Technical information supporting the 2023 Coorong waterbirds populations environmental trend and condition report card

Department for Environment and Water
August, 2023

DEW Technical note 2023/32

Government of South Australia
Department for Environment and Water

Department for Environment and Water
Government of South Australia
August 2023

81-95 Waymouth St, ADELAIDE SA 5000
Telephone +61 (8) 8463 6946
Facsimile +61 (8) 8463 6999
ABN 36702093234

www.environment.sa.gov.au

Disclaimer

The Department for Environment and Water and its employees do not warrant or make any representation regarding the use, or results of the use, of the information contained herein as regards to its correctness, accuracy, reliability, currency or otherwise. The Department for Environment and Water and its employees expressly disclaims all liability or responsibility to any person using the information or advice. Information contained in this document is correct at the time of writing.

Preferred way to cite this publication

Department for Environment and Water (2023). *Technical information supporting the 2023 Coorong waterbirds populations environmental trend and condition report card*, DEW Technical report 2023/32, Government of South Australia, Department for Environment and Water, Adelaide.

Download this document at https://data.environment.sa.gov.au

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.

Acknowledgements

This document was prepared by Gareth Oerman (DEW). Rebecca Quin (DEW) provided principal oversight throughout and technical review of this report. Improvements were made to this report and associated report card based on reviews by Adrienne Rumbelow and Luke Vial.

The data used in this report was collected by The University of Adelaide (Associate Professor David Paton) for The Living Murray's Lower Lakes, Coorong and Murray Mouth condition monitoring program. The Living Murray is a joint initiative funded by the New South Wales, Victorian, South Australian and Commonwealth governments.

Contents

Acknowledgement of Country ii

Acknowledgements ii

Summary v

1 Introduction 1

1.1 Environmental trend and condition reporting in SA 1

1.2 Purpose and benefits of SA's trend and condition report cards 1

1.3 Coorong waterbirds populations 2

2 Methods 3

2.1 Indicator 3

2.2 Data sources 4

2.3 Data collection 4

2.4 Methods to assign trend, condition and reliablity 4

2.4.1 Trend 4

2.4.2 Condition 5

2.4.3 Reliability 5

2.5 Data transparency 6

3 Results 7

3.1 Trend 7

3.2 Condition 11

3.3 Reliability 12

4 Discussion 13

4.1 Trend 13

4.1.1 Coorong habitat quality 13

4.1.2 Continental wetland availability 15

4.1.3 Waterbird populations 15

4.2 Condition 15

5 Conclusion 17

6 Appendices 18

A. The 40 selected waterbird species in the Coorong set within the Waterbird chapter of the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan (DEWNR 2017) for assessment of condition targets. A subset of 19 of the 40 target waterbird species were selected to assess the trend and condition of Coorong waterbirds populations in this report card. 18

B. Managing environmental knowledge chart for Coorong waterbirds populations 20

7 References 21

List of figures

Figure 3.1. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species in the Coorong from 2000 to 2022. Posterior values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse). Data source: University of Adelaide (Assoc. Prof. David Paton). 8
Figure 3.2. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species from the resident shorebird, piscivore, generalist, migratory shorebird and herbivore guilds in the Coorong from 2000 to 2022. Posterior values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse). Data source: University of Adelaide (Assoc. Prof. David Paton). 8
Figure 3.3. Mean min-max normalised abundance of Coorong waterbird guilds from 2000 to 2022. For each selected species, minimum abundances over the census period were transformed into a 0 and the maximum abundance transformed into a 1, and other values were transformed into a decimal between 0 and 1. Data collected in 2022 occurred prior to flooding in the South Australian River Murray. Data source: University of Adelaide (Assoc. Prof. David Paton). 9
Figure 3.4. Abundance of selected waterbird species during annual January census' over the Coorong from 2000–2022 with reference to the long-term (2000–2015) median abundance of each species (horizontal red dashed line). Note: to meet the ecological target, selected species must exceed their recent median abundance value in two of the last three years. Data collected in 2022 occurred prior to flooding in the South Australian River Murray. Data source: University of Adelaide (Assoc. Prof. David Paton). 10
Figure 4.1. Murray–Darling Basin rainfall deciles from 2019 to 2021 (BOM 2022). 16

List of tables

Table 2.1. Coorong waterbird species grouped by guild that were assessed in this report card. 3
Table 2.2. Alignment of trend outcomes based upon their likelihood of an increase or decrease (modified from Mastrandrea et al. 2010) with categories used for report cards. 5
Table 2.3. Alignment of condition classes used for report cards with the proportion of selected species from each waterbird guild meeting their respective abundance targets. 5
Table 2.4. Scoring system for the reliability of data used to assess and analyse trend and condition for Coorong waterbird populations. 6
Table 2.5. Conversion of the final score (0–12) of data reliability to an information reliability rating that ranges from poor to excellent for report cards. 6
Table 3.1. Outcomes from the Bayesian modelling assessment of trend for all selected species within the Coorong waterbird community and selected species within the resident shorebird, piscivore, generalist, migratory shorebird and herbivore guilds. The likelihood of improvement in annual January census counts of selected species within each guild and as a whole in the Coorong are provided in addition to their associated confidence rating (as per Mastrandrea et al. 2010). The report card trend category aligns with the confidence rating. 7
Table 3.2. Selected waterbird species within each guild that met their abundance target, having exceeded their long-term (2000-2015) median abundance in two of the last three years (2020-2022) in the Coorong. The proportion of selected species in each guild that met their abundance target in 2022 was calculated to determine guild condition. 11
Table 3.3. Reliability of data obtained from waterbird census of the Coorong to assess trend and condition of the waterbird community in 2022. 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 were scored 2 points – Yes, 1 point – Partially, 0 points – No. 12

Summary

The 2023 release of South Australia's environmental trend and condition report cards summarises our understanding of the current condition of the South Australian environment, and how it is changing over time.

This document describes the indicators, information sources, analysis methods and results used to develop this report and the associated 2023 Coorong waterbirds populations report card. The reliability of information sources used in the report card is also described.

The Coorong waterbirds populations report card sits within the report card Biodiversity theme and Inland waters sub-theme. Report cards are published by the Department for Environment and Water and can be accessed at www.environment.sa.gov.au.

1 Introduction

1.1 Environmental trend and condition reporting in SA

The Minister for Climate, Environment and Water under the *Landscape South Australia Act 2019* is required to 'monitor, evaluate and audit the state and condition of the State's natural resources, coasts and seas; and to report on the state and condition of the State's natural resources, coasts and seas' (9(1(a-b)). Environmental trend and condition report cards are produced as the primary means for the Minister to undertake this reporting. Trend and condition report cards are also a key input into the State of the Environment Report for South Australia, which must be prepared under the *Environment Protection Act 1993*. This Act states that the State of the Environment Report must:

- include an assessment of the condition of the major environmental resources of South Australia (112(3(a))), and
- include a specific assessment of the state of the River Murray, especially taking into account the Objectives for a Healthy River Murray under the *River Murray Act 2003* (112(3(ab))), and
- identify significant trends in environmental quality based on an analysis of indicators of environmental quality (112(3(b))).

1.2 Purpose and benefits of SA's trend and condition report cards

South Australia's environmental trend and condition report cards focus on the state's priority environmental assets and the pressures that impact on these assets. The report cards present information on trend, condition, and information reliability in a succinct visual summary.

The full suite of report cards captures patterns in trend and condition, generally at a state scale, and gives insight to changes in a particular asset over time. They also highlight gaps in our knowledge on priority assets that prevent us from assessing trend and condition and might impede our ability to make evidence-based decisions.

Although both trend and condition are considered important, the report cards give particular emphasis to trend. Trend shows how the environment has responded to past drivers, decisions, and actions, and is what we seek to influence through future decisions and actions.

The benefits of trend and condition report cards include to:

- provide insight into our environment by tracking its change over time
- interpret complex information in a simple and accessible format
- provide a transparent and open evidence base for decision-making
- provide consistent messages on the trend and condition of the environment in South Australia
- highlight critical knowledge gaps in our understanding of South Australia's environment
- support alignment of environmental reporting, ensuring we 'do once, use many times'.

Environmental trend and condition report cards are designed to align with and inform state of the environment reporting at both the South Australian and national level. The format, design and accessibly of the report cards has been reviewed and improved with each release.

1.3 Coorong waterbirds populations

The Coorong, and Lakes Alexandrina and Albert Wetland (Ramsar site) supports nationally and internationally significant populations of waterbird species (Paton et al. 2009), which is a major reason for its recognition as a Wetland of International Importance under the Ramsar Convention (Paton et al. 2018). The Coorong; a long, shallow and estuarine to hyper-saline lagoon, generally supports twice the number of waterbirds than the freshwater habitats of Lakes Alexandrina and Albert (Paton et al. 2018). Waterbird numbers in the Coorong are greatest during summer and in drought (Paton 2010; Paton et al. 2018), with an average of 165,000 waterbirds recorded during annual summer censuses from 2000 to 2020 (DEW 2021). The waterbird assemblage in the Coorong is comprised of large numbers of resident shorebirds (e.g. stilts, avocet, plovers), migratory shorebirds (e.g. stints, sandpipers), piscivores (e.g. cormorants, pelicans, terns), herbivores (e.g. swans, ducks) and generalists (e.g. gulls, egrets, herons) (Paton et al. 2018, 2022).

The condition of waterbird populations in the Coorong is assessed each summer, with annual counts having occurred in the Coorong since 2000 (Paton et al. 2017a). A key parameter to evaluate the condition of waterbird populations in the Coorong is abundance (Paton et al. 2017a). The factors affecting waterbird abundance in the Coorong differ between guilds and species based upon their life histories. As a waterbird community, abundance is likely influenced by factors that affect the quantity, quality and accessibility of food and habitat in the Coorong, such as freshwater flows, water levels, salinity and other water quality factors (i.e. nutrients and filamentous algae) (Paton et al. 2010; Paton et al. 2018; Jackson et al. 2022; Paton et al. 2022). Numerous waterbird species that use the Coorong are either highly mobile, nomadic or migratory, meaning that their population dynamics are impacted by factors outside of the Coorong. Therefore, it is also likely that the availability and condition of wetlands at regional (Mott et al. 2022), national (Porter et al. 2021; Mott et al. 2022) and international scales for migratory species (Clemens et al. 2016) also contributes to 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 Coorong each summer (Rogers and Gosbell 2006; Minton et al. 2014; Paton et al. 2018; Porter et al. 2021).

This report card evaluates the trend and condition of Coorong waterbird populations (abundance) at the guild and community levels.

2 Methods

2.1 Indicator

The indicator used for the Coorong waterbird populations report card is abundance. Targets for the abundance of selected waterbird species in the Coorong were as described in Paton et al. (2017a) in the Lower Lakes, Coorong and Murray Mouth (LLCMM) Icon Site Condition Monitoring Plan (DEWNR 2017) (Appendix A). Selected species were considered to meet their abundance target if they exceeded their 2000–2015 median abundance in two of the past three annual censuses. An expert elicitation process conducted in DEW (2020) subset 19 of the 40 target waterbird species for South Australian Basin Plan Environmental Outcome Evaluation. The 19 species were used to assess the trend and condition of Coorong waterbirds populations in this report card (Table 2.1). Waterbird species selected for assessment were allocated to guilds – groups of birds with similar body shapes, habitat use and diets.

Table 2.1. Coorong waterbird species grouped by guild that were assessed in this report card.

Scientific name	Common name	Guild
Pelecanus conspicillatus	Australian pelican	Piscivores
Sternula nereis	fairy tern	
Poliocephalus poliocephalus	hoary-headed grebe	
Hydroprogne caspia	Caspian tern	
*Tringa nebularia**	common greenshank*	
Anas castanea	chestnut teal	Herbivores
Cygnus atratus	black swan	
Tadorna tadornoides	Australian shelduck	
Numenius madagascariensis	eastern curlew	Migratory shorebirds
*Tringa nebularia**	common greenshank*	
Calidris acuminata	sharp-tailed sandpiper	
Calidris ferruginea	curlew sandpiper	
Calidris ruficollis	red-necked stint	
Cladorhynchus leucocephalus	banded stilt	Resident shorebirds
Recurvirostra novaehollandiae	red-necked avocet	
Charadrius ruficapillus	red-capped plover	
Haematopus longirostris	pied oystercatcher	
Chroicocephalus novaehollandiae	silver gull	Generalists
Egretta novaehollandiae	white-faced heron	
Ardea alba modesta	great egret	

*Captured in both the piscivore and migratory shorebird guilds.

2.2 Data sources

Data were sourced from the University of Adelaide (Associate Professor David Paton), who has lead an annual waterbird census of the Coorong each January from 2000 to 2022. The census is jointly funded by the South Australian and Australian governments as part of *The Living Murray* initiative.

The January 2022 census was conducted prior to flooding over the South Australian River Murray system in late 2022.

2.3 Data collection

The methodology for the annual waterbird census of the Coorong is detailed in Paton et al. (2017a) and summarised below.

The Coorong and the Murray estuary was divided into 1 km sections that run perpendicular to the south-east to north-west orientation of the wetland lagoons. Within each 1 km section, waterbirds are counted 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 are conducted by a minimum of two surveyors on foot or by boat.

2.4 Methods to assign trend, condition and reliablity

2.4.1 Trend

A Bayesian modelling approach was used to assess trend in the data collected for the abundances of selected waterbird species in the Coorong. This modelling approach provides a detailed assessment of trend based on variability inherent in the data. Bayesian models provide an estimate of the likelihood of the trend in the time series data assessed.

Trend analysis was undertaken in R Studio (R version 4.2.1, R Core Team 2022) using Bayesian generalised linear mixed models (using the stan-glmer function in the rstanarm package, Goodrich et al. (2020), 4,000 runs). Models aimed to determine the likelihood of trend (either positive or negative) in the abundance of selected species. The waterbird community model included time step (the number of years since the inaugural year of monitoring) as a fixed effect and species as a random effect (allowing species to have different slopes as well as intercepts), while the guild model included an interaction effect between time step and guild and included species as a random effect (again allowing different slopes). Slope (trend) was estimated from the posterior distribution resulting from the Bayesian analysis. Trend direction was assessed using calculated probability (as per McBride 2019). A graduated scale was used to describe outcomes. Outcomes from the trend assessment were aligned with the categories used for report cards (

Table 2.2).

Table 2.2. Alignment of trend outcomes based upon their likelihood of an increase or decrease (modified from Mastrandrea et al. 2010) with categories used for report cards.

Outcome	Likelihood of outcome	Report card
Virtually certain increase	>+99 to +100%	Getting better
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%	Getting worse
Very likely decrease	<-90 to -95%	
Extremely likely decrease	<-95 to -99%	
Virtually certain decrease	<-99 to -100%	

Annual abundances for all selected species were graphed using ggplot2 (Wickham et al. 2016) in R Studio (R version 4.2.1, R Core Team 2022). To graph trends in the abundances of guilds, all selected species had their abundances normalised using a min-max normalisation, where minimum abundances over the census period were transformed into a zero and the maximum abundance transformed into a one, and other values were transformed into a decimal between zero and one. The mean normalised abundance value for each guild was used to show how the abundances of guilds has changed annually over the census (2000 to 2022).

2.4.2 Condition

The condition assessment for waterbird populations in the Coorong in 2022 followed the methodology described in DEW (2020), where condition is based upon the proportion of selected waterbird species from each guild that met their respective abundance targets during the annual census in January 2022 (see Paton et al. 2022). Alignment of condition classes used for report cards with the proportion of selected species from each guild meeting their abundance targets are shown in Table 2.3, and were based on expert opinion. The waterbird guild in the lowest condition class is used to reflect the condition of the waterbird community as a whole.

Table 2.3. Alignment of condition classes used for report cards with the proportion of selected species from each waterbird guild meeting their respective abundance targets.

Abundance	Condition rating
1.00	Very good
≥0.66–0.99	Good
≥0.50–0.65	Fair
<0.50	Poor

2.4.3 Reliability

The reliability of data to assess the trend and condition of Coorong waterbird populations in this report card was scored based upon the method devised by Battisti et al. (2014) with modifications to improve its applicability to the report card process. This scoring system assesses answers to questions relating to the method used for data collection, representativeness and repetition. A scoring system as shown in Table 2.4 was used to determine a final score for data 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 2.5.

Table 2.4. Scoring system for the reliability of data used to assess and analyse trend and condition for Coorong waterbird populations.

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				
Space	Has sampling been conducted across the spatial extent of the Coorong 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 2.5. Conversion of the final score (0–12) of data reliability to an information reliability rating that ranges from poor to excellent for report cards.

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

2.5 Data transparency

Data transparency for this report card is represented in Appendix B.

3 Results

3.1 Trend

The abundance of all selected species in the Coorong waterbird community over the monitoring program (2000–2022) was determined to have very likely (90% likelihood) decreased (Table 3.1; Figure 3.1), and therefore Coorong waterbird populations are assessed as **getting worse**. However, there is significant variation in the trends between guilds (Table 3.1; Figure 3.2). It is extremely likely (95% likelihood) and very likely (90% likelihood) respectively that selected species from the migratory and resident shorebirds have declined in abundance. Similarly, it is likely (73%) that selected species from the piscivore guild have declined, while it is about as likely as not (51%) that selected generalist species have increased in abundance. Conversely, it is likely that selected species from the herbivore (72% likelihood) guild have increased in abundance.

Table 3.1. Outcomes from the Bayesian modelling assessment of trend for all selected species within the Coorong waterbird community and selected species within the resident shorebird, piscivore, generalist, migratory shorebird and herbivore guilds. The likelihood of improvement in annual January census counts of selected species within each guild and as a whole in the Coorong are provided in addition to their associated confidence rating (as per Mastrandrea et al. 2010). The report card trend category aligns with the confidence rating.

Guild/group	Outcome	Likelihood of outcome	Report card trend category
All selected species	Very likely decrease	90%	Getting worse
Resident shorebird	Extremely likely decrease	90%	Getting worse
Piscivore	Very likely decrease	73%	Getting worse
Generalist	About as likely as not to increase	51%	Stable
Migratory shorebird	Very likely decrease	95%	Getting worse
Herbivore	Likely increase	72%	Getting better

Mean min-max normalised abundances for each waterbird guild demonstrates how abundances of selected species in each guild have changed over the monitoring program (2000–2022) (Figure 3.3). Abundances of generalist species were variable with no distinct trend, however, were lower during the Millennium Drought (2001–2010). Herbivores were also less abundant during the Millennium Drought, however, increased in abundance from 2018–2022. Migratory shorebirds were more abundant in the earlier years (2000–2010) of the census, however, have since been in low abundance, with the exception of 2014–2016. Similarly, resident shorebird species, although variable in abundance, had a greater frequency of years with high abundance in the earlier years (2000–2010) of the census. Piscivores were most abundant from 2000–2002 and have since been variable.

The abundances of selected species contributing to these trends for each waterbird guild are shown in Figure 3.4, and highlight that within guilds there are species specific changes in abundance between years. For example, hoary-headed grebe and Caspian tern are both in the piscivore guild, however, in 2017, hoary-headed grebe were recorded in their lowest recorded abundance while Caspian tern were recorded in their highest recorded abundance.

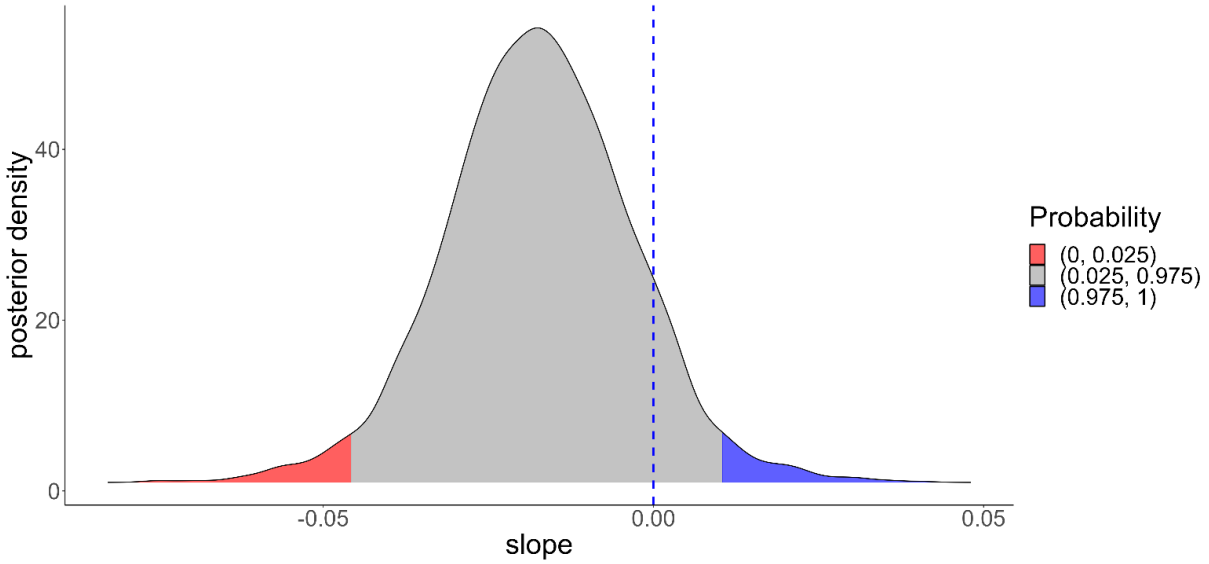


Figure 3.1. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species in the Coorong from 2000 to 2022. Posterior values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse). Data source: University of Adelaide (Assoc. Prof. David Paton).

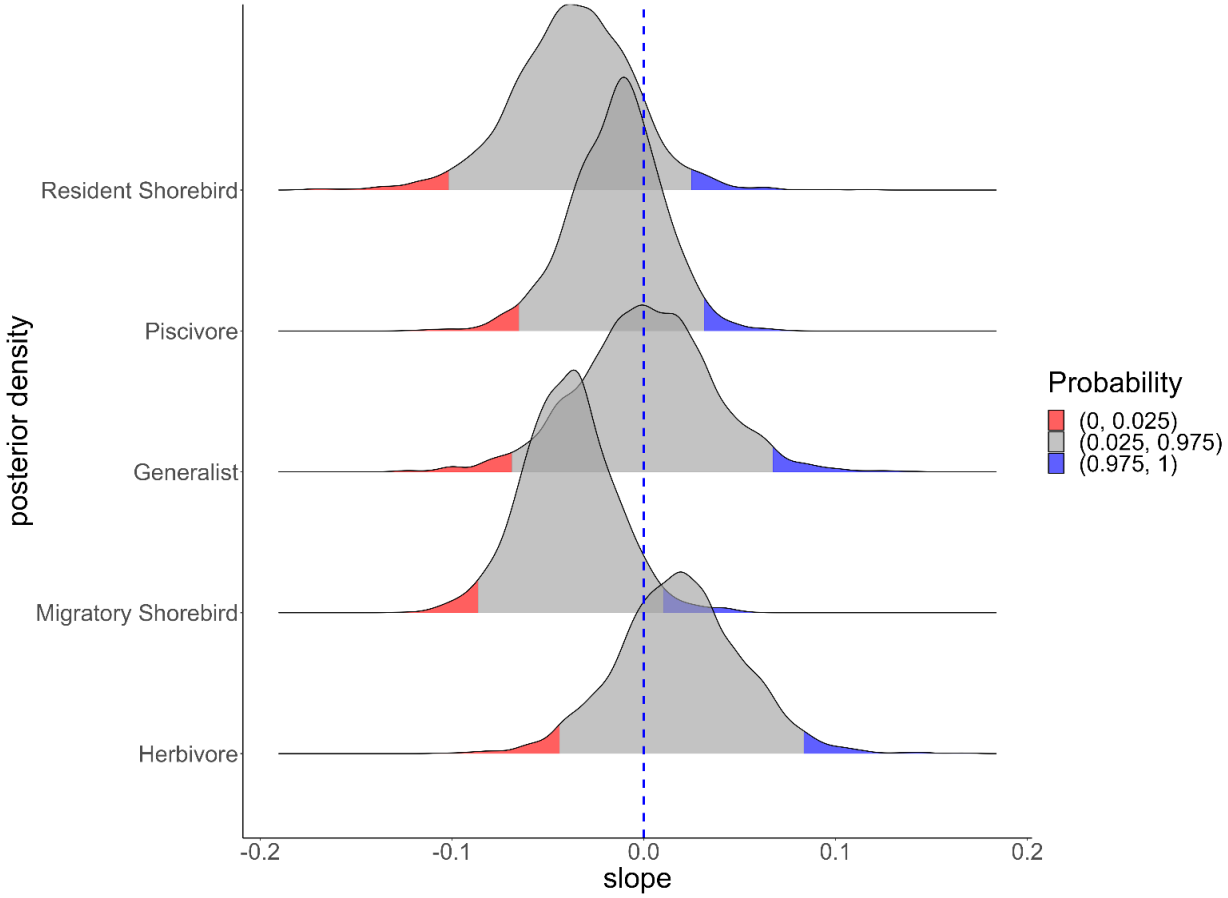


Figure 3.2. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species from the resident shorebird, piscivore, generalist, migratory shorebird and herbivore guilds in the Coorong from 2000 to 2022. Posterior values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse). Data source: University of Adelaide (Assoc. Prof. David Paton).

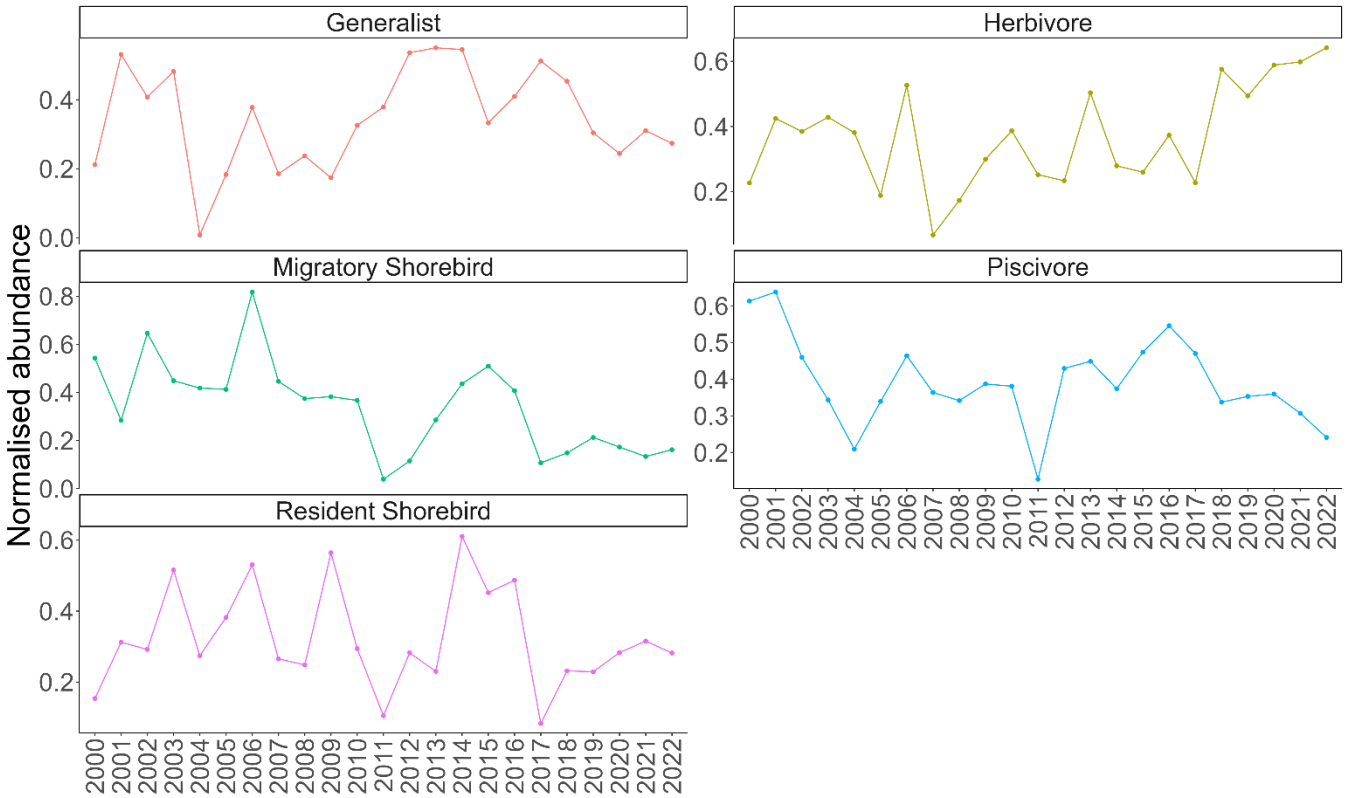


Figure 3.3. Mean min-max normalised abundance of Coorong waterbird guilds from 2000 to 2022. For each selected species, minimum abundances over the census period were transformed into a 0 and the maximum abundance transformed into a 1, and other values were transformed into a decimal between 0 and 1. Data collected in 2022 occurred prior to flooding in the South Australian River Murray. Data source: University of Adelaide (Assoc. Prof. David Paton).

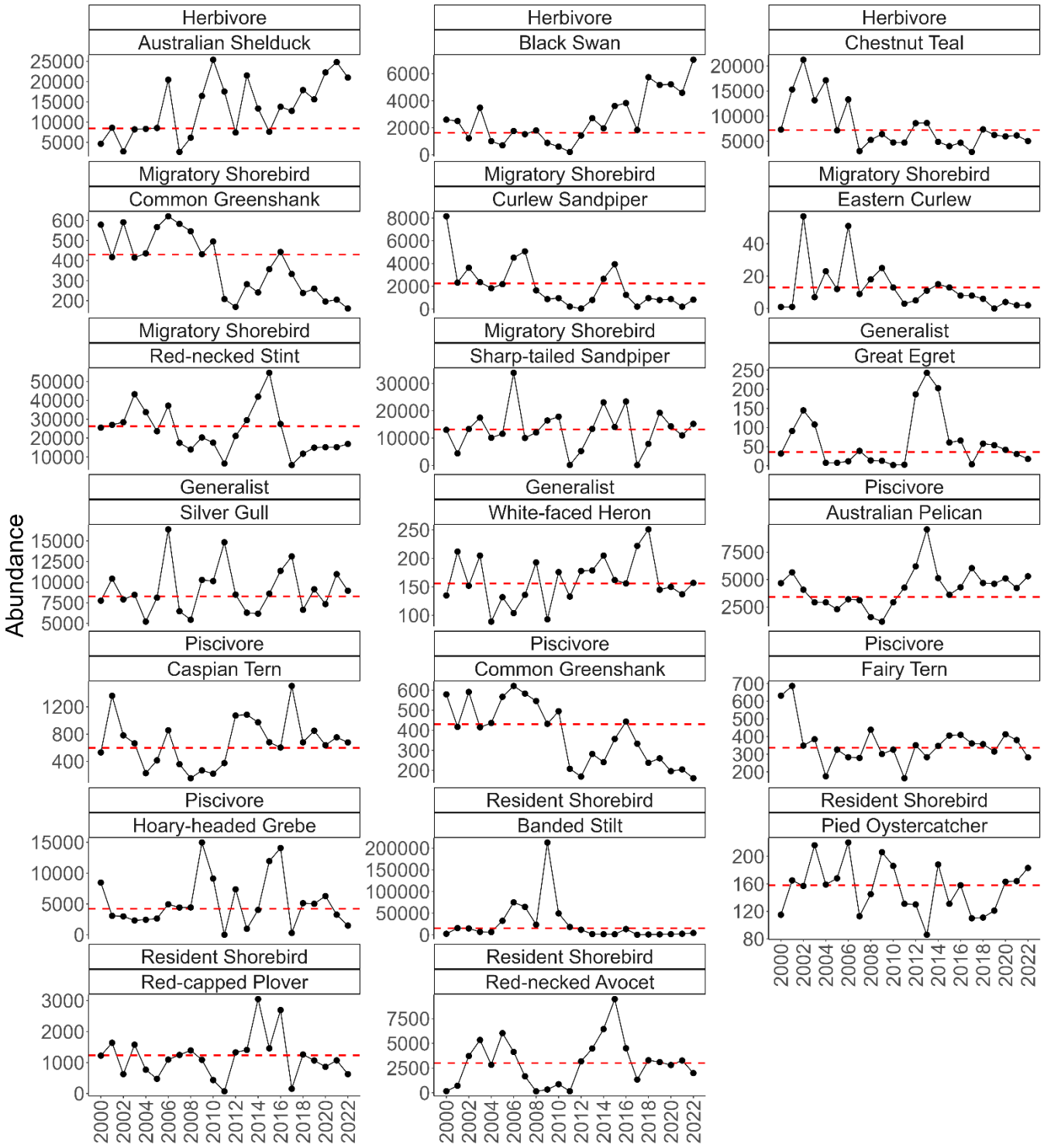


Figure 3.4. Abundance of selected waterbird species during annual January census' over the Coorong from 2000–2022 with reference to the long-term (2000–2015) median abundance of each species (horizontal red dashed line). Note: to meet the ecological target, selected species must exceed their recent median abundance value in two of the last three years. Data collected in 2022 occurred prior to flooding in the South Australian River Murray. Data source: University of Adelaide (Assoc. Prof. David Paton).

3.2 Condition

Guilds within the Coorong waterbird community varied in condition, with herbivores in good condition, piscivores in fair condition, and migratory shorebirds, resident shorebirds and generalists all in poor condition (Table 3.2). As the overall condition score is based on the guild in the poorest condition, the condition of Coorong waterbird populations in 2022 was **poor**.

Table 3.2. Selected waterbird species within each guild that met their abundance target, having exceeded their long-term (2000-2015) median abundance in two of the last three years (2020-2022) in the Coorong. The proportion of selected species in each guild that met their abundance target in 2022 was calculated to determine guild condition.

Species	Guild	Target met	Proportion of species in guild to meet target	Condition
Australian pelican	Piscivore	Yes	0.60	Fair
fairy tern	Piscivore	Yes		
hoary-headed grebe	Piscivore	No		
Caspian tern	Piscivore	Yes		
common greenshank*	Piscivore	No		
chestnut teal	Herbivore	No	0.66	Good
black swan	Herbivore	Yes		
Australian shelduck	Herbivore	Yes		
eastern curlew	Migratory Shorebird	No	0.20	Poor
common greenshank*	Migratory Shorebird	No		
sharp-tailed sandpiper	Migratory Shorebird	Yes		
curlew sandpiper	Migratory Shorebird	No		
red-necked stint	Migratory Shorebird	No		
banded stilt	Resident Shorebird	No	0.25	Poor
red-necked avocet	Resident Shorebird	No		
red-capped plover	Resident Shorebird	No		
pied oystercatcher	Resident Shorebird	Yes		
silver gull	Generalist	Yes	0.33	Poor
white-faced heron	Generalist	No		
great egret	Generalist	No		

3.3 Reliability

The overall reliability score for this report card is **very good**. Justification for the data reliability assessment scores for Coorong waterbird populations is provided in Table 3.3.

Table 3.3. Reliability of data obtained from waterbird census of the Coorong to assess trend and condition of the waterbird community in 2022. 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 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 *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017).	**2**
Standard methods	Has the same method been used over the assessment period?	**Yes.** Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary by surveyors on foot or by boat. Method has remained the same over all censuses conducted.	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the Murray estuary and Coorong with equal effort?	**Yes.** Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary.	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Censuses were conducted in the Coorong from 2009–2022, and therefore, includes a range of hydrological conditions (i.e. flood, drought and years in between).	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** The same spatial extent of the Coorong is surveyed for waterbirds each year of the monitoring programs.	**2**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Partially.** Annual January census data of waterbirds in the Coorong 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 (with the exception of 2022) and spring data is considered a weakness.	**1**
Final score			**11**
Information reliability			**Very good**

4 Discussion

Overall, the Coorong waterbird populations are in **poor condition** and **getting worse**.

4.1 Trend

Abundances of selected species within the Coorong waterbird community are **getting worse**. Trends in abundance differ between guilds in the waterbird community, with herbivores getting better, generalists remaining stable, and piscivores and both resident and migratory shorebirds getting worse. These trends are particularly concerning given that the assessment period (2000–2022) included years during the Millennium Drought (i.e. 2001-2010), which severely affected habitat quality and food resource availability for all waterbird guilds, and therefore, a stable or increasing trend should be relatively easy to achieve.

Prowse (2020) conducted Bayesian trend analyses for each of the 40 TLM target waterbird species (Appendix A) in the Coorong. The study sought to determine how each species performed during the Millennium Drought and post-drought in the Coorong South Lagoon. During the Millennium Drought, 23 species had statistically significant trends with 70% (16 species) of those declining, inclusive of six shorebirds, six piscivores, one generalist and three herbivores. Post-drought, only 10 species had statistically significant trends, with 60% of those declining. The results from Prowse (2020) show that many waterbird species failed to recover or continued to decline post-drought, which aligns with the findings of this report card.

The abundances of selected Coorong waterbird species are getting worse likely as a result of factors internal and external to the Coorong, including:

- Coorong habitat quality,
- declines of waterbird populations at national and international scales, and
- continental wetland availability.

4.1.1 Coorong habitat quality

Habitat quality for waterbirds in the Coorong is species specific and a product of a range of interacting environmental conditions, including flow, water level, salinity and productivity that ultimately influence the availability and accessibility of food resources and habitat (Paton 2010; Paton et al. 2018; DEW 2020; Jackson et al. 2022). During the Millennium Drought, habitat quality for the vast majority of waterbirds in the Coorong significantly deteriorated, particularly between 2007 and 2010 when barrage flows ceased (Paton 2010). The lack of flow caused extremely low water levels and greatly elevated salinities, which led to:

- low species richness and biomass of benthic invertebrates in the Murray estuary and North Lagoon (Dittmann et al. 2022)
- sandy sprat, an abundant, small-bodied fish, becoming constricted in distribution to near the Murray estuary and occurring in low abundance (Giatas and Ye 2016; Bice et al. 2019)
- extirpation of key food resources from the Coorong South Lagoon, including the Ruppia community (inclusive of all submergent aquatic plant species), chironomid larvae and small-mouthed hardyhead (Paton 2010)
- extremely high abundance of brine shrimp in the Coorong South Lagoon when salinities exceeded 150 parts per thousand, despite not having previously been recorded in the Coorong (Paton 2010).

Waterbird numbers are greatest in the Coorong during drought (Paton 2010; Paton et al. 2018), however, due to the severity of the Millennium Drought and the adverse impacts on food resources for all waterbird guilds,

abundances and distributions of numerous waterbird species were greatly affected, especially from 2007–2010 (Paton 2010; Prowse 2020). One exception was the banded stilt, with over 200,000 individuals recorded in the Coorong during the 2009 census in response to significant increases in food availability (i.e. brine shrimp) (Paton 2010).

Extensive flooding over the Murray–Darling Basin ended the Millennium Drought and greatly improved flow to the Coorong in 2010–11. The 2010–11 flow event increased water levels and restored salinities to those more typical for the system in the Coorong (DEW 2020). Since the 2010–11 flow event, patterns in hydrology have been marked by years of high flow in 2011–12, 2012–13, 2016–17 and 2021–22, with low to moderate flows recorded in intervening years. Greater barrage flows since the end of the Millennium Drought has contributed to the following key changes to waterbird habitat quality:

- Brine shrimps remained abundant in 2011, however, were completely absent in 2012 (Paton and Bailey 2012). The loss of brine shrimp may have affected banded stilt, with lower abundances observed since the end of the Millennium Drought.
- Recovery of the distribution and abundance of chironomid larvae in the Coorong South Lagoon within half a year of flows in 2010–11 (Paton and Bailey 2012). Since 2010–11, the abundance of chironomid larvae has been variable but significantly higher than abundances recorded during the Millennium Drought (Dittmann et al. 2022; Paton et al. 2022). Chironomids are key prey items for resident and migratory shorebirds (Giatas et al. 2022), and are likely consumed by certain generalist (i.e. silver gull) (Auman et al. 2008) and herbivore species (chestnut teal) (Giatas et al. 2022).
- Recovery of the distribution, diversity and biomass of the benthic macroinvertebrate community in the Murray estuary and Coorong North Lagoon in 2015, which has since been maintained (Dittmann et al. 2022). Macroinvertebrates are key prey items for resident and migratory shorebirds (Giatas et al. 2022) and generalists (Marchant and Higgins 1990; Auman et al. 2008).
- Recovery of the distribution and abundance of small-mouthed hardyhead in the Coorong South Lagoon following a one year lag of flows in 2010–11 (Ye et al. 2012). Since 2010–11, the population condition of small-mouthed hardyhead, which considered distribution, abundance and recruitment, has varied from poor to very good in association with prevailing barrage flows and salinity (Ye et al. 2022). Small-mouthed hardyhead are a key food resource for piscivores (Rogers and Paton 2009; Paton 2010) and also likely consumed by generalist species (Marchant and Higgins 1990).
- Increase in distribution of sandy sprat to include Murray estuary and Coorong North Lagoon (Giatas and Ye 2016). Abundance varied in response to flow, with very high abundances in moderate to high flow years and lower abundances in low flow years (Ye et al. 2020a). Sandy sprat are the most abundant small-bodied fish in the northern Coorong (Ye et al. 2020a; Dittmann et al. 2022), and therefore likely an important food resource for piscivore and generalist species (Ye et al. 2020a).
- Reduced mudflat extent during years of high flow due to high water levels and a dampened tidal signal (Paton and Bailey 2012; Paton et al. 2017b). The limited mudflat extent reduces foraging habitat for shorebirds (Jackson et al. 2022) and other wading species, including those in the generalist guild.
- The Ruppia community recovered to its 43 km historic distribution in 2013 (Paton and Bailey 2013) and in 2022 was recorded over 60 km (Lewis et al. 2022). The densities of Ruppia community shoots, seed and turions have slowly recovered since the Millennium Drought, and have benefited from favourable reproductive and growing conditions attributed to back-to-back La Nina years (2020-21 and 2021-22) (Lewis et al. 2022). The recovery of the Ruppia community likely increased food resources for herbivores (Paton 2010; Giatas et al. 2022), and species from other guilds that forage on Ruppia seed and turions, such as shorebirds (Paton 1982; Giatas et al. 2022).
- The Coorong South Lagoon is in a high nutrient (hyper-eutrophic) state due to nutrient loading associated with inadequate flushing flows (Priestly et al. 2022). Symptomatic of the high nutrient loads are blooms of filamentous algae that are present annually over spring and summer (Auricht et al. 2019; Lewis et al. 2022).

Herbivores consume filamentous algae; however, it is a less nutritious food resource than the Ruppia community (Moore 2014). Blooms of filamentous algae aggregate and decay, and form mats over mudflats. This may prevent shorebirds from accessing prey and reduce food availability (Paton et al. 2017b).

4.1.2 Continental wetland availability

In Australia, waterbirds respond positively to water at sub-continental and continental scales (Bino et al. 2020). The number and composition of waterbirds in the Coorong varies annually based on wetland availability across the continent and the breeding success at these wetlands (Paton et al. 2015). When drought prevails over the Murray–Darling Basin, waterbirds use the Coorong as a drought refuge (Paton 2010). This typically increases the abundance of waterbirds in the Coorong; however, this did not occur for numerous species during the later years of the Millennium Drought due to the severe impacts on habitat quality (described in Section 4.1.1). Conversely, when there is widespread flooding over the Murray–Darling Basin, waterbird abundances in the Coorong are lower (Paton and Bailey 2011; Paton et al. 2017b). Such significant increases in wetland availability associated with flood can stimulate large breeding events (Bino et al. 2020; Brandis et al. 2021). In years of large breeding events in the Murray–Darling Basin, such as 2010–11 and 2016–17 (Porter et al. 2021), there was an exodus of waterbirds that breed inland from the Coorong. For example, in January 2011 and 2017, abundances of hoary-headed grebes in the Coorong were less than 5% of their long-term median. However, the extent to which these species use alternate wetland habitats remains a knowledge gap. The total numbers of waterbirds over eastern Australia show a marked increase in the year following these large breeding events (Porter et al. 2021), and this may influence the number of waterbirds present in the Coorong the following summer (Paton et al. 2018).

4.1.3 Waterbird populations

Waterbird populations are in decline at national (Porter et al. 2021) and international scales (Clemens et al. 2016; Studds et al. 2017). At a national scale, the Eastern Australian Waterbird Survey found that the abundances of ducks, herbivores, large wading birds, piscivores and shorebirds have declined from 1983 to 2021 (Porter et al. 2021). At an international scale, migratory shorebirds dependent on staging sites in the Yellow Sea for their migrations in the East Asian–Australasian flyway are also in serious decline (Hansen et al. 2021), due to the reclamation of tidal foraging grounds (Hua et al. 2015). Eastern curlews and curlew sandpipers are dependent on Yellow Sea staging sites and are estimated to have an annual population decline of 2–7% and 5–11%, respectively (Clemens et al. 2016; Studds et al. 2017).

Declines in waterbird populations at national and international scales have likely contributed to the declining trend in Coorong waterbird populations identified in this report card. However, it must be recognised that certain species, such as chestnut teal, are stable at the continental scale (Porter et al. 2021) but are declining in the Coorong. Similarly, migratory shorebirds are declining in the Coorong well above the national rate (Clemens et al. 2016; Bino et al. 2020), and some migratory shorebird species with relatively stable populations, such as red-necked stint (Studds et al. 2017), were recorded in exceedingly low numbers in recent years. Therefore, it is unlikely that population declines alone explain the declining trend for waterbird populations in the Coorong, and therefore, changes in habitat quality may be impacting abundances of these species.

4.2 Condition

The condition of the Coorong waterbird populations in 2022 was **poor**. Guilds within the Coorong waterbird community varied in condition, with herbivores in good condition, piscivores in fair condition, and migratory shorebirds, resident shorebirds and generalists all in poor condition.

Condition was assessed using January census data from 2020–2022. Over this period, the barrage flows in 2019 and 2020 were low (805 GL and 1226 GL, respectively), while more moderate flow volumes were recorded in 2021 (3,222 GL). Similarly, over this period, rainfall over the Murray–Darling Basin increased from very much below average in 2019 to above average in 2021 (Figure 4.1). Despite the variability in climate and flow conditions, the

abundances of the vast majority of selected waterbird species were comparable over this three-year period. As described in Section 4.1 for *Trend*, the poor condition of the waterbird community in the Coorong is also likely to be a product of Coorong habitat quality, continental wetland availability and declines of waterbird populations at national and international scales.

Notable observations of habitat quality for Coorong waterbirds that may influence their January census counts from 2020 to 2022 were:

- Filamentous algae were less prominent and almost non-existent in the southern Coorong over the January censuses between 2020 and 2022 (Paton et al. 2021, 2022).
- The Ruppia community has improved significantly, with densities of seeds, shoots and turions either at or approaching their highest density recorded since the Millennium Drought (Lewis et al. 2022)
- Abundances of small-mouthed hardyhead across the Murray estuary and Coorong were high in late summer/autumn surveys in 2019, 2020 and 2021, with respect to the results over the monitoring program (2007–2020) (Ye et al. 2022).
- Macroinvertebrate diversity and biomass in the Murray estuary and Coorong North Lagoon remained high in December 2019, 2020 and 2021, with respect to the results over the monitoring program (2004–2021) (Dittmann et al. 2022).
- Chironomid densities in January 2020 and 2021 were low; however, moderate to high densities were recorded in 2022, with respect to the results over the monitoring program (2011–2022) (Paton et al. 2022).
- Water levels were low in January 2021 and moderate in 2020 and 2022, and therefore, mudflats were extensive and accessible by shorebirds and wading species in the generalist guild.

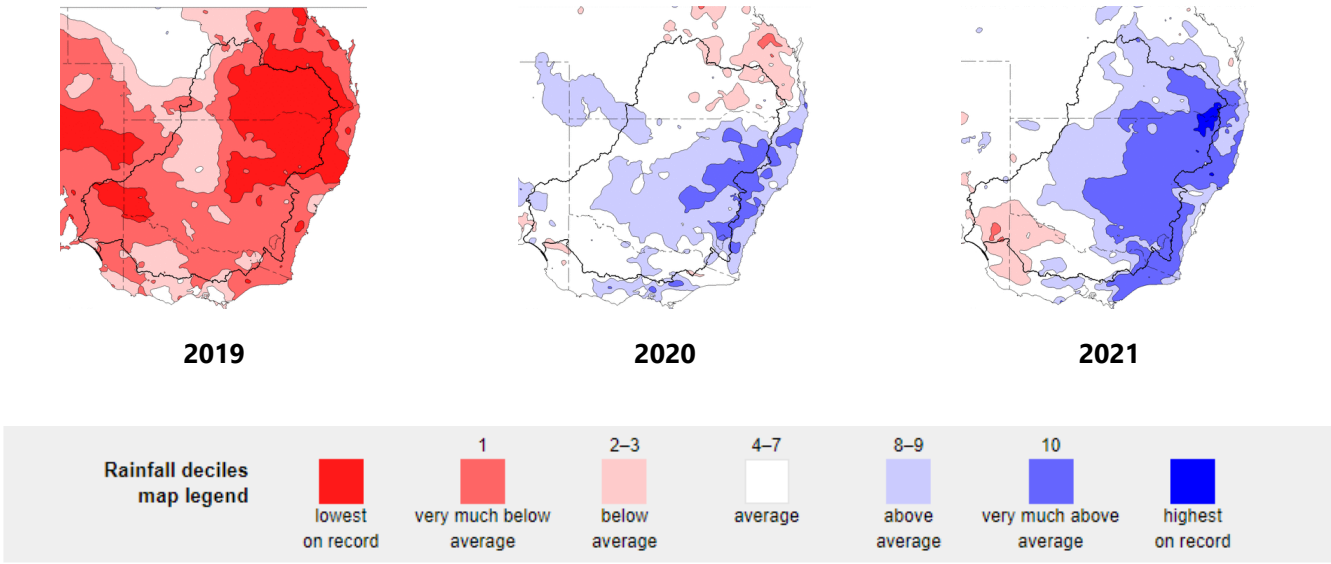


Figure 4.1. Murray–Darling Basin rainfall deciles from 2019 to 2021 (BOM 2022).

5 Conclusion

The Coorong waterbird community is in **poor condition** and **getting worse**. This outcome is likely the result of factors internal and external to the Coorong, including habitat quality within the wetland, continental wetland availability and declines of waterbird populations at national and international scales.

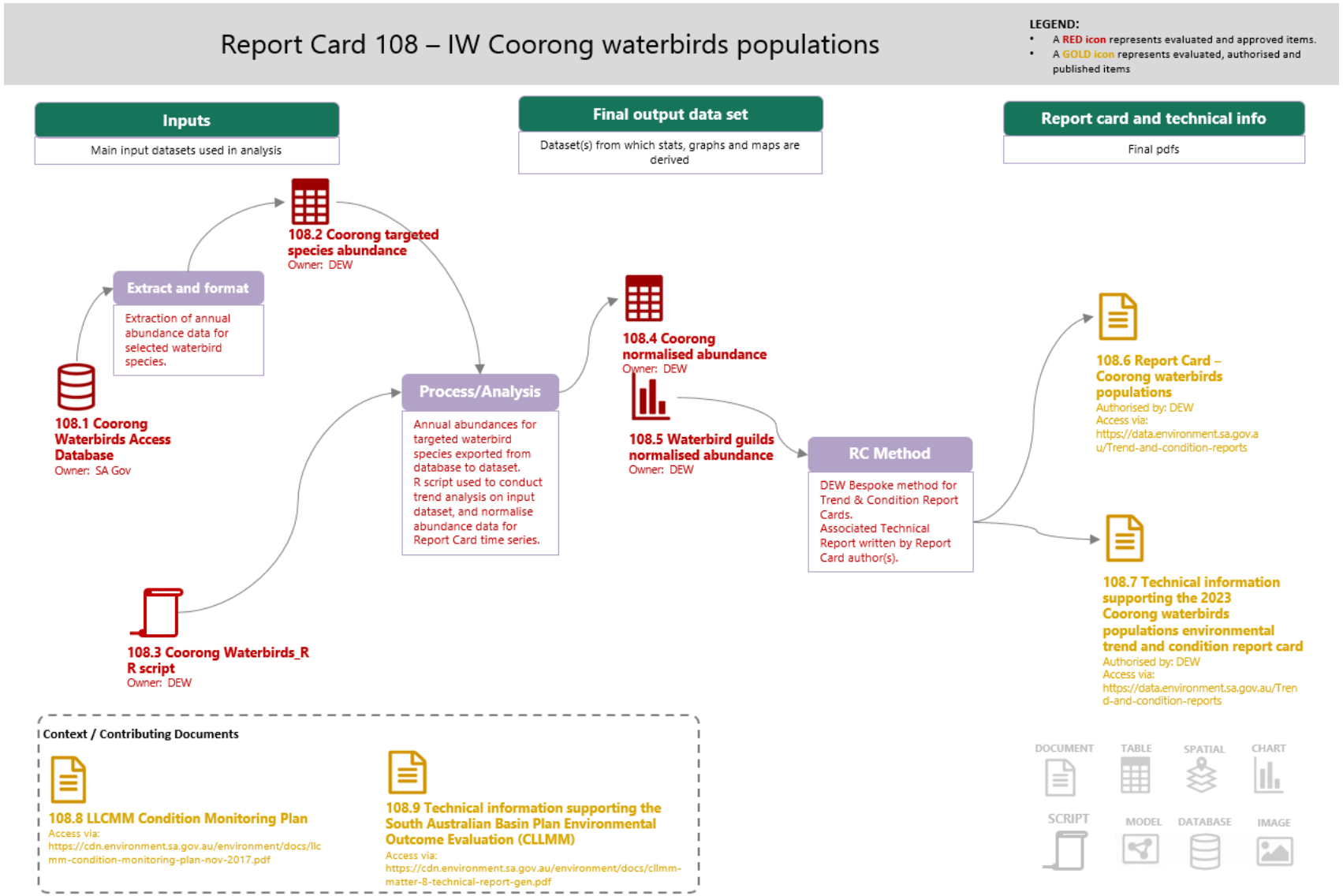
6 Appendices

A. The 40 selected waterbird species in the Coorong set within the Waterbird chapter of the Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring Plan (DEWNR 2017) for assessment of condition targets. A subset of 19 of the 40 target waterbird species were selected to assess the trend and condition of Coorong waterbirds populations in this report card.

Waterbird species	Species selected for report card evaluation
Australian pelican	Yes
Australian shelduck	Yes
Australian white ibis	No
black-faced cormorant	No
banded stilt	Yes
black-winged stilt	No
Caspian tern	Yes
Cape Barren goose	No
chestnut teal	Yes
Eurasian coot	No
crested tern	No
curlew sandpiper	Yes
eastern curlew	Yes
fairy tern	Yes
common greenshank	Yes
great crested grebe	No
great cormorant	No
great egret	Yes
grey teal	No
hoary-headed grebe	Yes
hooded plover	No
little black cormorant	No
little egret	No
little pied cormorant	No
musk duck	No
masked lapwing	No
Pacific black duck	No
Pacific golden plover	No
pied cormorant	No
pied oystercatcher	Yes
red-capped plover	Yes
red-necked avocet	Yes
red-necked stint	Yes

Waterbird species	Species selected for report card evaluation
royal spoonbill	No
silver gull	Yes
straw-necked ibis	No
sharp-tailed sandpiper	Yes
white-faced heron	Yes
whiskered tern	No

B. Managing environmental knowledge chart for Coorong waterbirds populations



7 References

Auman HJ, Meathrel CE and Richardson A (2008) Supersize me: Does anthropogenic food changes the body condition of silver gulls? A comparison between urbanised and remote, non-urbanised areas, *Waterbirds* 31(1): 122-126.

Auricht H, Clake K and Waycott M (2019) *Investigations of the application of remote sensing to estimate coverage of surface exposed (floating) filamentous algae in the Coorong, South Australia*, Goyder Institute for Water Research Technical Report Series No. 19/34.

Battisti C, Dodaro G and Franco D (2014) The data reliability in ecological research: a proposal for a quick self assessment tool, *Natural History Sciences*, 1(2):75–79.

Bice C, Zampatti B and Fredberg J (2019) *Fish assemblage structure, movement and recruitment in the Coorong and Lower lakes in 2018–19*, SARDI (Aquatic Sciences), SARDI Publication No. F2011/000186-9, Research Report Series no. 1043.

Bino G, Brandis K, Kingsford R, Porter J (2020) Waterbird synchrony across Australia's highly variable dryland rivers – Risks and opportunities for conservation, *Biological Conservation* 243, 1-13.

BOM (Bureau of Meteorology) (2022) *Daily rainfall totals for Australia, Australian Government, Bureau of Meteorology*, viewed 10 August 2022, http://www.bom.gov.au/climate/history/rainfall/

Brandis KJ, Bino G, Kingsford RT (2021) More than just a trend: Integrating population viability models to improve conservation management of colonial waterbirds, *Environmental Management* 68: 468–476.

Clemens R, Rogers D, Hansen B, Gosbell K, Minton C, Straw P, Bamford M, Woehler E, Milton D, Weston M, Venables B, Weller D, Hassell C, Rutherford B, Onton K, Herrod A, Studds C, Choi C, Dhanjal-Adams K, Murray N, Skilleter G and Fuller R (2016) Continental-scale decreases in shorebird populations in Australia, *Emu*, 116:119–135.

Department for Environment and Water (2020) *South Australian River Murray Basin Plan Environmental Outcome Evaluation: Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environmental Asset*, DEW Technical report 2020/18, Government of South Australia, Department for Environment and Water, Adelaide.

Department for Environment and Water (2021) Waterbird metrics for the Coorong, and Lakes Albert and Alexandrina Ramsar site, DEW Technical report 2021/18, Government of South Australia, Department for Environment and Water, Adelaide.

Department of Environment, Water and Natural Resources (DEWNR) (2017) *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site*, DEWNR Technical report 2016–17. Government of South Australia, through Department of Environment, Water and Natural Resources, Adelaide.

Dittmann S, Lam-Gordillo O & Newberry A (2022) *Benthic macroinvertebrate survey 2021-2022 report*, Coorong, Lower Lakes and Murray Mouth Icon Site, Report for the Department for Environment and Water and the Murray-Darling Basin Authority. Flinders University, Adelaide.

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

Giatas G and Ye Q (2016) *Conceptual food-web models for the Coorong: A focus on fishes and the influence of freshwater inflows*, SARDI (Aquatic Sciences), SARDI Publication No. F2016/000124-1, Research Report Series No. 892.

Giatas G, Catalano S, Dittmann S, Ye Q, Jackson M, Mott R and Markos K (2022) *Primary food resources for key waterbirds and benthic fish in the Coorong*, Goyder Institute for Water Research Technical Report Series No. 22/02.

Goodrich B, Gabry J, Ali I & Brilleman S (2020) *rstanarm: Bayesian applied regression modelling via rstan. R package version 2.19.3* https://mc-stan.org/rstanarm.

Hansen B, Szabo J, Fuller R, Clemens R, Rogers D and Milton D (2021) Insights from long-term shorebird monitoring for tracking change in ecological character of Australian Ramsar sites, *Biological Conservation* 260 (2021) 109189.

Jackson MV, Mott R, Prowse TAA, Delean S, Shu Y, Brookes J and Cassey P (2022) *Recommended habitat quality measures for key waterbird species in the Coorong*, Goyder Institute for Water Research Technical Report Series No. 21/05.

Lewis R, Waycott M, O'Loughlin EJ, Urgl C, van Dijk K, Calladine A and Nicol J (2022) *Distribution and seasonality of the Ruppia dominated aquatic macrophyte community and filamentous algae in the southern Coorong*, Goyder Institute for Water Research Technical Report Series No. 22/09.

Marchant S & Higgins PJ (1990) *Handbook of Australian, New Zealand and Antarctic Birds, Volume 1 Ratites to Ducks*, Oxford Press, Melbourne.

Mastrandrea M, Field C, Stocker T, Edenhofer O, Ebi K, Frame D, Held H, Kriegler E, Mach K, Matschoss P, Plattner G, Yohe G and Zwiers F (2010) *Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties*, Intergovernmental Panel on Climate Change (IPCC).

McBride GB (2019) Has water quality improved or been maintained? A quantitative assessment procedure, *Journal Environmental Quality* 48, 412-420.

Minton C, Jessop R & Hassel C (2014) Wader breeding success in the 2013 Arctic summer, based on juvenile ratios of birds, which spend the non-breeding season in Australia, *Stilt* 65, 47-60.

Moore L (2014) *The distribution of herbivorous waterfowl and their aquatic food resources in the Coorong, South Australia*, B.Sc. Hons thesis, University of Adelaide.

Mott R, Jackson M, Sanchez-Gomez S, Hunt B, Prowse T, Brookes J and Cassey P (2022*) Spatial and temporal habitat use by key waterbird species in the Coorong*, Goyder Institute for Water Research Technical Report Series No. 21/xx.

Paton D, Paton F and Bailey C (2015) *A broad synthesis of waterbird knowledge for the Coorong, Lower Lakes and Murray Mouth region, including comment on future management and monitoring options*, University of Adelaide.

Paton DC and Bailey CP (2011) *Condition monitoring of the Lower Lakes, Coorong and Murray Mouth: waterbirds using the Coorong and Murray Estuary 2011*, Report for the Department for Water, University of Adelaide, Adelaide.

Paton DC & Bailey CP (2012) *Condition monitoring of the Lower Lakes, Coorong and Murray Mouth Icon Site: Waterbirds using the Coorong and Murray Estuary 2012*, The University of Adelaide.

Paton DC (2010) *At the End of the River: The Coorong and Lower Lakes,* ATF Press, Hindmarsh.

Paton DC and Bailey CP (2013) *Response of Ruppia tuberosa in the Coorong South Lagoon to enviromental water delviery over summer 2012-13*, University of Adelaide, Adelaide.

Paton D, Paton FL & Bailey C (2017a) *Birds*, In: Condition Monitoring Plan (Revised) 2017, The Living Murray – Lower Lakes, Coorong and Murray Icon Site, DEWNR Technical Report 2016-17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 17-25.

Paton DC, Paton FL & Bailey CP (2017b) *Condition Monitoring of the Coorong, Lower Lakes and Murray Mouth Icon Site: Waterbirds in the Coorong and Lower Lakes 2017*, The University of Adelaide.

Paton DC, Paton FL & Bailey CP (2018) *Waterbirds of the Coorong, Lower Lakes and Murray Mouth*, In: Mosley L, Ye Q, Shepherd S, Hemming S, Fitzpatrick R (eds) Natural History of the Coorong, Lower Lakes, and Murray Mouth Region (Yarluwar-Ruwe), Royal Society of South Australia, Adelaide, pp 371-399.

Paton DC, Paton FL & Bailey CP (2021) *Condition monitoring of the Lower Lakes, Murray Mouth and Coorong Icon Site: Waterbirds in the Coorong and Lower Lakes 2021*, The University of Adelaide.

Paton DC, Paton FL, Whittaker DA & Markos DG (2022) *Condition monitoring of the Lower Lakes, Murray Mouth and Coorong Icon Site: Waterbirds in the Coorong and Lower Lakes 2022*, The University of Adelaide.

Paton DC, Rogers DJ, Hill BM, Bailey CP & Ziembicki M (2009) Temporal changes to spatially stratified waterbird communities of the Coorong, South Australia: implications for the management of heterogeneous wetlands, *Animal Conservation* 12, 408-417.

Paton P (1982) *Biota of the Coorong*, A study for the Cardwell Buckingham Committee, Department of Environment and Planning.

Porter JL, Kingsford RT, Francis R & Brandis K (2021) *Aerial survey of wetland birds in Eastern Australia – October 2021 Annual Summary Report*, Department of Planning Industry & Environment and the University of New South Wales, Sydney.

Priestly S, Mosley L, Farkas J, Tyler J, Shao Y, Shanafield M, Banks E, Wong WW and Leyden E (2022). *Sources and transport of nutrients in the Coorong*, Goyder Institute for Water Research. Technical Report Series No. 22/11.

Prowse TAA (2020). *Review of the ecology, status and modelling of waterbird populations of the Coorong South Lagoon*, Goyder Institute for Water Research Technical Report Series No. 20/12.

R Core Team (2022) *R: A language and environment for statistical computing. R Foundation for Statistical Computing*, Vienna, Austria. URL https://www.R-project.org/.

Roger KG & Gosbell K (2006) Demographic models for red-necked stint and curlew sandpiper in Victoria, *Stilt* 50: 205-214.

Rogers D and Paton D (2009) *Spatiotemporal variation in the waterbird communities of the Coorong*, CSIRO: Water for a Healthy Country National Research Flagship, Canberra.

Stewardson M and Guarino F (2019) *2017–18 Basin scale evaluation of Commonwealth environmental water – Hydrology*, final report prepared for the Commonwealth Environmental Water Office by La Trobe University, Publication 232/2019.

Studds C, Kendall B, Murray N, Wilson H, Rogers D, Clemens R, Gosbell K, Hassell C, Jessop R, Melville D, Milton D, Minton C, Possingham H, Riegen A, Straw P, Woehler E and Fuller R (2017) Rapid population decline in migratory shorebirds relying on Yellow Sea tidal mudflats as stopover sites, *Nature Communications*, 8(1), 14895.

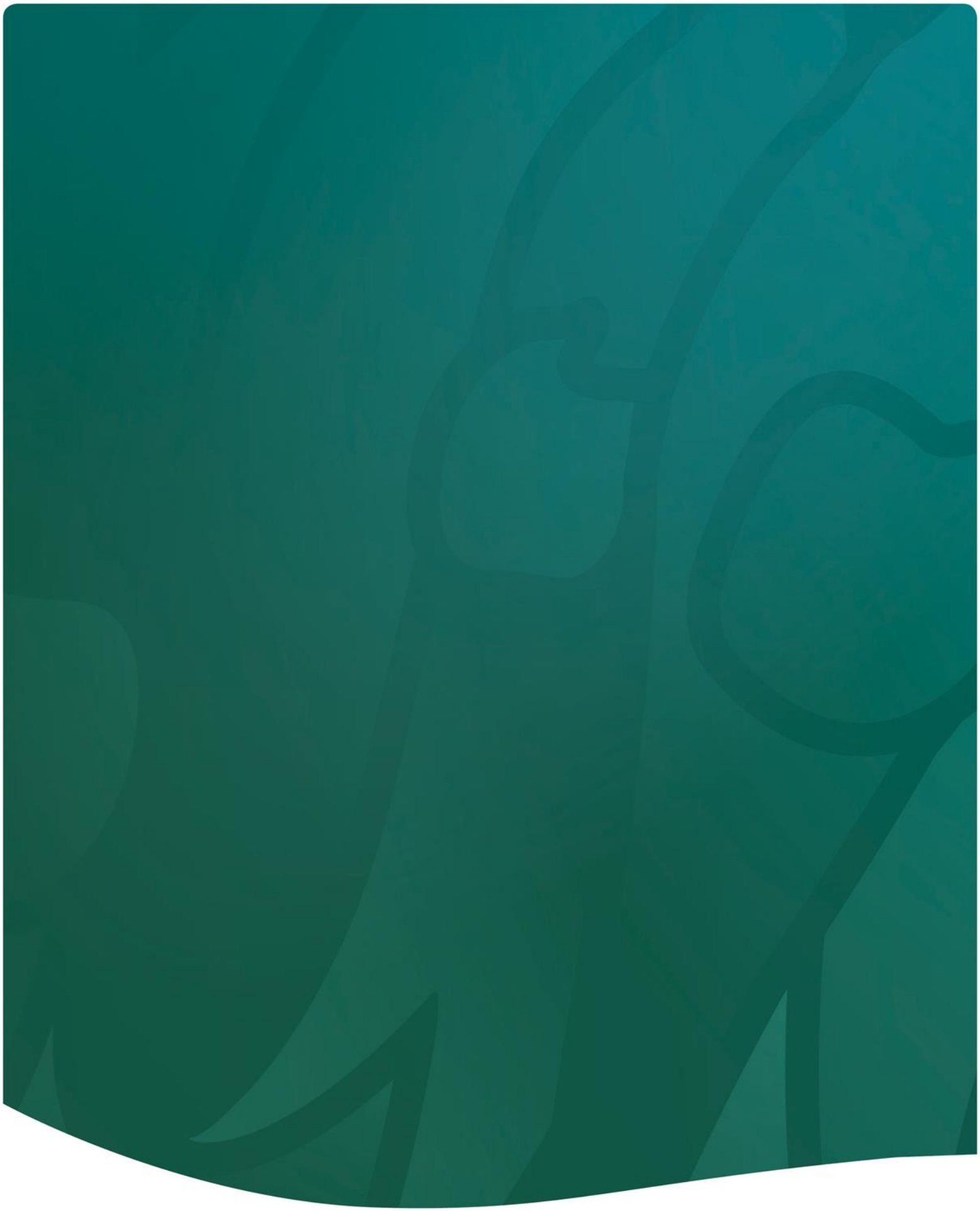
Wickham H, Chang W, Henry L, Lin Pedersen T, Takahashi K, Wilke C, Woo K, Yutani H and Dunnington D (2016) *ggplot2: Elegant graphics for data analysis,* Spring-Verlag New York, 2016.

Ye A, Bucater L, Short DA and Giatas GC (2022) *Coorong fish condition monitoring 2008–2021: Black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouthed hardyhead (Atherinosoma microstoma) populations,* South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2011/000471-9, SARDI Research Report Series No. 1129. 77pp.

Ye Q, Bucater L, Short D and Earl J (2012) *Coorong fish condition monitoring 2008–2012: The black bream (Acanthopagrus butcheri), greenback flounder (Rhombosolea tapirina) and smallmouthed hardyhead (Atherinosoma microstoma) populations*, South Australian Research and Development Institute (Aquatic Sciences), Adelaide, SARDI Publication No. F2011/000471-2, SARDI Research Report Series No. 649. 72pp.

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

Ye Q, Giatis G, Brookes J, Furst D, Gibbs M, Oliver R, Shiel R, Zampatti B, Aldridge K, Bucater L, Busch B, Hipsey M, Lorenz Z, Maas R and Woodhead J (2020b) *Commonwealth Environmental Water Office Long-Term Intervention Monitoring Project 2014–2019: Lower Murray River Technical Report*, report prepared for the Commonwealth Environmental Water Office by SARDI (Aquatic Sciences).



Government
of South Australia

Department for
Environment and Water