numerous small, flat-bodied crustaceans.
Aquatic macrophytes	Plants that grow in or near the water either wholly submerged, floating or some portion of the plant above the water surface.
Aquatic vegetation	The plant community that grow partly or wholly within aquatic environments.
Barrage	In the Coorong, Lower Lakes and Murray Mouth there are five weirs built where the Lakes meet the Murray estuary. They prevent seawater entering the fresh lakes and river system and help to control water levels in the Lakes and River Murray below Lock 1.
Basin Plan	A widespread, across governments, agreement to manage and protect water in the Murray-Darling basin.
Biogeochemical processes	Any of the natural pathways by which essential elements of living matter are circulated.
Biomass	The total mass of living organisms (plants or animals) in a sampled area, measured as a wet, dry or ash free dry mass.
Bioturbation	The reworking of sediments by animal activities, including burrowing, ingestion, and defecation of sediment grains, and by plants. It has a profound effect on sediment condition and the environment.
Catadromous	Fish that migrate from freshwater habitats to marine habitats to spawn.
Catch per unit effort (CPUE)	The quantity of fish caught (in number or in weight) with one standard unit of fishing effort, e.g., number of fish taken per 1000 hooks per day or weight of fish, in tons, taken per hour of trawling. CPUE is often considered an index of fish biomass (or abundance).
Cohort	A group of individuals who share a common trait, such as birth year.
Commonwealth Environmental Water	Water in the Murray–Darling Basin owned by the Commonwealth.
Denitrification	The microbial process by which nitrate is converted to nitrogen gas bubbles, which are released to the atmosphere. If the sediment is anoxic, then nitrification-denitrification cannot occur and the nitrogen remains in the nutrient cycle.
Diadromous (fish)	A fish that travels between salt water and fresh water as part of its life cycle
East Asian-Australasian Flyway	The east Asian-Australasian flyway stretches from the Russian far east and Alaska, southwards through east Asia and south-east Asia, to Australia and New Zealand and encompasses 22 countries.

Ecosystem	All biological, physical or chemical processes that maintain ecosystems and biodiversity and provide inputs and waste treatment services that support human activities
Emergent plant species	Plants that are rooted in the water but have leaves and stems extending out of the water.
Environmental Water	See 'water for the environment'
Estuary	Semi-enclosed water bodies at the lower end of a freshwater stream that are subject to marine, freshwater and terrestrial influences, and experience periodic fluctuations and gradients in salinity.
Eutrophication	Degradation of water quality due to enrichment by nutrients (primarily nitrogen and phosphorus), causing excessive plant growth and decay. See also algal bloom.
Evapo-concentration	The concentration of solutes such as salt and contaminants as water evaporates. The effects of evapo-concentration increase with increasing water residence time, and at higher temperatures in summer.
Evapotranspiration	The term used to describe the part of the water cycle which removes liquid water from an area with vegetation and into the atmosphere by the processes of both transpiration and evaporation.
Filamentous algae	Colonies of microscopic plants that link together to form threads or mesh-like filaments. The green filamentous algal community which occurs in the Coorong, consisting of <i>Ulva paradoxa</i> , <i>Rhizoclonium</i> sp. and <i>Cladophora</i> sp.
Fishway	A structure that provides fish with passage past an obstruction (i.e. a barrage).
Fyke net	A fish net that consists of netting mounted on rings. It can have one (single winged) or two wings (double winged) which guide the fish into the net.
Herbivore	An organism that mostly feeds on plants.
Hypereutrophic	A high-nutrient state due to eutrophication.
Hypersaline	Salinities that are greater than that of normal seawater.
Inorganic	Not consisting of or deriving from living matter.
Littoral vegetation	Plant community that occupies the fringes of waterbodies.
Macroinvertebrates	Aquatic invertebrates visible to the naked eye including insects, crustaceans, molluscs and worms that inhabit a river channel, pond, lake, wetland or ocean.
Mesotrophic	Containing a moderate amount of dissolved nutrients.
Microbes	Organisms that are too small to be seen without a microscope.
Millennium Drought	From late 1996 to mid 2010, much of southern Australia (except parts of central Western Australia) experienced a prolonged period of dry conditions, known as the Millennium Drought. The drought conditions were particularly severe in the more densely populated southeast and southwest and severely affected the Murray–Darling Basin and virtually all of the southern cropping zones. The period from 2007–2010 was

	particularly extreme with extended periods of no flow through the barrages to the Coorong.
Murray–Darling Basin (MDB)	An area of about 1 million km ² in the south east of Australia, it is almost 1,400 km long and about 800 km wide.
Nitrification	Nitrification is the process by which ammonium is converted to nitrite and then nitrate. It can also take place in the sediment and requires oxygen.
Nitrogen	A nutrient that is essential to plants and animals and forms compounds such as amino acids and proteins. Nitrogen can be found in aquatic environments in dissolved, particulate, inorganic, organic and gaseous forms. Too much nitrogen can be associated with eutrophication.
North Lagoon	The area of The Coorong between Pelican Point in the north to Parnka Point.
Organic	Relating to or derived from living matter.
Osmoregulatory	Osmoregulation is a process that regulates the osmotic pressure of fluids and electrolytic balance in organisms.
Otoliths	Part of the fish's inner ear, allowing fish to hear and sense vibrations in the water and providing a sense of balance so they may better navigate their surroundings.
Pelagic	Inhabiting the water column.
Phosphorus	A nutrient essential to life and strongly influencing water and sediment quality in the Coorong. Phosphate is the dissolved form of phosphorus, which is taken up by plants and algae.
Phytoplankton	Small plankton algae that is essential to aquatic food webs.
Piscivore	A carnivorous animal that primarily eats fish.
Polychaete	A segmented marine worm.
Pugging	Affecting the soil structure, mainly reducing pores in the sediment caused by livestock.
QSA	Flow at the South Australian border, expressed as mega litres per day (ML day ⁻¹).
Ruppia Community	The multi species assemblage that has become established across the southern Coorong and includes <i>Ruppia tuberosa</i> , <i>Althenia cylindrocarpa</i> along with an as yet unresolved species of <i>Ruppia</i> .
<i>Ruppia tuberosa</i>	An aquatic plant that is the dominant species in the Coorong South Lagoon and an important habitat and food resource for fish and waterbirds.
Salinity and units of measurement	Salinity is the measure of the concentration of dissolved (soluble) salts in water. Salinity in the Lakes is described using electrical conductivity (EC) which is often the adopted unit for freshwater systems. EC is a measure of how well a solution can carry an electrical charge and is described in microsiemens per centimetre (µS cm⁻¹) or EC. Typically the higher the salinity the better it will carry a charge. Absolute pure water has a low EC value of around 0.055 µS/cm, tap water typically has a value of

	around 50-100 $\mu\text{S}/\text{cm}$ and sea water has a value of around 50,000 $\mu\text{S}/\text{cm}$. Salinity in the Estuary and Coorong is described using parts per thousand (ppt) which is generally the adopted measure for saltwater environments. Ocean salinity is 35 ppt (49,900 EC) which means that there is 35 grams of salt in every kilogram (1,000 grams) of seawater.
Salt-wedge	Seawater intrusion in an estuary as a wedge-shaped bottom layer which hardly mixes with the overlying fresh water layer.
Seine Net	A fishing net that hangs vertically in the water with weights on the bottom and floats on the top.
Semi-catadromous	Fish that migrate from freshwater to estuarine habitats rather than marine habitats to spawn.
Submergent plant species	A plant that grows completely underwater.
South Lagoon	The area of the Coorong between Parnka Point and the southern end of the Coorong.
Transect	A path/line along which one counts and records occurrences of the objects of study.
Trophic Level	The position of an organism in the food chain.
Turion	Reproductive structure of <i>Ruppia tuberosa</i> (Type I and Type II) and <i>R. polycarpa</i> (Type I), produced on rhizomes underground that are capable of forming into a new plant.
Vertical slot fishways	A concrete channel structure divided into individual pools, each connected by a baffle with a vertical gap or slot.
Water for the environment	Environmental water is 'held' or 'planned' environmental water, defined in the Water Act 2007. <i>Held</i> environmental water is available under a water access right for the purposes of achieving environmental outcomes; <i>planned</i> environmental water is committed to environmental outcomes and cannot be used for any other purpose unless required in emergency circumstances.
Weir	A barrier which is built across a river in order to control the flow of water.
Weir pool	The body of water stored behind a weir.
Zooplankton	Microscopic floating animals that rely on water currents to move.

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15 Appendices

Appendix A: Ecological objective, target and indices for aquatic and littoral vegetation condition in the Lakes (Nicol 2017).

Characteristic	Description
Ecological Objective	Maintain or improve diversity of aquatic and littoral vegetation in the Lakes as quantified using the LLCMM vegetation indices.
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in Lake Alexandrina as quantified using the LLCMM vegetation indices.
Ecological Indices	1. Littoral +0.8 to +0.6 m AHD: <40% of quadrats in any given survey containing >75% combine cover (Braun-Blanquet score 5) of <i>Typha</i> and <i>Phragmites</i>. 2. Littoral +0.8 to +0.6 m AHD: <20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 3. Littoral +0.8 to +0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater). 4. Littoral +0.8 to +0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score of 2 or greater). 5. Aquatic +0.4 to 0 m AHD: <40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score of 4 or greater) of <i>Typha</i> and <i>Phragmites</i>. 6. Aquatic +0.4 to 0 m AHD: Minimum of 20% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score 2 or greater). 7. Aquatic +0.4 to 0 m AHD: Minimum of 35% of quadrats in any given survey contain native submergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater). 8. Deep water <0 m AHD: permanent inundation.
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in Lake Albert as quantified using the LLCMM vegetation indices.
Ecological Indices	1. Littoral +0.8 to +0.6 m AHD: <40% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 4 or greater) of <i>Typha</i> and <i>Phragmites</i>. 2. Littoral +0.8 to +0.6 m AHD: <40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 3. Littoral +0.8 to +0.6 m AHD: Minimum of 35% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater). 4. Littoral +0.8 to +0.6 m AHD: Minimum of 35% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score of 2 or greater). 5. Aquatic +0.4 to 0 m AHD: <40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score of 4 or greater) of <i>Typha</i> and <i>Phragmites</i>. 6. Aquatic +0.4 to 0 m AHD: Minimum of 20% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score 2 or greater). 7. Aquatic +0.4 to 0 m AHD: Minimum of 20% of quadrats in any given survey contain native submergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater). 8. Deep water <0 m AHD: permanent inundation.
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in Goolwa Channel as quantified using the LLCMM vegetation indices.

Characteristic	Description
Ecological Indices	1. Littoral +0.8 to +0.6 m AHD: <50% of quadrats in any given survey containing 75% combined cover (Braun-Blanquet score of 5 or greater) of <i>Typha</i> and <i>Phragmites</i>. 2. Littoral +0.8 to +0.6 m AHD: <20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 3. Littoral +0.8 to +0.6 m AHD: Minimum of 50% of quadrats in any given survey contain emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score 2 or greater). 4. Littoral +0.8 to +0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun and Blanquet score 2 or greater). 5. Aquatic +0.4 to 0 m AHD: <50% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Typha</i> and <i>Phragmites</i>. 6. Aquatic +0.4 to 0 m AHD: Minimum of 20% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score 2 or greater). 7. Aquatic +0.4 to 0 m AHD: Minimum of 40% of quadrats in any given survey contain native submergent species with a combined cover of >5% (Braun-Blanquet score of 2 or greater). 8. Deep water <0 AHD: Minimum of 20% of quadrats in any given survey contain native submergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in permanent wetlands as quantified using the LLCMM vegetation indices.
Ecological Indices	1. Littoral >+0.6 m AHD: <35% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 5 or greater) of <i>Typha</i> and <i>Phragmites</i>. 2. Littoral >+0.6 m AHD: <20% quadrats in any given survey containing >50% combined cover (Braun-Blanquet score of 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 3. Littoral >+0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater). 4. Littoral >+0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover of >5% (Braun-Blanquet score 2 or greater). 5. Aquatic <+0.6 m AHD: <40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Typha</i> and <i>Phragmites</i>. 6. Aquatic <+0.6 m AHD: Minimum of 20% of quadrats in any given survey contain native emergent species (other than <i>Typha</i> and <i>Phragmites</i>) with a combined cover >5% (Braun-Blanquet score 2 or greater). 7. Aquatic <+0.6 m AHD: Minimum of 50% of quadrats in any given survey contain native submergent species with a combined cover of 5 to 50% (Braun-Blanquet score 2 to 4).
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in seasonal spring wetlands as quantified using the LLCMM vegetation indices.
Ecological Indices	1. Edge: <20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 2. Edge: Minimum of 50% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score of 2 or greater). 3. Edge: Minimum of 50% of quadrats in any given survey contain native emergent species with a combined cover >5% (Braun-Blanquet score 2 or greater). 4. Bed: Minimum of 20% of quadrats in any given survey contain native emergent species with a combined cover >5% (Braun-Blanquet score 2 or greater). 5. Bed: Minimum of 50% of quadrats in any given survey contain native submergent species with a combined cover of >25% (Braun-Blanquet score 3 or greater). 6. Bed: Minimum of 25% of quadrats in any given survey contain amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater).

Characteristic	Description
Ecological Target	Maintain or improve diversity of aquatic and littoral vegetation in seasonal autumn wetlands as quantified using the LLCMM vegetation indices.
Ecological Indices	1. Edge: <20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of <i>Cenchrus</i> and <i>Paspalum</i>. 2. Edge: Minimum of 50% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score of 2 or greater). 3. Edge: Minimum of 50% of quadrats in any given survey contain native emergent species with a combined cover >5% (Braun-Blanquet score 2 or greater). 4. Bed: Minimum of 20% of quadrats in any given survey contain native emergent speices with a combined cover >5% (Braun-Blanquet score 2 or greater). 5. Bed: Minimum of 25% of quadrats in any given survey contain amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater).



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