Condition Monitoring Plan (Revised) 2017

The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site

August 2017

Government of South Australia

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Cover photo: Kirsty Wedge

Foreword

The *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site* is a key plan for the management of the nationally and internationally significant Lower Lakes, Coorong and Murray Mouth (LLCMM) wetland. The plan builds on years of work undertaken by The Living Murray Program and the scientific service providers that have added invaluable expertise in refining the condition monitoring plan.

The Living Murray condition monitoring has been ongoing since 2008 and is an example of a long-term monitoring program that has made important contributions to the development and implementation of the Murray-Darling Basin Plan. The LLCMM monitoring data and findings have been invaluable for improving our knowledge of this wetland and the River Murray system as a whole. It has also been vital to understanding the LLCMM's physical and biological components and in particular, how these have responded over time to changing environmental water and flow conditions. Data collected through this program has been instrumental in annual environmental water planning, the development of the Long Term Environmental Water Plan for the SA River Murray and the assessment of environmental water delivery outcomes.

The scientific expertise provided by service providers to The Living Murray program has enabled continued improvements and refinements in monitoring methodology and analysis to be made. This Condition Monitoring Plan is a culmination of these improvements, which is a result of the collaboration of state and federal governments, scientific organisations and traditional owners.

The Living Murray program and the Condition Monitoring Plan, demonstrates the Government's commitment to the use of the best scientific, cultural and local knowledge in the delivery of environmental water to South Australia as part of the Murray-Darling Basin Plan.

I would like to thank all those who have been involved in the planning, management and monitoring of environmental water for South Australia and look forward to many more successful watering years in the future.

Ben Bruce, Group Executive Director, Water
Department of Environment, Water and Natural Resources
August 2017

Acknowledgement of the Traditional Owners

The Department of Environment, Water and Natural Resources acknowledges and pays respect to the traditional owners, and their Nations, of the Murray-Darling Basin, who have a deep cultural, social, environmental, spiritual and economic connection to their lands and waters.

The Ngarrindjeri Nation have occupied, enjoyed, managed and used their inherited lands and waters of the River Murray, Lakes and Coorong since time immemorial. They pay their respect to Creators, ancestors, elders, and young people who have cared for their country since creation.

Acknowledgements

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In addition to staff in the Department of Environment, Water and Natural Resources (DEWNR), input from representatives and employees of the following organisations has been gratefully received:

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- Dr. Jason Nicol
- Dr. Susan Gehrig
- A. Prof. Qifeng Ye
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- Christopher Bice
- Brenton Zampatti

The University of Adelaide

- A. Prof. David Paton
- Dr. Scotte Wedderburn
- Fiona Paton
- Colin Bailey

Flinders University

- Prof. Sabine Dittmann

The Ngarrindjeri Regional Authority (NRA).

Members of the DEWNR Lower Lakes, Coorong and Murray Mouth (LLCMM) Scientific Advisory Group.

Murray–Darling Basin Authority staff working on The Living Murray Program.

Contents

Figures

Tables

Part 1: Background

Figure 1. Aerial view of Murray Mouth, May 2008.

1. The Living Murray Program

The Living Murray (TLM) is one of Australia's most significant river restoration programs. Established in 2002, TLM is a partnership of the New South Wales, Victorian, South Australian, Australian Capital Territory and the Commonwealth governments, coordinated by the Murray–Darling Basin Authority (MDBA). The long-term goal of this program is to achieve a healthy working River Murray system for the benefit of all Australians.

The Living Murray aims to improve the environmental health of six icon sites (Figure 2) that were chosen for their significant ecological, cultural, recreational, heritage and economic values:

- Barmah–Millewa Forest
- Gunbower–Koondrook–Perricoota Forest
- Hattah Lakes
- Chowilla Floodplain and Lindsay–Wallpolla Islands (including Mulcra Island)
- River Murray Channel
- Lower Lakes, Coorong and Murray Mouth.

The Living Murray icon sites were chosen for their high ecological value – most are listed as internationally significant wetlands under the Ramsar Convention – and also their cultural significance to Indigenous people and the broader community. Ecological objectives have been developed for each icon site and are aimed at retaining, restoring or improving the sites' ecosystems, habitats, and native flora and fauna.

The Lower Lakes, Coorong and Murray Mouth (LLCMM) total approximately 140,000 hectares, covering 23 different wetland types ranging from fresh to hypersaline waters. The LLCMM is one of the 10 major havens for large concentrations of wading birds in Australia, and is recognized internationally as a breeding ground for many species of waterbirds and native fish.

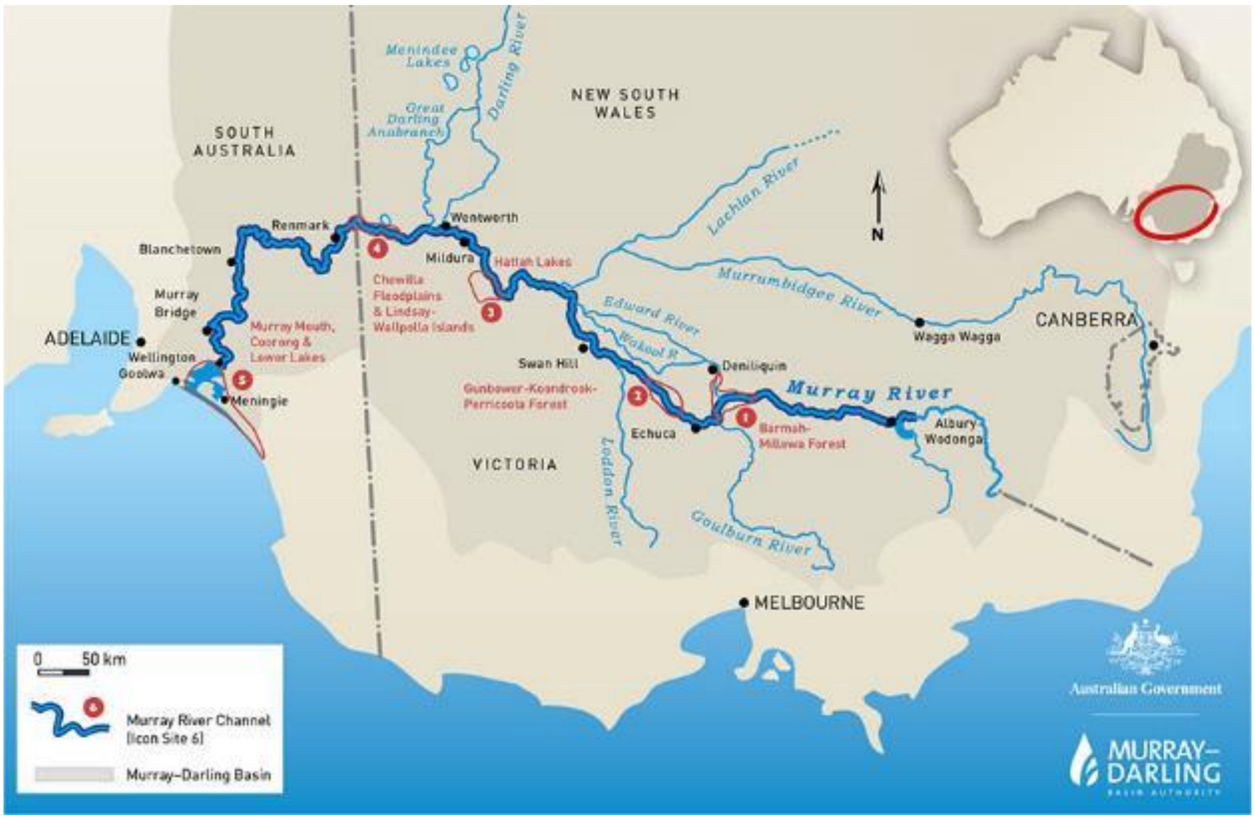

Figure 2 Location of The Living Murray Icon Sites. 1. Barmah-Millewa Forest; 2. Gunbower-Koondrook-Perricoota Forest; 3. Hattah Lakes; 4. Chowilla Floodplain and Lindsay-Wallpolla Islands; 5. Lower Lakes, Coorong and Murray Mouth; 6. River Murray Channel (Source: MDBA website).

1.1. Lower Lakes, Coorong and Murray Mouth Environmental Water Management Plan (EWMP)

The desired vision for the site outlined in the LLCMM Environmental Water Management Plan (EWMP) (MDBA 2014) is "*a healthier Lower Lakes and Coorong estuarine environment.*" As part of The Living Murray First Step Decision three higher level ecological objectives were developed for the icon site:

- an open Murray Mouth;
- more frequent estuarine fish spawning and recruitment; and
- enhanced migratory waterbird habitat in the Lower Lakes and Coorong.

The LLCMM Icon Site EWMP builds on these higher level objectives by identifying 16 ecological and physical targets that quantify changes in the condition of the icon site.

The LLCMM Icon Site EWMP also outlines the environmental water needs of the site, which are based on the volumes and flow regimes required to achieve the ecological objectives and targets, to ensure the site functions in a 'healthy' ecosystem state. These flow targets and water requirements are aspirational and focus on water required for real-time management of the icon site.

Chapter 3 of the EWMP Plan outlines the need for icon site condition and intervention monitoring. This Condition Monitoring Plan (Revised) 2017 (DEWNR, 2017) is a schedule to the LLCMM Icon Site EWMP and supersedes the previous Condition Monitoring Plan (Maunsell 2009).

Figure 3. Flows through Goolwa Barrage.

2. Development of Condition Monitoring Plan

2.1. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site Condition Monitoring plan

Condition monitoring assesses icon site condition in relation to icon site ecological objectives. It is typically conducted on a medium frequency and focuses on key indicators of vegetation, fish and waterbird condition. The methods for monitoring ecological objectives are outlined in icon site Condition Monitoring Plans.

In 2007-08 icon site Condition Monitoring Plans were developed by icon site managers and monitoring providers to enable monitoring and reporting on The Living Murray initiative. These Plans built on the monitoring activities already undertaken at the icon site and where possible, used standard methods to enable similar variables to be reported across icon sites.

At this time there was limited data to inform the development of quantitative targets, and therefore targets focused on maintaining or improving condition. As the Basin was experiencing drought conditions at this time maintain or improve were considered reasonable targets.

Following the end of the drought, and the development and implementation of the Basin Plan, it was recognised that further work should be undertaken to refine ecological outcomes at icon sites against quantifiable targets and more statistically robust methodology.

An external review was initiated in 2011, to enable assessment of the adequacy of the Condition Monitoring Plans to detect change in icon site condition over time. The review (Robinson 2013) enabled further clarification of the purpose and objectives of the Condition Monitoring Program; and enabled the refinement of some monitoring objectives which inform monitoring variables, indicators and targets (Robinson 2014a,b). Further work was undertaken from 2013 to 2015 by icon site managers and monitoring service providers to develop clear indices and methods for data analysis, leading to the revision of Condition Monitoring Plans.

This Condition Monitoring Plan (Revised) 2017 has been updated to incorporate the refinements recommended by the independent review (Robinson 2013; 2014a,b) that have been developed by the icon site service providers.

It is anticipated that the LLCMM Icon Site Environmental Water Management Plan should be revised and updated in conjunction with the LLCMM Icon Site Condition Monitoring Plan, which is due for review in 2019.

Icon Site Objectives and Targets

The targets identified through the previous LLCMM Icon Site Condition Monitoring Plan (Maunsell 2009), and included as ecological targets in the LLCMM EWMP (2014), were mostly qualitative and aimed to maintain or improve conditions post drought.

The Condition Monitoring Refinement Project included a revision of icon site targets with the aims of improving the ability of the monitoring to detect change quantitatively and tailoring a standardised reporting approach for TLM condition monitoring.

The development of quantitative targets for each component (fish, birds, etc.) included an analysis of statistical power to detect change in icon site condition along with clear definitions on the reference terms used.

This overall process has been documented separately in a technical document (Robinson 2014a) and the refined targets and monitoring methodologies are included in this Condition Monitoring Plan in Section 4.

NOTE:

the targets identified in the CMP (2009) and LLCMM EWMP (2014) have been refined in this CMP (2017) and are now referred to as **OBJECTIVES**

The targets identified in the previous LLCMM Icon Site Condition Monitoring Plan (Maunsell 2009) are now referred to as 'ecological objectives' within this updated Condition Monitoring Plan. The new quantitative targets developed through the Condition Monitoring Refinement Project are nested below the ecological objectives. The linkages between the LLCMM documents and the progression of the icon site objectives and targets are outlined in Figure 4.

Intervention Monitoring

While condition monitoring assesses trends in condition over time, intervention monitoring aims to assign ecological responses to management actions (see McCarthy et al. 2006 and MDBC 2007, for more information on intervention and compliance monitoring) (Maunsell 2009).

The aim of intervention monitoring is to improve understanding about the causal links between environmental watering and other management actions, and ecological responses at icon sites. This knowledge enables managers to continually adapt and improve management of icon sites and watering into the future to optimise ecological outcomes (Maunsell 2009). A number of intervention monitoring projects have been funded in the LLCMM icon site from 2007–17, a number of which have focussed on fish migration through barrage fishways and the response of frogs and threatened fish to lake level variations.

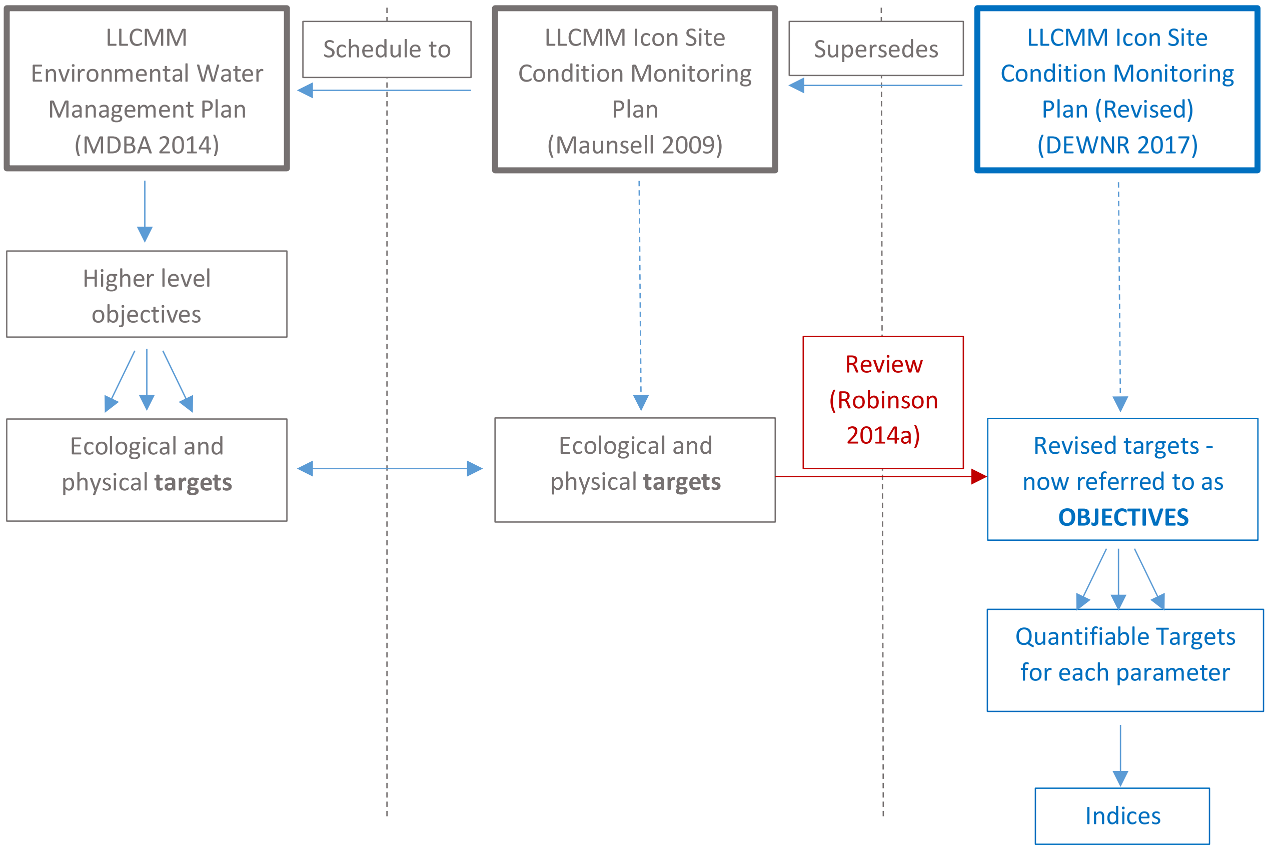

Figure 4: Linkages between the LLCMM documents and site objectives and targets.

2.2. Importance of Condition Monitoring Data and Results

The Living Murray condition monitoring has been undertaken since 2008. The LLCMM condition monitoring data and findings have been invaluable in improving our knowledge of the LLCMM system, its physical and biological components, and how they have responded over time to changing environmental water and flow conditions. Data collected through this program has been instrumental in annual environmental water planning, the development of the Long Term Environmental Water Plan for the SA River Murray, the assessment of environmental water delivery outcomes, and supports the evaluation of the Murray-Darling Basin Plan.

2.2.1. Annual Planning

Information from condition and intervention monitoring is necessary for environmental water planning (annual and real time management) for the LLCMM icon site. It informs the development of the annual LLCMM Icon Site Watering Proposal provided to the water holders, which is used for system wide water planning, and supports negotiations between South Australia and the water holders for environmental water for the site.

The ongoing commitment of The Living Murray initiative for the condition monitoring program, and the collection and use of long-term data sets, has provided an evidence base to support the allocation and delivery of significant volumes of environmental water to the LLCMM site. This has contributed to achieving multiple ecological outcomes for the site and for the Murray–Darling Basin, including end of system targets.

2.2.2. Long Term Watering Plan

The LLCMM Icon Site monitoring program provided critical input into the development of the Long Term Environmental Watering Plan (LTEWP) for the South Australian River Murray Water Resource Plan Area (DEWNR 2015) as part of the Basin Plan Implementation. This includes the identification of the environmental water requirements for the LLCMM (referred to as Coorong, Lower Lakes and Murray Mouth (CLLMM)) priority asset. The targets/objectives developed within the Condition Monitoring Plan (Mansell 2009) and further refined through the Condition Monitoring Refinement Project were incorporated into the LTEWP for the CLLMM priority asset, and as such, the TLM monitoring program also informs Matter 8 reporting on the implementation of the LTEWP and the Basin Plan.

2.2.3. Ecological Outcomes of Environmental Water Delivery

Resources to support high frequency monitoring of ecological responses to environmental water actions are scarce. As well as assessing condition over time, annual condition monitoring, in conjunction with intervention monitoring, is essential for the assessment of ecological outcomes from management actions and environmental water delivery.

2.2.4. Adaptive Management Process

It is crucial that the data collected, and the processes and outcomes observed, are reviewed as part of an adaptive management cycle. Monitoring that is not embedded in an effective adaptive management cycle typically ends up simply recording the decline of ecosystems (Storey et al. 2001). The regular review of the data collected from the condition and intervention monitoring program, interpretation of that data with regard to the conceptual model and ecological objectives and targets, and subsequent review and modification is essential to the adaptive management process. Knowledge and learning improves the effectiveness of environmental water planning and delivery, and helps to achieve management and ecological outcomes.

The assessment of Ecological Objectives and Targets provide a framework to support:

- decisions regarding the need for targeted management actions
- development and rationalisation of monitoring programs
- streamlined reporting of monitoring programs
- focussed assessment of outcomes of management actions.

2.3. Implementation of the Condition Monitoring Plan

The following sections provide a brief summary of the implementation of the LLCMM Icon Site Condition Monitoring Plan including how condition monitoring information is used. This process is well established and has matured over many years of collaboration and coordination.

The Living Murray Baseline

The quantifiable targets developed for each component of the LLCMM Condition Monitoring Plan as part of a Condition Monitoring Refinement Project have been designed so that change in icon site condition may be detected. Experimental design and statistical analyses that has been identified for each target aims to detect a deviation from a defined baseline condition. The definition of baseline condition is different for each parameter and is dependent on the availability of past data.

The data collected since the beginning of the TLM monitoring program has been used by service providers to inform the refined targets and the baseline conditions that are used as a reference point to assess change in condition. The baseline condition is different for each parameter as it is dependent on the availability of past data. In most cases, the accepted baseline relates to pre-drought condition of flora and fauna, and change is expressed as relative to this baseline.

Data Analysis and Reporting

A report for each of the monitoring components is provided by the service providers on an annual basis (where funds have enabled monitoring, analysis and reporting to be undertaken). Data is analysed by individual service providers as per the refined targets and methodologies outlined in this Condition Monitoring Plan (revised). The reports are reviewed by the DEWNR icon site managers and MDBA staff prior to finalisation.

A synthesis report for the LLCMM Icon Site is produced each year, which summarises the findings of the condition monitoring reports, in particular how they relate to the achievement of icon site objectives and targets.

Data Management and Storage

A data management protocol has been established by the MDBA so that datasets collected through The Living Murray program can be held in a form that is readily available for analyses. The purpose of the protocol is to ensure data will be easily accessible, accurate, ready for analysis, and managed in a way that promotes re-use and integration.

Data and condition monitoring reports are submitted by the service providers to the icon site team within DEWNR on an annual basis, where monitoring has been undertaken, and are then provided to the MDBA according to the timeframes agreed in the funding agreements.

2.4. Modification of Prescribed Requirements

The icon site manager may be required to modify information (e.g. methodologies, sites, outputs) prescribed within this section due to environmental conditions (e.g. low water levels caused by drought or the subsequent return of flows). The requirements detailed within this updated Condition Monitoring Plan may also need to be amended at shorter time periods (e.g. annually) to reflect changes in sampling sites, methodologies, targeted species, outputs, analysis and/or data as knowledge advances or when resource limitations impact on the scale or scope of the monitoring that can be undertaken.

The monitoring that is undertaken in any given year is dependent on the availability of funding. In most years there is not enough funding to cover the full suite of parameters and/or the number of survey rounds recommended in this condition monitoring plan. Generally the number of survey rounds will be reduced to maintain the long term integrity of the data set for as many parameters as possible. Data collection is often prioritised in preference to funding the development of reports. A reduction in the number of sampling rounds may have the effect of reducing the statistical power of the analysis.

Destructive Sampling

Modification to sampling methodologies may include limiting future impacts resulting from destructive sampling. For example, if reliable age and length relationships have been established for certain fish species, it may be possible to use size structure as a surrogate for age. This will limit the need for the ongoing collection and sacrifice of individuals for subsequent age determination using otoliths. The number of individuals sacrificed should be reported as part of any condition monitoring contract. Further information is provided in the 'Guidelines to promote the wellbeing of animals used for scientific purposes' (National Health and Medical Research Council 2008). Service providers should adhere to their own organisation's animal ethics guidelines.

Scientific Permits

Scientific research within the state's system of conservation reserves is encouraged by DEWNR and improves understanding of conservation management. Scientific permits ensure that research does not impact on animal and plant populations, the environmental integrity of habitats or the conservation values of our protected areas.

The National Parks and Wildlife Act 1972 (SA) and regulations, and the Wilderness Protection Act 1992 (SA) and regulations, require that any scientific research on a reserve, in a wilderness area or involving protected species of flora and fauna is approved under a Scientific Permit.

Research using established captive colonies of native fauna does not require a Scientific Permit unless the work involves capturing new animals or releasing animals into the wild. However, other DEWNR permits are required to keep most native animals.

Landholder Permission

All scientific research undertaken on private property will require permission from the landholder to access the site prior to field work commencing. Landholders are to be informed of the type of monitoring being undertaken, and the dates and duration of each field visit. Any landholder requests for information on the monitoring results should be coordinated through the Icon Site Coordinator.

2.5. Cultural principles and guidelines for research and engagement on Ngarrindjeri Country

Guidelines have been developed for those undertaking research projects that provide information and advice about how to engage and encourage involvement by Ngarrindjeri people and contribute towards Ngarrindjeri goals. Below provides information on how to consult respectfully and meaningfully with Ngarrindjeri when conducting research and monitoring on our Ruwe/Ruwar.

Cultural principles

Ngarrindjeri encourage agencies and their sub-contractors to use the following principles as foundations for research and monitoring work.

- Our lands, our waters, our people, all living things are connected.
- We implore people to respect our Ruwe/Ruwar as it was created in the Creation (Kaldowinyeri).
- The land and waters are a living body. We the Ngarrindjeri people are a part of its existence.
- Because of our knowledge, our inherent rights to our lands and waters, and our cultural spiritual responsibility, we must be recognised as equal partners in Caring for Ruwe/Ruwar.

- For the lands and waters to be healthy Ngarrindjeri must be heard and Ngarrindjeri must speak as Country (Yannarumi).
- We invite all who respect us to join with us in our responsibility and duty to Care for our Ruwe/Ruwar.
- Ngarrindjeri are committed to respecting, maintaining and restoring our Ruwe/Ruwar and ask that all researchers take account of Ngarrindjeri cultural values.
- The terrestrial, marine and freshwater environments are inseparable and should be considered as a whole in all research and monitoring activities.

Guidelines for conducting research and monitoring

The Ngarrindjeri commitment to the future wellbeing of Ruwe/Ruwar requires that all research and monitoring activities adhere to the appropriate cultural protocols and intellectual and cultural property rights.

To gain support and approval from Ngarrindjeri, research and monitoring agencies (and their sub-contractors) must respect our cultural principles and work in partnership with the Ngarrindjeri Regional Authority (NRA).

We require compliance with the following additional principles:

- Respectful processes, time and support for Ngarrindjeri to Care for Ruwe/Ruwar, which includes caring for people past, present and future.
- Ngarrindjeri actively involved in research and monitoring activities on Ngarrindjeri Ruwe/Ruwar.
- Cultural knowledge and intellectual property protected across Ngarrindjeri engagements with governments and research organisations.
- Ngarrindjeri cultural values integral to all planning and future management arrangements.
- Active Ngarrindjeri participation in planning and future management arrangements through employment, education and training opportunities.

Research partnerships with Ngarrindjeri

Ngarrindjeri have a range of research interests and priorities. The NRA has established a Sea Country (Yarluwar-Ruwe) Program to coordinate all Caring for Ruwe/Ruwar activities. We seek to establish collaborative research partnerships through the NRA Research, Policy and Planning Unit hosted by Flinders University. Central to these partnerships is the goal of delivering outcomes relevant to the Ngarrindjeri community, including building skills, capacity, employment opportunities and pathways to tertiary education.

This goal reflects the Ngarrindjeri understanding of the interconnectedness of the lands, waters and all living things.

NRA contact details and key Ngarrindjeri positions

Please contact us if you would like advice on how to engage and work with us.

Ngarrindjeri Regional Authority, 50 Princes Hwy Murray Bridge East SA, Tel: (08) 8531 3868

- Chair, Ngarrindjeri Regional Authority
- Chair, Ngarrindjeri Heritage Committee
- Chair, Ngarrindjeri Native Title Management Committee
- NRA Heritage Manager
- Chair, NRA Yarluwar-Ruwe Program
- Chair, NRA RPPU

THE NRA RESEARCH CHECKLIST

- Understand and respect Ngarrindjeri governance structures. The peak Ngarrindjeri representative body is the Ngarrindjeri Regional Authority (NRA).

- Understand and respect the key Ngarrindjeri cultural principles that apply to Ngarrindjeri Caring for Country (Ruwe/Ruwar).
- Undertake appropriate cultural awareness training offered by the NRA.
- Understand and respect the protocols and processes for engagement between the Government of South Australia and the Ngarrindjeri Nation. For example, the KNY Agreement 2009, the KNY Agreement Taskforce, and associated statements of commitment, working groups and legislative requirements.
- Understand that research conducted on Ngarrindjeri Ruwe/Ruwar is of interest to Ngarrindjeri - research is critical to the ongoing health of our region.
- Incorporate Ngarrindjeri engagement into all aspects of research and monitoring programs - including policy development, planning and implementation.
- Recognise that Ngarrindjeri possess knowledge of Ngarrindjeri Ruwe/Ruwar that has been developed over thousands of years.
- Understand and respect that, for Ngarrindjeri, the lands, waters and all living things are part of a living body - Ngarrindjeri are part of this body.
- Negotiate the resources required for Ngarrindjeri engagement in research and monitoring programs - include these in project planning (costs may be covered by major projects such as Murray Futures).
- Recognise and respect that Ngarrindjeri are researchers and have research goals and objectives.
- Ensure that opportunities for building Ngarrindjeri research and monitoring capacity are recognised and where possible included.
- Prioritise formal research partnerships with the NRA and seek to create opportunities for collaboration.
- Recognise that Ngarrindjeri cultural knowledge belongs to Ngarrindjeri - the NRA has developed a process for cultural knowledge protection.
- Understand that the NRA has the following responsibilities and goals: ‘Caring for our people, lands, waters and all living things’; Strong Culture; Sovereign First Nation; Secure Future; Healthy Country; Confident People; Creative Economy; Respected History; Regional Leader

Key documents

- CLLMM Monitoring and Research Program – Statement of Commitment
- Ngarrindjeri Nation Yarluwar-Ruwe Plan (Sea Country Plan)
- NRA Guidelines for Researching on Ngarrindjeri Ruwe/Ruwar

2.6. Conceptual Models

A series of conceptual models were developed for the LLCMM Icon Site (e.g. MDBC 2006; Wilkinson et al. 2007a,b; Figure 5 and Figure 6) to assist in the design of monitoring programs under the TLM initiative. The specific focus of the models is the management of freshwater inputs to the system.

The models provided a useful starting point for the subsequent modelling of the icon site, and a number of sub-models have been developed for various sub-components within the system (e.g. fish, birds, vegetation). These are subject to ongoing revision as new information becomes available to inform an improved understanding of how the system and its components function.

The following conceptual models are modifications of those initially presented in MDBC (2006) and have been developed to aid the selection of monitoring measures and indicators according to Wilkinson et al. (2007a,b). A legend of the symbols used in the models is also presented below. See Wilkinson et al. (2007a,b) for a more detailed description of these models.

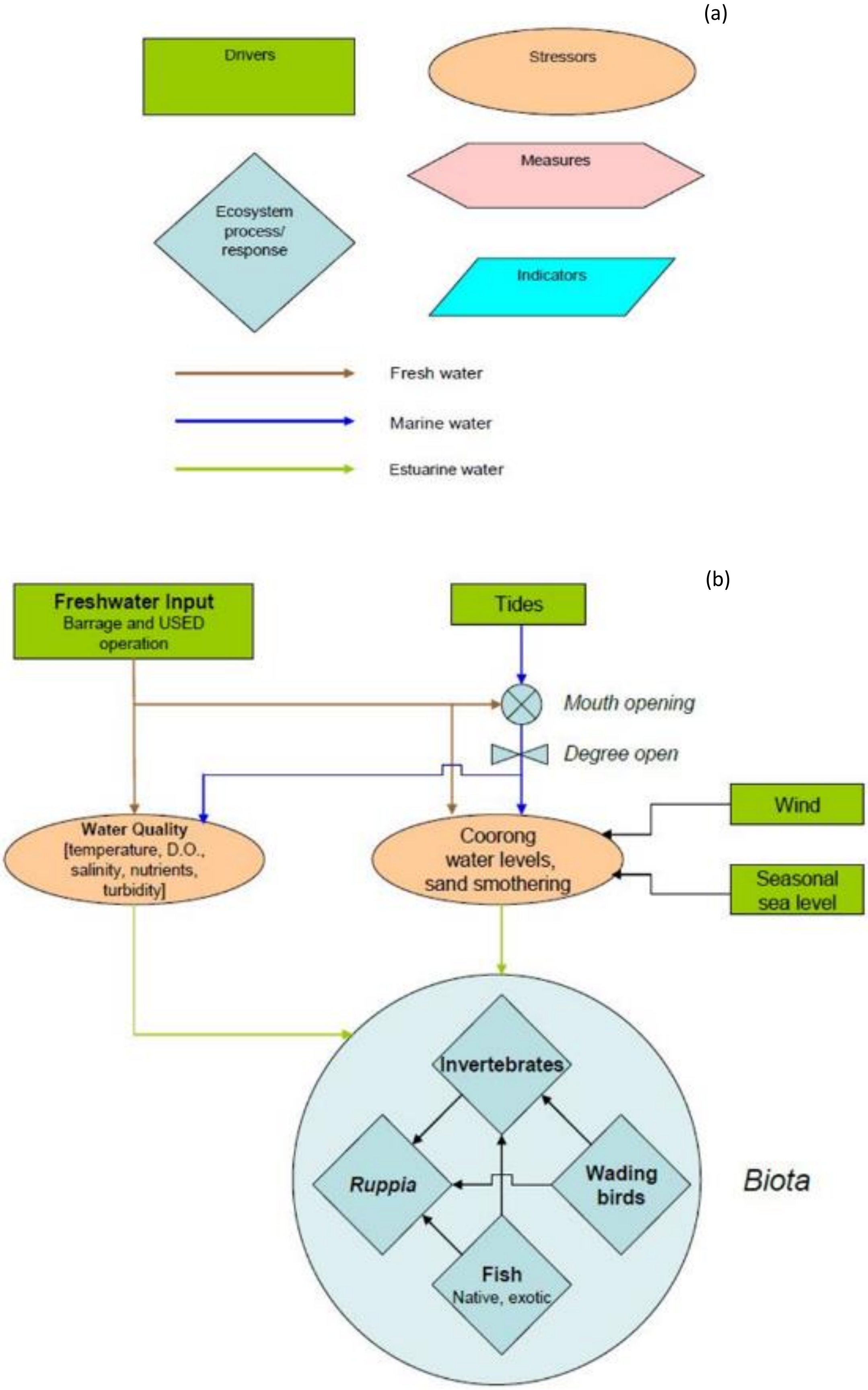

Figure 5. (a) Model symbology, (b) Coorong model initially presented in MDBC (2006), with modifications as outlined in Wilkinson et al. (2007a,b).

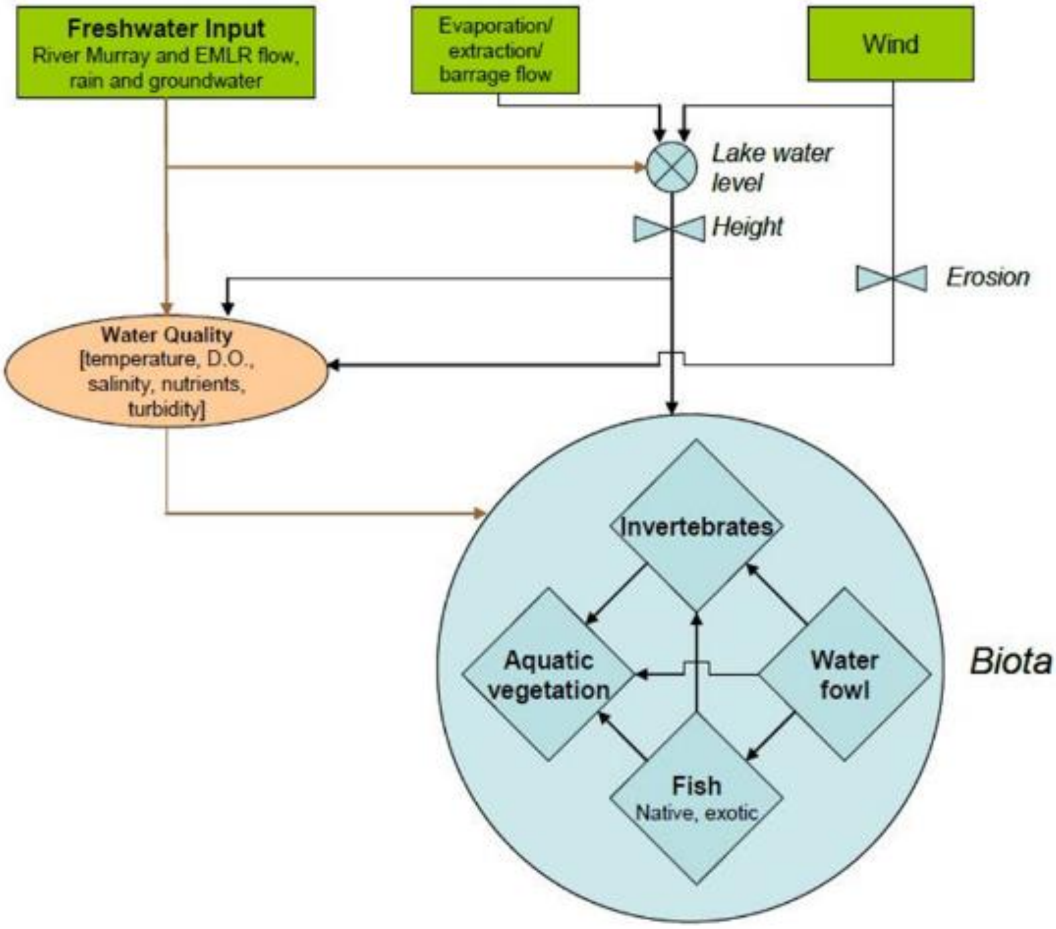

Figure 6. Lower Lakes model initially presented in MDBC (2006), with modifications as outlined in Wilkinson et al. (2007a,b).

Part 2: LLCMM Icon Site Condition Monitoring Plan

Figure 7. Processing fish at Shadow's Lagoon, November 2012, photo Scotte Wedderburn.

3. LLCMM Icon Site EWMP Objectives & Targets

3.1. Ecological Objectives

The indicators and methodologies addressed through the LLCMM Condition Monitoring Plan relate to:

- Biotic groups: birds, fish, vegetation, invertebrates
- Abiotic groups: mudflats, water

Through the Condition Monitoring Refinement Project (Robinson 2013; 2014a,b), the ecological objectives in the Condition Monitoring Plan (Maunsell 2009) were reviewed and a number of quantitative ecological targets developed to enable a more detailed assessment of the condition of the icon site.

The review also recommended 4 of the 17 ecological objectives be removed from TLM condition monitoring program as they are either unfunded or are covered within another target. The objectives to be removed are:

I-2 provide freshwater flows that provide food sources for Goolwa cockles

V-1 maintain or improve *Ruppia megacarpa* colonization and reproduction in North Lagoon

M-1 facilitate frequent changes in exposure and submergence of mudflats

W-4 maximise fish passage connectivity between the Coorong and the sea.

The mudflat objectives M-2 and M-3 are combined as 'maintain or improve habitable sediment conditions in mudflats'. A comparison of the previous Condition Monitoring Plan (Maunsell 2009) ecological objectives and how they are linked to the First Step Decision (FSD) higher level objectives (outlined in section 1.1) is provided in Table 1.

3.2. Refined Quantitative Targets

The new ecological targets have been developed so that progress towards achieving the TLM LLCMM icon site ecological objectives could be assessed at a whole of icon site scale, with a known level of power or effect size. The review has identified baseline conditions where possible, to enable the assessment of relative changes in icon site condition. A key output is also the clear description of the outcomes and reference terms for each of the components (Robinson 2014b).

Section 4 of this report outlines the monitoring method, statistical analysis and sensitivity of the sampling method for each of the new ecological targets.

3.3. Reporting

As part of the condition monitoring reports for each component, the monitoring providers are required to incorporate a discussion of each of the targets and whether they have been met or not. It is also important that the reports discuss whether the ecological objectives have been achieved in light of the results of the targets nested within it. Reports should also provide discussion of the objectives and targets in a management context and make reference to environmental water delivery. Where possible, results should be mapped and/or graphically presented to assist in visually communicating outcomes.

Table 1. A comparison of revised ecological objectives (known as targets in the EWMP) with the First Step Decision (FSD) objectives. Categories are classed as follows for monitoring types: A – recommended TLM standard; B – Icon Site specific method linked to FSD objectives; O – other specific method not easily linked to FSD objectives.

ID	Ecological Objective (refined)	Open Mouth	Fish Recruitment	Bird Habitat	Category
	Birds (B)				
B-1	Maintain or improve waterbird populations in the Lower Lakes, Coorong and Murray Mouth.			✓	**A, B**
	Fish (F)				
F-1	Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong.	✓	✓		**B**
F-2	Ensure recruitment success of threatened fishes in the Lower Lakes to maintain or establish self-sustaining populations.		✓		**B**
F-3	Maintain abundant self-sustaining populations of small-mouthed hardyhead in the North Lagoon and South Lagoon of the Coorong.		✓		**B**
F-4	Restore resilient populations of black bream and greenback flounder in the Coorong.	✓	✓		**B**
	Invertebrates (I)				
I-1	Maintain or improve mudflat invertebrate communities that are of high condition relative to southern Australian estuarine mudflat ecosystems.	✓	✓	✓	**B**
	Mudflats (M)				
M-2 M-3	Maintain or improve habitable sediment conditions in mudflats: - Maintain sediment size range in mudflats (M-2) - Maintain organic content for mudflats (M-3)	✓		✓	**B**
	Vegetation (V)				
V-2	Maintain or improve *Ruppia tuberosa* colonisation and reproduction		✓	✓	**B**
V-3	Maintain or improve aquatic and littoral vegetation in the Lower Lakes.		✓	✓	**B**
	Water (W)				
W-1	Support aquatic habitat by establishing and maintaining variable salinity regimes in the Murray Mouth Estuary, North Lagoon and South Lagoon.		✓	✓	**O**
W-2	Maintain a permanent Murray Mouth opening through freshwater outflows to improve water quality and maximise connectivity.	✓	✓	✓	**O**
W-3	Maximise fish passage connectivity between the Lower Lakes and Coorong.		✓		**O**

3.4. Terminology

An explanation of the characteristics used to define and describe the monitoring methodologies are provided in Table 2.

Table 2. Terminology used to define the condition monitoring program for each ecological objective.

Characteristic	Definition / description
Ecological objective	This is the refined target in the Condition Monitoring Plan (Maunsell 2009) and LLCMM EWMP (MDBA 2014) which is now referred to as an ecological objective
Definition of how objective and targets are interpreted	Definitions and / or explanations are provided for specific terms used in the ecological objective and targets, e.g. *"colonisation" is defined as …*
Ecological targets	List of the quantitative ecological targets nested within the ecological objectives developed through the Condition Monitoring Refinement Project
CMP monitoring objective	A brief description of the purpose of the monitoring methods and how it relates to assessing the ecological objective
Key use of data	Description of how the data is used to inform decisions, e.g. whether the data is used to inform long-term planning, timing of environmental water delivery, management of the Lower Lake water levels, management of Coorong water levels, timing of barrage releases or management of fringing Lower Lakes wetlands, etc.
Sampling strategy	Number of sites
	Frequency and timing of data collection
	List of the sub-regions within the LLCMM that are monitored
	Description of the monitoring methodology, i.e. data collection (short summary)
	Name of service provider and organisation that undertake the monitoring
Index/Indices	Description of each index, including target values and standard errors or confidence intervals where relevant
Calculation of index	Explanation of the development of point of reference / baseline
	Basic description of how the indices are calculated
	Basic description of how data is to be presented in the condition monitoring report
Calculation of whole of icon site score for parameter	Description of the method for calculating the whole of icon site score (WOISS) for the ecological objective
Power/Effect size	Description of the sensitivity of the sampling method to change in condition in terms of the power or effect size

4. Condition Monitoring Targets

4.1. Birds (David Paton, Fiona Paton and Colin Bailey)

Preferred citation for the Birds chapter:

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

Refined objective: Maintain or improve waterbird populations in the Lower Lakes, Coorong and Murray Mouth (B-1).

Original: Maintain or improve bird populations in the Lower Lakes, Coorong and Murray Mouth (B-1).

This monitoring and reporting component conducts a systematic census of waterbirds using the Coorong during January and using the Lower Lakes in January–February to determine if the ecological targets for the distributions, abundances and behaviour of waterbirds are met. The waterbird communities in the Lower Lakes, Coorong and Murray Mouth (LLCMM) region have changed over the last 50 or so years (e.g. Paton et al. 2009; Paton 2010; Paton et al. 2015b). Although no waterbird species have been lost from the region, many now occur in lower abundances or with more restricted spatial and temporal distributions within the region. The current and historic distributions and abundances of waterbirds are influenced by abiotic (water levels, salinities) and associated biotic (food resources) factors, and by the conditions of other wetlands that are used by the waterbirds. Wetlands in the LLCMM region provide important summer and drought refuges, with abundances of many species higher during summer and autumn than winter and spring (Paton 2010). Most waterbirds use the margins of wetlands, where the water levels allow access to aquatic foods by wading or surface diving. The Coorong supports a waterbird community that differs from the Lower Lakes. The major differences are that large numbers of shorebirds (sandpipers, stints, plovers, stilts, avocets) use the saline wetlands of the Coorong, while few shorebirds use the freshwater wetlands of the Lower Lakes. Both areas support large and comparable numbers of waterfowl (ducks, swans), and large numbers of waterbird species that primarily feed on fish (cormorants, grebes, pelicans, terns). The composition of these two major groups of birds differs, however, where some species largely are found in the Coorong while other species mainly are found in the Lower Lakes. These differences in waterbird communities generally reflect differences in the habitats provided by the Coorong and Lower Lakes. Reeds are prominent around the freshwater shorelines of the Lower Lakes, while the Coorong provides extensive areas of shallow, gently sloping shorelines without emergent reeds. These differences provide justification for assessing the waterbird use of the Coorong separately from waterbird use of the Lower Lakes.

The original annual waterbird monitoring program for the Coorong commenced in 2000 and follows the technique used to census birds in the southern Coorong in 1984–5 (Paton et al. 2009). Additional behavioural data was added to the census program in 2006. Waterbird use of the Lower Lakes has been assessed annually since 2009. Systematic counts were used to document changes in the distributions and abundances of waterbirds within the different components of the LLCMM to assess various waterbird-related targets (e.g. Paton and Bailey 2012a,b; 2013) listed in the original LLCMM Icon Site Condition Monitoring Plan (Maunsell 2009). These targets and the associated annual monitoring programs were refined and new ecological targets set (e.g. Paton 2014; Robinson 2014a; Paton et al. 2015b). The annual counts of waterbirds within the LLCMM are now placed in context of a wetland system that has been recovering from severe perturbations during the Millennium Drought that resulted in the quality of wetland habitats deteriorating for waterbirds. Therefore, a key focus for the current waterbird condition monitoring is to establish if the waterbird communities have recovered.

The refined condition monitoring involves assessments of waterbird distributions, abundances and behaviour to be conducted annually in January for the Coorong and in January–February for the Lower Lakes (Table 4). For the Coorong, the abundances and distributions of 40 species of waterbirds are used as the basis for assessing the targets, where the abundances of each species should exceed the long-term (2000–2015) median abundance in two out of three years in the future (Table 5). For the Lower Lakes, the abundances and distributions of 25 species of waterbirds are used as the basis for assessing the targets, where the abundances of each species should exceed the recent (2013–2015) median abundance in two out of three years in the future (Table 6). The use of medians, and the requirement to exceed the median in two out of three years, takes into account the inherent variability that exists in waterbird count data and the goal of enhancing waterbird populations across the wetlands. A further index, namely the percent of birds that were foraging when counted during the census, provides a measure of the quality of the habitat or resources for different waterbird species.

Figure 8. Waterbird breeding in the Lower Lakes 2015, photo Adrienne Rumbelow.

Table 3. Linkages between icon site specific ecological objective and ecological targets for waterbirds.

Characteristic	Description
Ecological objective	Maintain or improve waterbird populations in the Lower Lakes, Coorong and Murray Mouth.
Definition of how objective and targets are interpreted	'Maintain' means continuing to meet the long-term threshold ecological targets set for the abundances and distributions of selected species of waterbirds in the Coorong (40 species) and in the Lower Lakes (25 species). A simple index (negative) based on the number of species that failed to meet their threshold ecological targets is used for the Coorong and for the Lower Lakes. Maintain means that the index calculated in a particular year is on or above the 2015 index.
	'Improve' means that the waterbird indices for the Lower Lakes and for the Coorong have exceeded the 2015 indices (Table 5 and Table 6) for these two wetland systems for three consecutive years.
Ecological target(s)	Coorong waterbirds 1. 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. 2. Exceed the 75% threshold for the long-term (2000–2015) area of occupation (AOO) for each of 40 selected waterbird species in the Coorong. 3. Exceed the 75% threshold for the long-term (2000–2015) extent of occurrence (EOO) for each of 40 selected waterbird species in the Coorong. 4. All waterbird species to spend less than 70% of their time foraging. Lower Lakes waterbirds 1. 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. 2. Exceed the lower 75% threshold for the recent (2013–2015) AOO for each of 25 selected waterbird species in the Lower Lakes. 3. Exceed the lower 75% threshold for the recent (2013–2015) EOO for each of 25 selected waterbird species in the Lower Lakes. 4. All waterbird species to spend less than 70% of their time foraging.
CMP monitoring objective	To conduct a systematic census of waterbirds using the Coorong during January and using the Lower Lakes in January–February. These surveys determine if the ecological targets (above) for the distributions, abundances and behaviour of waterbirds are met.
Key use of data	Data informs on the ability of the Coorong and Lower Lakes to maintain and enhance waterbird populations in a particular year or sequence of years. These data also inform management about the species of concern and areas of concern (i.e. sections of the Coorong and Lower Lakes). These data can be related to management of salinity and water levels through effects on food resources and habitat quality. The census data can also be used to assess the on-going Ramsar status of these wetlands.

Table 4. Summary description of sampling strategy and calculation of Index for waterbirds in the Coorong and Lower Lakes.

Characteristic	Description
Sampling strategy	Number of sites: Two wetland systems are assessed – the Coorong and the Lower Lakes.
	Frequency & Timing: Assessments of waterbird distributions, abundances and behaviour are conducted annually in January for the Coorong and in January-February for the Lower Lakes.

Characteristic	Description
	Sub-regions covered: In the Coorong they are the South Lagoon, North Lagoon and Murray estuary, while in the Lower Lakes they are Lake Albert, Lake Alexandrina and the Goolwa Channel.
	Waterbird census of the Coorong In order to census the waterbirds of the Coorong, the system was divided into 1-km sections, running approximately perpendicular to the direction of the wetlands (Figure 9). This sampling strategy was initially established in 1984–5 when the birds using the South Lagoon were first counted and the same sampling strategy was applied to the whole Coorong, when complete counts commenced in 2000, to allow historical comparisons. The Murray Estuary was, therefore, divided into 17×1-km sections running from Pelican Point to Goolwa Barrage, while the North Lagoon of the Coorong was divided into 45×1-km sections running from Parnka Point to Pelican Point. The South Lagoon consisted of 55×1-km sections running from Parnka Point to 42-Mile Crossing; however, the number of sections actually counted in summer in the South Lagoon varies (between 43 and 48) with inter-annual variations in water levels (with the southernmost end being completely exposed in years with low water levels). Figure 9 provides an example of a section of the Coorong divided into the 1-km strips used in mapping the locations of birds counted during a census. Within each 1-km section, counts of waterbirds are conducted both on foot, and by boat. All waterbird observations are made using either binoculars (8–10x magnification), or spotting scopes (×20−60 magnification). Birds are identified to species, counted, and their activity classified to one of four categories (foraging, resting, flying-over or breeding). Scaled maps are used to assign birds to each 1-km section. The eastern shorelines of each section are walked by at least two observers while open water areas in the middle of the Coorong and other areas inaccessible by foot (such as islands) are counted from a boat, again by at least two observers. The western shorelines are either counted on foot or from a small boat, again with at least two observers. All waterbirds detected within each component (e.g. eastern shoreline, western shoreline, centre, islands) of each 1-km section are recorded. This division of the data into 1-km sections allows for assessments of changes in distribution through time, at a fine-scale, and allows AOO and EOO to be determined. Since 2006, the behaviour of all birds counted has been scored to allow an assessment of the quality of the wetland from a waterbird perspective where higher proportions of birds foraging indicate lower quality habitat and resources. Within a census period, between 10 and 20 consecutive 1-km sections are counted per day, depending on the number of birds, their geographical location within each section, as well as other factors such as weather conditions. Some variance occurs in the total duration (7−16 days) of the census. However, the counts always commence at the southern end of the Coorong and systematically work northwards during each census. **Waterbird census of the Lower Lakes** For the census of waterbirds of the Lower Lakes, the shorelines of each lake have been divided into 1 km x 1 km grid cells (based on Transverse Mercator Projection, Map Grid of Australia (MGA94, Zone 54)) and the numbers of birds present in each grid cell are recorded along with their activity (foraging, flying, resting, breeding), allowing the abundance, distribution and behaviour of birds over the Lower Lakes to be determined. Grid cells, however, differ in the amount of shoreline present and also in the extent of shallow water but no adjustment is undertaken to account for differences between grid cells. Within each section, shoreline counts of waterbirds are conducted either by foot, from a small boat, or both, depending on the extent of backwaters and ease of access with a boat to the shoreline. Usually two or three observers work collaboratively to cover each grid cell. The time

Characteristic	Description
	spent surveying each 1 km × 1 km grid varies depending on the length of shoreline and extent of aquatic habitat and the ease with which the cell can be covered. The time spent in each cell is set as the time required to cover all aquatic habitat and count all of the birds within the cell. During the counts, the location of observers is continuously verified using hand-held GPS units. A complete census of the waterbirds of the Lower Lakes takes 8-10 days with suitable weather and is usually spread out over a period of 20–25 days. Typically 50–80 1 km^2 grid cells are counted on any one day. Counts usually commence in mid-January (after the Coorong has been counted) and are completed by mid-February.
	Data collected by trained field ecologists led by David Paton, The University of Adelaide.
Index/Indices	Four parameters are used to assess the condition of waterbird populations in the Coorong and Lower Lakes: abundance, distribution (both AOO and EOO) and behaviour (% foraging). The key requirement is for selected species to exceed baseline conditions (Table 5 and Table 6). Thus for each of the two wetland systems, the abundances of selected waterbird species must exceed median values for two out of the last three years, their area AOO and their EOO must exceed 75% of the average AOO and EOO, and fewer than 70% of the birds counted should be foraging.
Calculation of index	The baseline values and hence targets for condition monitoring of waterbirds in the Coorong are based on annual January counts of waterbirds in the whole Coorong from 2000 to 2015 inclusive. Many of the waterbirds use the Coorong as a summer and drought refuge. Thus the numbers of waterbirds present in the Coorong in any one year can be influenced by conditions in other wetlands that could be used at other times of the year, and not necessarily reflect conditions in the Coorong. The numbers present in January can fluctuate greatly from one year to the next, and mean abundances of many species have high variance. The median is therefore a better measure of typical numbers and is used as the benchmark value. The requirement that abundances should exceed the median value in two of the last three years is consistent with the goal of not just maintaining but enhancing waterbird populations across the Coorong and Lower Lakes, and therefore appropriate, particularly given that numbers of waterbirds using the Coorong has declined historically. For the Lower Lakes, systematic counts of waterbirds did not commence until 2009 and the first two years of Lakes' censuses coincided with a period when the Lakes were at unprecedented low water levels and the waterbird community was atypical, as many of the reed dependent species were excluded. For the next two years (2011, 2012) the waterbird populations recovered and since then have been reasonably consistent and typical of the water community likely to have occupied the wetlands of the Lakes prior to the millennium drought. Thus, the census data collected in each of the last three Januaries (2013–2015) has been used to compile Table 6. Although the Coorong was also challenged ecologically during the same period, suitable habitats for birds were still available and the wetlands were still being used extensively by waterbirds. Importantly for the Coorong, the same perturbations that took place during the millennium drought could recur. Thus, for the Coorong, the 2000–2015 period is not likely to be atypical of future conditions. For the Lower Lakes, the intent of the Murray Darling Basin Plan is to prevent the unprecedented conditions from recurring. The AOO and EOO data for most species are surprisingly consistent from one year to the next for both the Coorong and Lower Lakes, which makes both of them sensitive to detecting change. For example, for some species like the Australian Pelican, which has a 95% confidence interval for EOO along the Coorong of 98−102 km, a small change in EOO of just a few kilometres along the Coorong can be significant statistically. However, such a small change, irrespective of it being statistically significant, is unlikely to be of ecological significance in a system that is over 100 km in length. However, not all species are as consistently distributed across these wetlands. If AOO and EOO are to be used as indicators, then a level of change

Characteristic	Description
	needs to be specified. A 25% reduction in AOO and, similarly, a 25% reduction in EOO are substantial and likely to be ecologically significant and are used to set targets where the distribution of species must be at least 75% of the average AOO and average EOO. An important aspect of using variables like AOO and EOO for reporting on condition is that they are also capable of showing change that is potentially independent of abundance. Furthermore, highlighting the actual locations (cells) that have been vacated will help inform management. The amount of time a waterbird allocates to foraging reflects the ease with which that species can harvest food. The more time that is allocated to foraging, the poorer the quality of the habitat. With the exception of some fish-eating species, waterbirds do not breed in January and February in the Coorong and Lower Lakes, and so most are just foraging to secure the food they need to survive. The selection of 70% as a benchmark maximum for foraging is arbitrary. However, with the onset of shorter days in February and March, species that allocate 70% of their daylight hours to foraging in January will need to allocate a higher proportion of their daylight hours to foraging in February and March, even if food resources have not declined.
	Abundances for each wetland system are determined by adding the counts for each 1-km strip (Coorong) and for each 1 km^2 cell (Lakes). For calculations of AOO and EOO, all birds that were flying when detected were excluded as these birds may not be using the particular section or cell. Calculating the AOO for the Coorong consists of dividing each 1-km section into three subsections (eastern shore, centre and western shore) and reporting on the number of subsections where a particular species was resting or foraging, while the EOO was calculated as the number of 1-km sections between the most northerly and most southerly presence of the species. For the Lower Lakes, the AOO represents the number of 1 km^2 cells in which the species was detected either resting or foraging, while the EOO was calculated using an ARC GIS tool for the minimum convex polygon that included all non-flying presences of a species. The percent of birds foraging is the sum of all birds that were foraging when counted divided by the total number of birds counted.
	The counts of waterbirds in the Coorong in January, and the Lower Lakes in January/February, provide four statistics for each species: abundance, distribution (both AOO and EOO), and behaviour (% birds foraging). The overall abundance, AOO, EOO and percent of birds foraging should be reported for each species, separately for the two wetland systems (Coorong, Lower Lakes) and compared to the baseline conditions. Species that fail to meet their targets should be highlighted and general explanations provided for likely reasons of failure to meet targets.
Calculation of whole of icon site score for parameter	A simple scoring system is used to provide a whole of icon site score for waterbirds (all assessed species combined) for each of the two wetland systems separately. This consists of assigning a score of −1 if the abundances for a species over the last three years fall below the baseline median value for two of the three years and −2 if the abundances fall below the baseline median in all three years. An additional −1 is added to the score for any species where the AOO in the current year falls below 75% of the baseline average AOO and a further −1 for any species where the EOO in the current year falls below 75% of the baseline average EOO.
Power/Effect size	The sampling method involves a complete census of waterbirds within the wetlands. The numbers of different species can vary substantially between years and so abundance as such has low power, but this is not an issue since a complete census is conducted. AOO and EOO for many species vary little between years and so changes of less than 10% are often statistically significant. However, such differences may have little ecological relevance and changes of greater than 25% are used to indicate significant changes in AOO and EOO.

Table 5. Median abundances, area of occupation (AOO) and extent of occurrence (EOO) for 40 waterbird species in the Coorong. Medians were calculated for 16 years of data (2000–2015) collected in January and excluding birds counted in the creek at Salt Creek. The abundance data include birds scored as flying. Data for AOO and EOO do not include birds that were flying over when counted, as these may not have been using the actual area in which they were seen. The AOO was based on dividing the 1-km strips that were used for the bird census into three parts (eastern, centre, western) for 110 km of the Coorong. Data for EOO is expressed as the length (km) of the Coorong between the most northerly and most southerly records in each year. The lower value of the 95% confidence interval (CI) and the 75% value for AOO and EOO are given. The target median abundance, AOO and EOO are shaded.

Waterbird species	Median abundance	Area of Occupation (km^2)			Extent of Occurrence (km^2)		
		Mean ±s.e.	Lower 95% CI	75% AOO	Mean ±s.e.	Lower 95% CI	75% EOO
Australian Pelican	3410	134 ±10	113	101	100 ±1.0	98	75
Australian Shelduck	8426	128 ±4	120	96	98 ±1.6	95	74
Australian White Ibis	300	29 ±3	23	22	36 ±3.6	29	27
Black-faced Cormorant	130	6 ±1	4	5	56 ±9.4	38	42
Banded Stilt	15092	61 ±11	40	46	86 ±4.8	76	65
Black Swan	1633	61 ±5	51	46	96 ±4.2	87	72
Black-winged Stilt	417	41 ±4	33	31	82 ±3.1	76	62
Caspian Tern	598	69 ±7	55	52	84 ±4.3	75	63
Cape Barren Goose	97	7 ±1	6	5	22 ±4.7	13	17
Chestnut Teal	7216	109 ±6	96	82	97 ±1.0	95	73
Eurasian Coot	62	7 ±3	2	5	19 ±7.2	5	14
Crested Tern	3897	66 ±8	50	50	93 ±1.6	90	70
Curlew Sandpiper	2252	35 ±5	26	26	82 ±5.3	72	62
Eastern Curlew	13	4 ±1	3	3	8 ±2.2	3	6
Fairy Tern	337	35 ±5	25	26	76 ±5.5	66	57
Common Greenshank	430	88 ±4	80	66	100 ±0.6	99	75
Great Crested Grebe	199	35 ±5	25	34	71 ±8.4	54	53
Great Cormorant	1287	41 ±3	34	31	62 ±6.3	50	47
Great Egret	36	26 ±7	12	20	53 ±8.6	36	40
Grey Teal	11846	124 ±13	99	93	101 ±1.2	98	76
Hoary-headed Grebe	4218	67 ±10	48	50	94 ±6.3	82	71
Hooded Plover	8	6 ±1	4	5	51 ±8.1	35	38
Little Black Cormorant	1253	34 ±6	22	26	66 ±7.5	51	50
Little Egret	8	6 ±1	4	5	52 ±7.2	38	39
Little Pied Cormorant	258	35 ±4	27	26	52 ±5.7	41	39
Musk Duck	171	18 ±2	14	14	82 ±4.7	73	62
Masked Lapwing	466	97 ±3	91	73	103 ±0.5	102	77
Pacific Black Duck	223	19 ±2	14	14	63 ±7.2	49	47
Pied Cormorant	271	45 ±5	35	34	66 ±6.1	54	50
Pacific Golden Plover	36	4 ±1	3	3	24 ±4.4	15	18
Pied Oystercatcher	158	41 ±3	35	31	92 ±1.4	89	69
Red-capped Plover	1234	77 ±5	68	58	99 ±2.4	94	74
Red-necked Avocet	3007	66 ±10	46	50	85 ±6.5	72	64
Red-necked Stint	26285	118 ±11	97	89	103 ±0.7	101	77
Royal Spoonbill	22	7 ±1	4	5	33 ±5.3	22	25
Silver Gull	8274	201 ±6	189	151	104 ±0.5	103	78

Waterbird species	Median abundance	Area of Occupation (km^2)			Extent of Occurrence (km^2)		
		Mean ±s.e.	Lower 95% CI	75% AOO	Mean ±s.e.	Lower 95% CI	75% EOO
Straw-necked Ibis	25	3 ±1	2	2	21 ±3.9	13	16
Sharp-tailed Sandpiper	13179	121 ±11	99	91	95 ±2.8	89	71
White-faced Heron	156	61 ±5	50	46	100 ±1.1	98	75
Whiskered Tern	5360	160 ±14	133	120	97 ±4.3	89	73

Table 6. Median abundance, area of occupation (AOO) and extent of occurrence (EOO) are given for 25 species of waterbirds using the Lower Lakes in January over the three years from 2013–2015. Area of occupation is given as an actual area (# 1 km^2 cells in which the bird was counted). Extent of occurrence is calculated as the area that contains the minimum convex polygon that includes all locations (cells) where the species was seen. Note that birds that were flying when encountered in a cell were excluded from calculations of AOO and EOO as these birds may not have been using that particular cell. The lower value of the 95% confidence interval (CI) and the 75% value for AOO and EOO are given. The target median abundance, AOO and EOO are shaded.

Waterbird species	Median abundance	Area of Occupation ($km^{2)}$			Extent of Occurrence (km^2)		
		Mean ±s.e.	Lower 95% CI	75% AOO	Mean ±s.e.	Lower 95% CI	75% EOO
Australian Pelican	5901	305 ±8	290	229	1729 ±8	1714	1297
Australian Shelduck	12704	183 ±4	175	137	1582 ±50	1484	1187
Australian White Ibis	568	107 ±6	95	80	1660 ±10	1640	1245
Black Swan	1786	200 ±7	186	150	1652 ±39	1575	1239
Caspian Tern	535	110 ±8	95	83	1508 ±18	1472	1131
Cape Barren Goose	974	36 ±5	27	27	1041 ±11	1019	781
Eurasian Coot	3339	152 ±41	72	114	1644 ±39	1569	1233
Crested Tern	418	92 ±17	59	69	1428 ±77	1277	1071
Darter	67	29 ±9	12	22	857 ±267	334	643
Great Crested Grebe	128	39 ±18	3	29	978 ±227	533	734
Great Cormorant	12509	304 ±18	270	228	1714 ±13	1688	1286
Great Egret	110	98 ±46	8	74	1281 ±339	616	961
Grey Teal	3782	89 ±30	29	67	1577 ±92	1396	1183
Hoary-headed Grebe	801	30 ±12	6	23	987 ±22	159	740
Little Black Cormorant	784	83 ±34	17	62	1456 ±140	1181	1092
Little Pied Cormorant	74	42 ±12	19	32	1384 ±116	1157	1038
Masked Lapwing	555	74 ±4	67	56	1560 ±42	1478	1170
Pacific Black Duck	4892	216 ±12	193	162	1700 ±16	1669	1275
Pied Cormorant	8390	228 ±17	194	171	1538 ±75	1390	1154
Purple Swamphen	461	111 ±8	95	83	1555 ±62	1434	1166
Royal Spoonbill	200	29 ±5	19	22	1338 ±35	1270	1004
Silver Gull	1650	99 ±15	69	74	1511 ±15	1481	1133
Straw-necked Ibis	1214	36 ±9	19	27	1322 ±154	1021	992
White-faced Heron	108	64 ±3	58	48	1595 ±8	1579	1196
Whiskered Tern	4086	357 ±27	303	268	1722 ±15	1693	1292

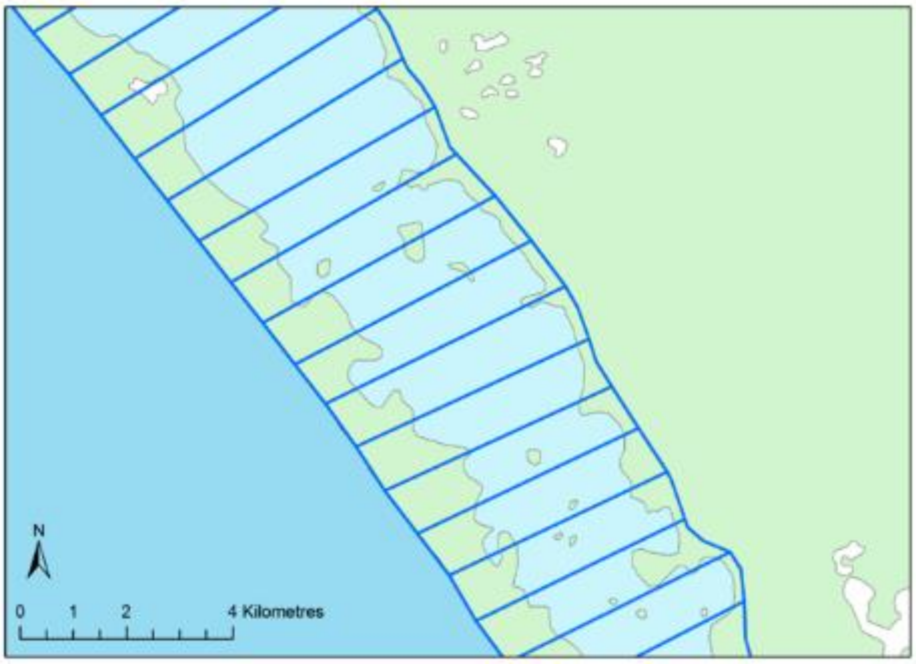

Figure 9. An example of a section of the Coorong showing the 1-km strips used to map the locations of waterbirds during a census.

Figure 10. Waterbirds at the Lower Lakes, photo Adrienne Rumbelow.

4.2. Fish

4.2.1. Diadromous fish (Chris Bice and Brenton Zampatti)

Preferred citation for the Diadromous fish chapter:

Bice C, Zampatti B (2017). Diadromous fish. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 26-32.

Refined objective: Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong (F-1).

Original: Maintain or improve recruitment success of diadromous fish in the Lower Lakes and Coorong (F-1).

This monitoring and reporting component collects data on the abundances of diadromous fishes migrating upstream at the Murray Barrages. Diadromous fishes require migration between marine, estuarine and fresh waters to complete their lifecycles, so population dynamics are fundamentally driven by connectivity between these environments during vital migratory periods and the advent of conditions that stimulate these migrations. In the Lower Lakes and Coorong, four species of diadromous fish have been commonly encountered over the past decade, representing two contrasting forms of diadromy: catadromy and anadromy. Congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*) are catadromous, a life history characterised by adult freshwater residence, downstream adult migrations for spawning in the estuarine (common galaxias) or marine environment (congolli), marine larval development and corresponding upstream migrations of juveniles into freshwater habitats. Pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) are the only anadromous fish species native to the Murray-Darling Basin. Their life-history is characterised by a parasitic marine adult life-stage, followed by large-scale upstream spawning migrations into freshwater habitats, freshwater larval/juvenile development and corresponding downstream migration to adult habitats (McDowall 1996).

There are nine existing fishways on the Murray Barrages, with a further two planned for completion in 2017, which effectively facilitate the upstream migrations of juvenile catadromous fishes and adult anadromous lampreys. The condition of diadromous fish populations is intrinsically linked with river flow, water level and barrage operation. For catadromous fishes, obstruction of downstream spawning migrations, during winter, over the period 2007–2010, led to subsequent declines in the abundance of upstream migrating juveniles, and failure to meet ecological targets. Furthermore, lamprey were not detected over this period, likely as a result of a lack of migratory cues (i.e. freshwater flow) in the Coorong and the nearshore marine environment. Nonetheless, 2015 represented the fifth consecutive year of freshwater discharge to the Coorong following the end of the Millennium Drought (2010-11); consecutive and substantial increases in the abundance of upstream migrants of catadromous species have been recorded, whilst upstream migrating pouched lamprey have been detected during winter in several years (2011, 2013 and 2015). The delivery of freshwater to the Coorong and provision of connectivity during key migratory periods is fundamental in determining site condition in regards to these diadromous species.

Monitoring of diadromous fish began in 2006 and has occurred annually since, except there was no sampling in 2012–13. The temporal extent of spring–summer sampling has varied across years, from seven months in 2006–07 (September–March) to three months in 2009–10 (November–January), but has otherwise occurred over ≥4 months (October–January). Several sites have been monitored since 2006–07, including the Tauwitchere vertical-slot, Tauwitchere rock ramp and Goolwa vertical-slot. Sampling locations have been added throughout the course of the project, including the site immediately downstream of the Goolwa Barrage (added in 2008–09), and the sites at Tauwitchere small vertical-slot and Hunters Creek vertical-slot added in 2010–11 (Table 8).

In the refined condition monitoring, the index values for congolli and common galaxias are derived from a combination of relative abundance and length data, where an annual recruitment value is derived each year (Table 9). This provides a measure of the overall abundance of upstream migrating young-of-the-year fish at the site and is compared against the reference values to determine condition (see Table 7). The recruitment values for congolli and common galaxias in 2014–15 were far greater than reference values. This indicates substantially enhanced recruitment in 2014–15, but also raises the question of whether the initial reference values calculated in the Condition Monitoring Refinement Project (Robinson 2014a) were disproportionately low, and perhaps not appropriate for accurately assessing condition. Nonetheless, the reference values were calculated from all available data, and future assessment and revision of reference values, potentially including incorporation of more recent data, is suggested to ensure appropriateness. An anadromous migration index is derived for pouched lamprey and short-headed lamprey (Table 10). The index values for pouched lamprey and short-headed lamprey are derived from data of spatial migratory extent rather than abundance, due to their rareness and the patchiness of data. Data from 2006–07 is used as a baseline for short-headed lamprey and data from 2011–12 for pouched lamprey. The indices are very sensitive, reflecting that the key migratory seasons for these species have been sporadically sampled from 2006–2015. Importantly, these indices appear appropriate when supported by monitoring that is timed to coincide with the key upstream migration period of anadromous fishes (June–August).

Figure 11. Barrage fishway monitoring, congolli (*Pseudaphritis urvillii*).

Table 7. Linkages between icon site specific ecological objective and ecological targets for diadromous fish

Characteristic	Description
Ecological objective	Promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong.
Definition of how objective and targets are interpreted	'Successful migration' is defined as passage through key migratory paths (e.g. the Murray Mouth) and barriers (i.e. the Murray Barrages), such that fish are able to complete obligate movements between marine, estuarine and freshwater environments, as specifically required by individual species.
	'Successful recruitment' is defined as upstream migrating young-of-the-year (YOY) of catadromous fishes (i.e. <60 mm total length), being present in abundances within the confidence intervals of/or greater than long-term averages. It is perceived that once individuals reach this life stage, chances of survival are high and high abundance of this life stage should correspond with maintenance of/or increased total population abundance.
Ecological target(s)	1. The annual abundance of upstream migrating YOY congolli (*Pseudaphritis urvillii*) is ≥ the lower confidence bound of the recruitment reference value (i.e. lower bound 22.67 YOY/hr). 2. The annual abundance of upstream migrating YOY common galaxias (*Galaxias maculatus*) is ≥ the lower confidence bound of the recruitment reference value (i.e. lower bound 3.00 YOY/hr). 3. Pouched lamprey (*Geotria australis*) and short-headed lamprey (*Mordacia mordax*) are sampled from ≥60% of vertical-slot fishway sites sampled in any given year.
CMP monitoring objective	To collect data on the abundance of YOY congolli and common galaxias, and adult pouched lamprey and short-headed lamprey, migrating upstream at the Murray Barrages.
Key use of data	Provides information on the overall abundance and recruitment of diadromous fish to determine condition of population, which informs environmental water planning, environmental water delivery and timing, and the location of barrage releases.

Table 8. Details of sampling sites at the Murray Barrages in 2014-15.

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

Table 9. Summary description of sampling strategy and calculation of Index for catadromous fish species

<table>
<tr><th>Characteristic</th><th>Description</th></tr>
<tr><td rowspan="5">Sampling strategy</td><td>Number of sites: 4–6 sites sampled annually, including fishways on Tauwitchere and Goolwa barrages, sites adjacent to these barrages, and the Hunters Creek fishway.</td></tr>
<tr><td>Frequency & Timing: Sampling conducted monthly over spring/summer, at a minimum from October to January (n = 4 trips).</td></tr>
<tr><td>Sub-regions covered: Murray estuary and Lower Lakes.</td></tr>
<tr><td>Method: vertical-slot fishways are sampled with specifically designed aluminium cage traps, and sites adjacent to Tauwitchere and Goolwa Barrage are sampled with specifically designed large fyke-nets. Sites are sampled overnight (17–24 hours) 1–3 times per sampling week, typically monthly from October–January.</td></tr>
<tr><td>Data collected by SARDI Aquatic Sciences.</td></tr>
<tr><td>Index/Indices</td><td>Catadromous annual recruitment index (RI_{cat}) for congolli and common galaxias: Index involves the calculation of overall site abundance of upstream migrating YOY (i.e. fish/hour). Annual RI_{cat} is compared against a reference value, with associated half confidence intervals, to determine condition.</td></tr>
<tr><td>Calculation of index</td><td>Data for congolli and common galaxias from years 2006/07, 2010/11, 2011/12 and 2013/14 were used to calculate the reference values. Within the context of the project, these years represent periods of connectivity and freshwater flow, and thus, are appropriate years from which to derive a reference.

The reference values were calculated incorporating overall species abundance and recruitment. Based upon expert opinion, the proportion of both species populations comprised of YOY, during spring–summer, should be >70% in any given year.

Calculation of the reference values is achieved with the equations below where S = site, X = abundance (fish/hour), 0.7 = recruitment component (proportion of YOY), RV = reference value. Note that data used for congolli reference value were derived from November–January and for common galaxias from October–December. These represent the peak upstream migration periods for these species.

Congolli

RV_{yearly} = mean (S_1(mean((0.7*X_{Nov})+(0.7*X_{Dec})+(0.7*X_{Jan})) + (S_2(mean((0.7*X_{Nov})+(0.7*X_{Dec})+(0.7*X_{Jan})).....S_n)

This calculation was carried out for each of 2006/07, 2010/11, 2011/12 and 2013/14 before calculating the final reference value as follows:

RV_{final} = mean ($RV_{2006/07}$ + $RV_{2010/11}$ + $RV_{2011/12}$ + $RV_{2013/14}$) ±half confidence interval

RV_{final} = 44.46 ±21.78 YOY/hr

Common galaxias

RV_{yearly} = mean (S_1(mean((0.7*X_{Oct})+(0.7*X_{Nov})+(0.7*X_{Dec})) + (S_2(mean((0.7*X_{Oct})+(0.7*X_{Nov})+(0.7*X_{Dec})).....S_n)

This calculation was carried out for each of 2006/07, 2010/11, 2011/12 and 2013/14 before calculating the final reference value as follows:

RV_{final} = mean ($RV_{2006/07}$ + $RV_{2010/11}$ + $RV_{2011/12}$ + $RV_{2013/14}$) ±half confidence interval

RV_{final} = 6.12 ±3.00 YOY/hr

NOTE: Reference values for both species could be revised periodically following collection of further data.</td></tr>
</table>

Characteristic	Description
	For each year of sampling, an annual recruitment value (RI_{cat}) is derived using the equations below, where S = site, X = abundance (fish/hour) and r = the proportion of the sampled population comprised of YOY (i.e. <60 mm in length). This provides a measure of the overall abundance of upstream migrating YOY at the site and is compared against the reference values stated above to determine condition. Half confidence intervals ('tolerance') are used for both the reference value and $RI_{cat.}$ Congolli $RI_{cat} = (S_1(mean((r*X_{Nov})+(r*X_{Dec})+(r*X_{Jan})) + (S_2(mean((r*X_{Nov})+(r*X_{Dec})+(r*X_{Jan})).....S_n)$ Common galaxias $RI_{cat} = (S_1(mean((r*X_{Oct})+(r*X_{Nov})+(r*X_{Dec})) + (S_2(mean((r*X_{Oct})+(r*X_{Nov})+(r*X_{Dec})).....S_n)$
	Data are best presented on a scatter plot of RI_{cat} against year, with reference values and half confidence levels overlaid.
Calculation of whole of icon site score for parameter	The current approach involves calculation of a whole of icon site score. This assumes adequate sampling of migratory population, given migratory pathways between the Coorong and Lower Lakes (e.g. fishways) are sampled.
Power/Effect size	The indices have been trialed and are sensitive to change in condition. Indices have not been statistically assessed for power, but half confidence intervals (tolerance), rather than standard error, has been adopted for reference values and annual RI_{cat}. Overall, these indices appear sensitive, particularly to changes in recruitment rates (i.e. proportion of migratory population comprised of YOY), and respond to changes in icon site condition.

Table 10. Summary description of sampling strategy and calculation of Index for anadromous fish species

Characteristic	Description
Sampling strategy	Number of sites: 4–6 sites sampled annually, including fishways on Tauwitchere and Goolwa, sites adjacent to these barrages, and the Hunters Creek fishway.
	Frequency & Timing: Targeted winter sampling for lamprey has been conducted during 2011, 2013 and 2015. It is suggested this be prioritised in future to allow determination of condition regarding anadromous species. In all other years sampling has solely been conducted monthly over spring–summer, at a minimum from October–January (n = 4 trips). Nonetheless, this is not ideal timing for sampling anadromous fishes, with this sampling more tailored towards catadromous fish targets.
	Sub-regions covered: Murray estuary and Lower Lakes.
	Method: vertical-slot fishways are sampled with specifically designed aluminium cage traps and sites adjacent to Tauwitchere and Goolwa Barrage sampled with specifically designed large fyke-nets. Sites are sampled overnight (17–24 hours) 1–3 times per sampling week, typically monthly from October–January. Nonetheless, future monitoring should be prioritised to winter (June–August).
	Data collected by SARDI Aquatic Sciences.
Index/Indices	Anadromous migration index (AMI_{anad}) for short-headed and pouched lamprey: Indices represent the proportion of sites sampled from which lamprey species were detected on an annual basis. This is compared against the proportion of sites these species were detected in a chosen reference year (i.e. short-headed lamprey in 2006/07 and pouched lamprey in 2011-12). These reference years were chosen because they represent years when the migratory period of these species was best covered by sampling.

Characteristic	Description
Calculation of index	Due to the patchy nature of existing data, in regards to timing of sampling in relation to anadromous species migration periods, and the low number of individuals sampled since 2006, the indices (and references) do not incorporate abundance. Rather, they focus on detection of these species across sites on the Murray Barrages, and thus, could be view as a measure of the 'presence' of migration and the spatial extent of this migration at the barrages. The reference years of 2006-07 for short-headed lamprey and 2011-12 for pouched lamprey were chosen as they represent years when the migratory period of these species was best covered by sampling. The reference values for each species is the proportion of sites sampled under TLM monitoring from which each species was detected in their respective reference years. Short-headed lamprey Reference value = 100% of sites Pouched lamprey Reference value = 80% of sites
	For each sampling year, an annual anadromous migration index (RI_{cat}) is derived using the equations below, where GVS = Goolwa vertical-slot, GDS = site immediately downstream Goolwa Barrage, TVS = Tauwitchere vertical-slot, TRR = Tauwitchere rock ramp and TSVS = Tauwitchere small vertical-slot: Short-headed lamprey $\text{AMIanad (year)} = \frac{Proportion\ sites\ where\ detected\ (of\ GVS, GDS, TVS, TRR\ and\ TSVS)}{Proportion\ sites\ where\ detected\ 2006/07}$ Pouched lamprey $\text{AMIanad (year)} = \frac{Proportion\ sites\ where\ detected\ (of\ GVS, GDS, TVS, TRR\ and\ TSVS)}{Proportion\ sites\ where\ detected\ 2011/12}$ Provides an AMI_{anad} value of ≤1.0. There is no error around this value so an arbitrary tolerance of 0.4 is applied (i.e. an AMI_{anad} value of ≥0.6 is taken to suggest target has been met). These indices are calculated from all monitoring undertaken in any given year. That is a combination of typical spring–summer (October–January) monitoring and targeted winter monitoring for anadromous fishes (occurred in 2011, 2013 and 2015). This should be revised in future to only include monitoring data drawn from key migration periods for these species, should monitoring of these periods be consistently undertaken in the future.
	Data are best presented on a scatter plot of AMI_{anad} against year, with reference values and tolerance levels overlaid.
Calculation of whole of icon site score for parameter	The current approach involves calculation of a whole of icon site score. This assumes appropriate spatial (number of fishways) and temporal (timing and number of sampling events) sampling of migratory populations, given migratory pathways between the Coorong and Lower Lakes (e.g. fishways) are sampled.
Power/Effect size	AMI_{anad} is sensitive to change in migration extent and detection and thus, in the absence of robust abundance data, are likely to respond to changes in Icon Site condition. No power analysis is documented due to high variability and sparse data. Whilst these indices appear to perform 'okay', in years where no winter monitoring is conducted AMI_{anad} may be artificially reduced as an artefact of sampling. As such, caution must be exercised when interpreting these indices and their robustness would be greatly improved with implementation of regular winter monitoring.

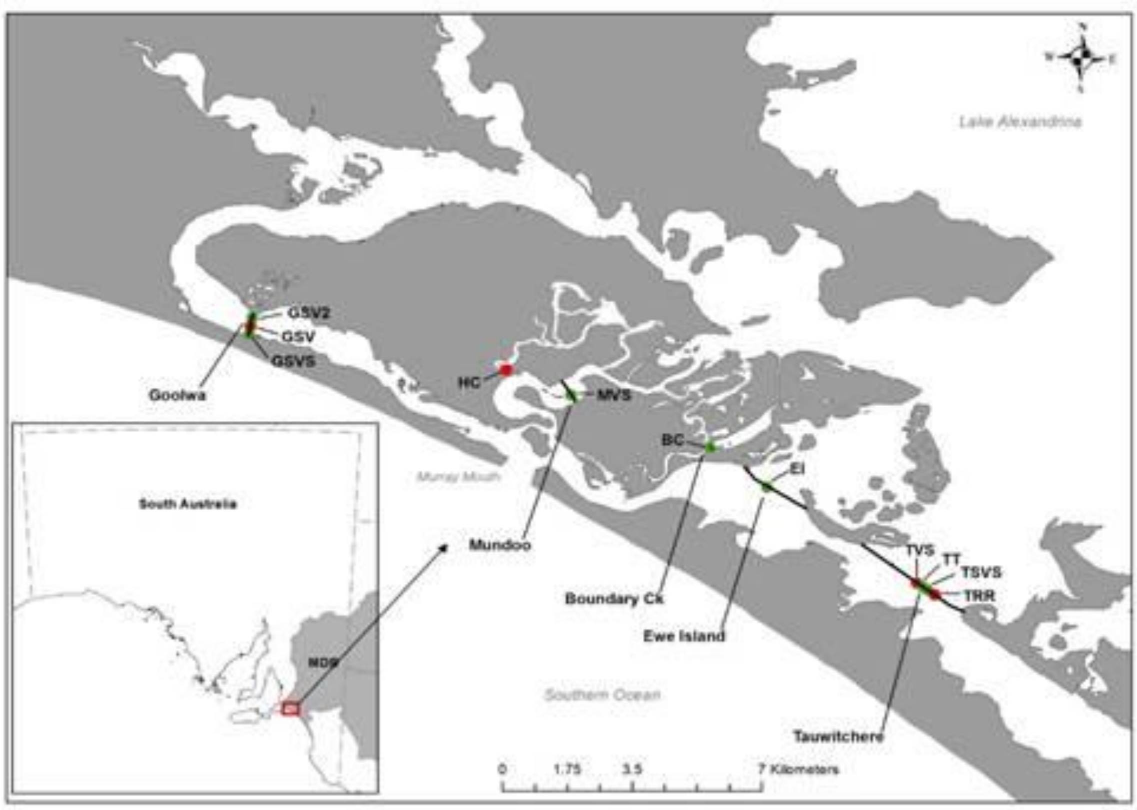

Figure 12. A map of the Coorong and Lake Alexandrina at the terminus of the River Murray, southern Australia with the Murray Barrages presented as bold lines. The positioning of fishways constructed under the CLLMM Program are presented in green circles, namely: Goolwa large vertical-slot 2 (GVS2, constructed 2015), Goolwa small vertical-slot (GSVS, to be constructed in 2016), Mundoo dual vertical-slot (MVS, constructed 2016), Boundary Creek vertical-slot (BVS, constructed 2015), Ewe Island dual vertical-slot (EVS, constructed 2015) and Tauwitchere trapezoidal (TT, to be constructed 2016, subject to funding). The positioning of pre-existing fishways are indicated by red circles, namely: Goolwa large vertical-slot (GVS), Hunters Creek vertical-slot (Hunters), Tauwitchere vertical-slot (TVS), Tauwitchere small vertical-slot (TSVS) and Tauwitchere rock ramp (TRR).

Figure 13. Crane pulling out a fish trap on the barrages, August 2016.

4.2.2. Lower Lakes threatened fish (Scotte Wedderburn)

Preferred citation for the Lower Lakes threatened fish chapter:

Wedderburn S (2017). Lower Lakes threatened fish. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 33-38.

Refined objective: Ensure recruitment success of threatened fishes in the Lower Lakes to maintain or establish self-sustaining populations (F-2).

Original: Maintain or improve recruitment success of endangered fish species in the Lower Lakes (F-2).

This monitoring and reporting component assesses the status of three threatened fish populations in the Lower Lakes (Table 11), namely Murray hardyhead (*Craterocephalus fluviatilis*), Yarra pygmy perch (*Nannoperca obscur*a) and southern pygmy perch (*Nannoperca australis*). The genetically distinct population of Yarra pygmy perch occurs nowhere else in the Murray–Darling Basin (Hammer et al. 2010). The species was extirpated from Lake Alexandrina during the Millennium Drought. Yarra pygmy perch is 'Vulnerable' under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (Cth) and 'Critically Endangered' in South Australia (Hammer et al. 2009). Southern pygmy perch is 'Endangered' in South Australia (Hammer et al. 2009). Importantly, the southern pygmy perch population in Lake Alexandrina is genetically unique from other populations in Australia (Unmack et al. 2013). The species was extirpated from the lake during the Millennium Drought (Wedderburn et al. 2014). Murray hardyhead is endemic to the Murray–Darling Basin, and the Lower Lakes population is genetically more diverse and distinct from populations upstream of Lock 1 (Adams et al. 2011). Murray hardyhead is 'Critically Endangered' in South Australia (Hammer et al. 2009) and 'Endangered' under the EPBC Act.

In the 2008 to 2015 condition monitoring there were inadequate samples in existing data for statistically valid targets around the young-of-the-year index. To establish a statistically applicable young-of-the-year index at an icon site level, a targeted sampling approach is required so each threatened fish species is detected at more sites and more individuals are captured at each site (see below regarding repeated samples). The target of >50% recruitment (i.e. over half the population are young-of-the-year in March) for Murray hardyhead is based on its biology (Table 12). Specifically, the species lives only for one year so annual recruitment is essential to achieve a self-sustaining population. A target of >30% recruitment for each pygmy perch species also is based on this principle, where they live for up to four years (Table 13). These targets would provide a reasonable level of certainty that an adequate level of recruitment has occurred to sustain the populations in the icon site.

The refined condition monitoring methods give a more accurate overall assessment of each population by producing a whole of icon site score for each species (Robinson 2014b; Wedderburn 2014). The point of reference used to assess the condition of a threatened fish population is data collected in 2003 when healthy native fish populations inhabited waterbodies fringing the Lower Lakes. The data was collected before the Millennium Drought impacted on habitats and fish populations, so the point of reference represents target conditions. The point of reference data can be used in a simple formula with current monitoring data to measure the condition of each threatened fish population (relative abundance index). The value of relative abundance is then combined with a measure of the level of recruitment (young-of-the-year index) to provide a whole of icon site score for each threatened fish species. The score fails to describe the extent of the threatened fish population throughout the Lower Lakes, so this would need to be reported separately. Estimation of occupancy, defined as the proportion of sites occupied by a threatened fish species, is based on data from repeated samples at each site (Table 14). The repeated sampling approach is necessary because detection of rare species generally is imperfect, which can lead to the incorrect classification of occupied sites as empty (Guillera-Arroita et al. 2010). If imperfect detection is not accounted for, bias is induced in the estimate of occupancy. Repeated sampling, targeting the threatened fishes, will be conducted in March when young-of-the-year fish are easier to detect. The repeated sampling approach also will improve the reliability and reduce the variation of the young-of-the-year index values at the icon site level because of the increase in sampling effort in the same month. Overall, therefore, the confidence intervals for the whole of icon site score would be minimised to provide the most accurate measure of population condition.

Figure 14. NRA Aboriginal Working on Country team assisting with Lower Lakes threatened fish monitoring, photo Scotte Wedderburn.

Table 11. Linkages between icon site specific ecological objective and ecological targets for threatened fish in the Lower Lakes

Characteristic	Description
Ecological objective	Ensure recruitment success of threatened fishes in the Lower Lakes to maintain or establish self-sustaining populations.
Definition of how objective and targets are interpreted	'Relative abundance' is defined as the proportion of sites at which a threatened fish species is recorded in relation to the proportion of sites it was recorded in the 2003 point of reference. The condition of a threatened fish population is improving if relative abundance increases over time.
	'Young-of-the-year' (YOY) is defined as fish in their first year of life, and total length is recorded as a surrogate measure of age. The recruitment success of a threatened fish population is defined by a target proportion of YOY in the total catch.
	In March, when sampling is undertaken, YOY Murray hardyhead and pygmy perches are defined as <50 mm and <40 mm total length, respectively.
	'Self-sustaining populations' of this small-bodied, short-lived species are defined as abundant and broadly distributed populations with annual recruitment success.
Ecological target(s)	Murray hardyhead 1. Relative abundance index >0.7 for Icon Site. 2. Young-of-the-year index >0.5 for Icon Site. 3. Maintain point of reference extent of occupancy which includes Lake Albert.
	Pygmy perches 1. Relative abundance index >0.7 for Icon Site. 2. Young-of-the-year index >0.3 for Icon Site. 3. Maintain or establish point of reference extent of occupancy which includes wetlands on Hindmarsh Island and Mundoo Island, and in the Finniss River–Goolwa Channel region.
CMP monitoring objective	Assess the status of threatened fish populations in the Lower Lakes.
Key use of data	Index values and the whole of icon site score give the status of each threatened fish species in March, which can be related to habitat conditions during the spring to autumn breeding and recruitment period. Water levels in fringing wetlands change in relation to Lower Lakes water levels, which influences biotic (e.g. water plants; zooplankton prey; alien fish abundances and interactions) and abiotic (e.g. salinity) components of threatened fish habitats.

Table 12. **Summary description of sampling strategy and calculation of Indices for Murray hardyhead**

Characteristic	Description
Sampling strategy	Number of sites: Sample at 20 sites (all sites listed in Table 14).
	Frequency & Timing: Sample sites twice in March (repeated samples approach).
	Sub-regions covered: Lake Alexandrina, Lake Albert and the Goolwa Channel.
	Method: Sample fish at each site using three seine shots (5 mm mesh net at 7 m × 1 m) targeting habitats suitable for Murray hardyhead, which can be changed to adapt to environmental conditions (e.g. drought). Record the numbers of all fish species captured. Measure total length of all Murray hardyhead.
	Data collected by Scotte Wedderburn, The University of Adelaide.
Index/Indices	Relative abundance index (RAI): A measure of the extent of distribution of Murray hardhead at the icon site scale. Target RAI >0.7 (i.e. >70% of point of reference). Young-of-the-year index (YOYI): A measure of the level of recruitment in the Murray hardyhead populations at the icon site scale. Target YOYI >0.5 for Icon Site.
Calculation of index	Relative abundance index is calculated using the proportion of sites occupied by Murray hardyhead in 2003 (point of reference) when healthy fish populations occurred in the Lower Lakes prior to the impacts of drought (10/43 sites = 0.23).
	RAI = proportion of sites recorded/0.23. YOYI = number YOY/total number of Murray hardyhead.
	Present a single RAI value for the Icon Site. Present a single YOYI value for the Icon Site (average of YOYI values for individual sites).
Calculation of whole of icon site score for parameter	Combine the RAI and YOYI values to give an overall measure of condition of the Murray hardyhead population as the whole of icon site score (WOISS). WOISS = (RAI + YOYI)/2. The tolerance (confidence interval) of the WOISS can be calculated using the variances: 1. Calculate the variance of each index 2. WOISS variance (VAR) = variance of RAI + variance of YOYI 3. Tolerance = t × √VAR(WOISS), where $t = t_{0.05,\ ndf}$ Present a WOISS for Murray hardyhead, and include 95% confidence interval. Target WOISS >0.5 for Icon Site.
Power/Effect size	Variance of the RAI is large under the previous condition monitoring method but a targeted, repeated sampling strategy would reduce the standard deviation and thereby reduce the confidence interval. The RAI is sensitive to change, however, power to declare change as significant requires Murray hardyhead to be almost totally absent to have a significantly lower abundance and extent than the point of reference. YOYI not effective for Murray hardyhead in original condition monitoring method but would have been if the species was detected at >12 sites. Statistically invalid to pool data across all sites so calculate YOYI for each site that threatened fish species recorded, so take an average for the entire Lower Lakes. Analyses of monitoring in March 2016 determined that two repeated samples is the optimal sampling strategy to accurately predicted occupancy for Murray hardyhead at its current level of abundance (Guillera-Arroita et al. 2010; Wedderburn and Barnes 2016).

Table 13. Summary description of sampling strategy and calculation of Indices for pygmy perches

Characteristic	Description
Sampling strategy	Number of sites: Sample at 17 sites (all sites in Table 14 excluding sites 16, 48 and 62). Frequency & Timing: Sample sites three times in March (repeated samples approach). Sub-regions covered: Lake Alexandrina, Hindmarsh Island, Mundoo Island, and the Finniss River–Goolwa Channel region. Method: Sample fish at each site using three 6 m single-leader fyke nets (5 mm mesh) targeting habitats suitable for southern pygmy perch and Yarra pygmy perch, which can be changed to adapt to environmental conditions (e.g. drought). Data collected by Scotte Wedderburn, The University of Adelaide.
Index/Indices	Relative abundance index (RAI): A measure of the extent of distribution of the pygmy perch populations at the icon site scale. Target RAI >0.5 (i.e. >50% of point of reference). Young-of-the-year index (YOYI): A measure of the level of recruitment in pygmy perch populations at the icon site scale. Target YOYI >0.3 for Icon Site.
Calculation of index	Relative abundance index is calculated using the point of reference proportion of sites occupied by the pygmy perches in 2003 when healthy fish populations occurred in the Lower Lakes prior to the impacts of drought (Yarra pygmy perch at 8/43 sites = 0.19; southern pygmy perch at 6/43 sites = 0.14). RAI for Yarra pygmy perch = proportion of sites recorded/0.19 RAI for southern pygmy perch = proportion of sites recorded/0.14 YOYI = number YOY/total number of the pygmy perch species Present a single RAI value for the Icon Site for each pygmy perch species. Present a single YOYI value for the Icon Site for each pygmy perch species (average of YOYI values for individual sites).
Calculation of whole of icon site score for parameter	Combine the RAI and YOYI values to give an overall measure of condition of the pygmy perch population as the whole of icon site score (WOISS). WOISS = (RAI + YOYI)/2. The tolerance (confidence interval) of the WOISS can be calculated using the variances: 1. Calculate the variance of each index 2. WOISS variance (VAR) = variance of RAI + variance of YOYI 3. Tolerance = $t \times \sqrt{VAR(WOISS)}$, where $t = t_{0.05,\ ndf}$ Present a WOISS for each pygmy perch species, and include 95% confidence interval. Target WOISS >0.5 for Icon Site.
Power/Effect size	The YOYI and RAI are sensitive to change in condition but power is undetermined because the data are highly variable and sparse as an outcome of pygmy perch population declines during the Millennium Drought. Sampling in March 2015, however, was conducted at all known sites inhabited by the pygmy perches, so index values are close to the truth (low tolerance level) because the entire population was sub-sampled. This aspect should be reassessed when distributions and abundances of the pygmy perches have expanded to levels similar to the point of reference condition. In that regard, analyses of monitoring in March 2016 determined that three repeated samples is the optimal sampling strategy to accurately predicted occupancy for southern pygmy perch at its current level of abundance (Guillera-Arroita et al. 2010; Wedderburn and Barnes 2016). Conversely, Yarra pygmy perch was undetected in March 2016 so the finding is inconclusive.

Table 14. Sites for condition monitoring of threatened fishes in the Lower Lakes (UTM zone 54H, WGS84)

Site	Site description	Easting	Northing
2	Wyndgate	309485	6066535
3	Hunters Creek (upstream Denver Road)	309489	6066309
5	Channel off Steamer Drain	310426	6066005
10	Dunn Lagoon	312568	6070380
14	Currency Creek (entrance)	302539	6070159
16	Narrung (Lake Albert)	334667	6068532
22	Mundoo Island	311065	6064130
25	Dog Lake	329963	6084901
26	Old Clayton	310519	6070104
30	Mundoo Island–Boundary Creek	313752	6063750
31	Boggy Creek	312194	6067197
Î32	Mundoo Island	312275	6064403
34	Shadows Lagoon	311165	6067555
38	Black Swamp	304679	6076719
48	Waltowa (Lake Albert)	352876	6058248
62	Belcanoe (Lake Albert)	337274	6052900
68	Shadows Lagoon–Hunters Creek	310784	6067009
71	Shadows Lagoon channel	311250	6067348
73	Hunters Creek–Steamer Drain junction	310038	6066429
86	Goolwa Channel (upstream of barrage)	300622	6066308

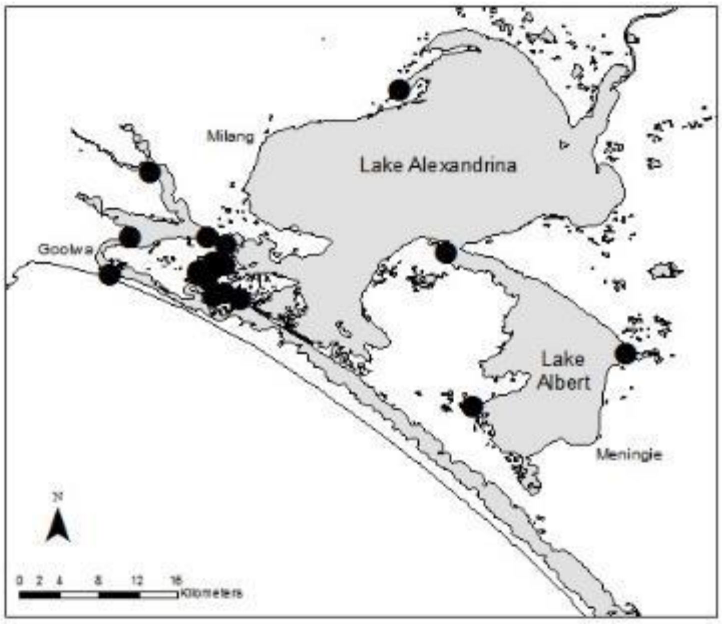

Figure 15. Condition monitoring sites (black dots) for threatened fishes in the Lower Lakes.

4.2.3. Small-mouthed hardyhead (Qifeng Ye, Luciana Bucater, George Giatas and David Short)

Preferred citation for the Small-mouthed hardyhead chapter:

Ye Q, Bucater L, Giatas G, Short D (2017). Small-mouthed hardyhead. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 39-43.

Refined objective: Maintain abundant self-sustaining populations of small-mouthed hardyhead in the North Lagoon and South Lagoon of the Coorong (F-3).

Original: Provide optimum conditions to improve recruitment success of small-mouthed hardyhead in the South Lagoon (F-3).

This monitoring and reporting component collects data on the abundance of adult and juvenile small-mouthed hardyhead (*Atherinosoma microstoma*) and their extent along the salinity gradient in the Coorong lagoons (Table 15). In the Murray–Darling Basin, small-mouthed hardyhead is restricted to the Lower Lakes and Coorong region (Molsher et al. 1994; Wedderburn and Hammer 2003), where it exhibits a protracted spawning period in which multiple batches of eggs are laid from September to December (Molsher et al. 1994). The highly euryhaline small-mouthed hardyhead can complete its annual life cycle in the Coorong across a broad range of salinities (freshwater, estuarine and hypermarine conditions) (Ye et al. 2015a). The species often is highly abundant in the Coorong, particularly in the North and South Lagoons, and has been recorded in salinities >130 psu (Noell et al. 2009). Despite this, monitoring in the Coorong from 2006–2010 found a significant decline in population abundance of small-mouthed hardyhead in the southern part of the Coorong due to a lack of freshwater inflow and increases in salinity >100 psu (Noell et al. 2009; Ye et al. 2011a). Being a highly abundant and broadly distributed small pelagic fish, small-mouthed hardyhead plays an important role in the trophic ecology of the region. For example, this species is an important prey source for piscivorous birds (Paton 2010) and predatory fish (Giatas and Ye 2015).

Condition monitoring from 2008-09 to 2013-14 provided valuable information on the abundance, distribution, population size structures and recruitment ecology of the small-mouthed hardyhead population in the Coorong (Ye et al. 2015a). The monitoring occurred during an extreme drought period followed by four years with significant barrage releases, all of which allowed a quantitative assessment of biological responses to flows and an investigation of population recovery. Throughout time, few modifications of the sampling regime had occurred. Small seine net sampling was incorporated into the regular sampling regime in February 2009 to target new recruits. Two additional sites (Mt Anderson and Villa dei Yumpa) were sampled in January and February 2011 and became part of the regular sites from 2011-12 onwards. Additionally, Hells Gate was grouped to the North Lagoon in previous reporting (Ye et al. 2015a). Following a data review (Ye et al. 2014a), however, this site will be grouped with the South Lagoon sites in future reporting.

The refined condition monitoring will directly measure the recruitment success, abundance and distribution of small-mouthed hardyhead to comprehensively assess its population condition (Table 16). Preliminary ‘points of reference’ were established using the baseline data from the previous condition monitoring, starting in 2008-09. Small-mouthed hardyhead will be sampled at eight sites along the salinity gradient in the Coorong, including four sites in the North Lagoon (Mark Point, Long Point, Noonameena and Mt Anderson) and four sites in the South Lagoon (Hells Gate, Villa dei Yumpa, Jack Point and Salt Creek) (Figure 16). The sites represent the primary occupancy range for small-mouthed hardyhead, where the condition (abundance, recruitment and distribution) of this species will be assessed to best represent the icon site.

Table 15. **Linkages between icon site specific ecological objective and ecological targets for small-mouthed hardyhead**

Characteristic	Description
Ecological objective	Maintain abundant self-sustaining populations of small-mouthed hardyhead (SMHH) in the North Lagoon and South Lagoon of the Coorong.
Definition of how objective and targets are interpreted	'Self-sustaining populations' of this small-bodied, short-lived species are defined as abundant and broadly distributed populations with annual recruitment success.
	'Recruitment success' is defined as an increase in the number of young fish through reproduction processes (i.e. spawning, larval development, survival, and growth of early life stages), which would lead to an increase in population abundances and extent over time.
	'Adult SMHH' is defined by fish ≥40 mm total length (TL) and 'juvenile SMHH' by fish <40 mm TL sampled by standard seine net and small seine net.
Ecological target(s)	1. Average Catch-Per-Unit-Effort (CPUE) of adult SMHH sampled in spring–early summer is >120 (based on 2014 point of reference), where one unit of effort is defined by one standard seine net and one small seine net, noting both gear types are used as complementary sampling method to cover the whole population. 2. Average CPUE of juvenile SMHH sampled in summer/early autumn is >800 fish. 3. At the icon site level >75% of sites have a proportional abundance of early juveniles of >60%. 4. Adult SMHH are present at 7 out of the 8 sites. 5. Juvenile SMHH are present at 7 out of the 8 sites.
CMP monitoring objective	To collect data on the abundance (CPUE) of adult SMHH and new recruits (juvenile SMHH) and their extent along the salinity gradient in the North Lagoon and South Lagoon of the Coorong.
Key use of data	Provides information on abundances and recruitment to determine condition of small-mouthed hardyhead populations, which informs environmental water planning. The data could inform environmental water delivery to maintain salinity gradient and fish habitat in the Coorong. The abundance and recruitment of SMHH could indicate the health of the Coorong foodweb, particularly with regard to its services as an important prey for higher level organisms (e.g. piscivorous fish and birds).

Table 16. **Summary description of sampling strategy and calculation of index for small-mouthed hardyhead**

Characteristic	Description
Sampling strategy	Number of sites: 3–4 sites in the North Lagoon and 3–4 sites in the South Lagoon (number of sites increased from 2008-09 to 2013-14).
	Frequency & Timing: Sampling conducted at each site during spring–summer/early autumn targeting the main spawning and recruitment season, typically with four trips per year.
	Sub-regions covered: North and South Lagoons.
	Method: Standard and small seine surveys at fixed sites. Large seine is 61 m long and consists of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh), and is deployed in a semi-circle, sampled to a maximum depth of 2 m and swept an area of about 592 m^2 per shot. The small seine net is 8 m long with a 2 m drop (2 mm mesh), which is hauled through water less than 0.5 m deep over a distance of 20 m by two people walking 5 m apart, thus sampling an area of about 100 m^2 per shot. Sampling is replicated (i.e. three standard shots) at each site for each seine net type.
	Data collected by SARDI Aquatic Sciences.
Index/Indices	1. Relative abundance: Catch-per-unit-effort (CPUE) of adults as defined by fish ≥ 40 mm TL sampled in spring–early summer. The target value (i.e. point of reference) uses 2011-12, 2012-13 and 2013-14 average CPUE ±25%: 158 ±40 fish per-unit-of-effort. 2. Recruitment: CPUE of early juveniles as defined by fish < 40 mm TL sampled in summer/early autumn (relative abundance of early juveniles). The target value (i.e. point of reference) uses 2011-12, 2012-13 and 2013-14 average CPUE ±25%: 1052 ±263 fish per-unit-of-effort. 3. Proportional abundance of early juveniles (new recruits) compared to adults in the season. Target: at each site the proportional abundance of early juveniles > 60%. At the entire icon site level > 75% of sites (i.e. 6 out of 8 sites) having a proportional abundance of early juveniles of >60%. 4&5. Distribution: Proportion of sites that SMHH are present. At the entire icon site level >87% (i.e. 7 out of 8 sites) for both adults and juveniles.
Calculation of index	Expert knowledge based on six years of data collection (2008-09 to 2013-14).
	1. Relative abundance: Based on spring/early summer (typically November and December) data of standard seine net and small seine net samples. Fish caught in each replicate at each site and month will be classified to adults if length is ≥ 40 mm TL and to early juveniles if it's <40 mm. CPUEs of adults for each of the 8 sites are calculated with standard errors estimated, then take an average across the sites for reporting adult abundance in the Coorong. 2. Recruitment: Based on January and February data of standard seine net and small seine net samples. Fish caught in each replicate at each site and month will be classified to early juveniles if length is < 40 mm and to adults if it's ≥ 40 mm TL, CPUEs of early juveniles for each of the 8 sites are calculated with standard errors estimated, then take an average across the sites for reporting the juvenile abundance in the Coorong. 3. Proportional abundance of early juveniles (new recruits): Calculated for each of the 8 sites. Proportional abundance of early juveniles is calculated as % = # of juveniles (Jan/Feb)/(# of juveniles (Jan/Feb) + # of adults (Nov/Dec)). Then % of sites exceeded 60% juveniles is calculated for the entire icon site: % sites = # of sites with > 60% juveniles/# of sites sampled.

	4&5.Distribution: This is calculated by % sites sampled where average SMHH CPUE are >5 fish per standard seine net using November and December data. Also to calculate % sites sampled where average SMHH CPUE for early juveniles are >5 fish per small seine net using January and February data.
	Display graphically how target tracks through time. A summary table of index assessment is presented with the WOISS calculated.
Calculation of whole of icon site score for parameter	Calculation of whole icon site score (WOISS) is performed by using the combination of proposed population indices and points of reference to assess the condition of SMHH in the Coorong during the sampling period. Score of 1 point is assigned if the index is met: Relative abundance CPUE of adults; CPUE of early juveniles; Proportional abundance of early juveniles at majority of sites; % of sites adult SMHH present; % of sites juvenile SMHH present. WOISS for condition assessment of SMHH populations in the Coorong is the sum of index score: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, 4 = Good, and 5 = Very Good.
Power/Effect size	All indices have been evaluated and are sensitive to change in population dynamics. Power analyses shows that a $\log_{10}$ CPUE index for adults will have an effect size of 19% of the mean, and for Juveniles the $\log_{10}$ index will have an effect size of 8%. The proportion of recruits index effect size is 11%. The overall fish population condition index is sensitive and a change in the fish population index is a significant change in its condition.

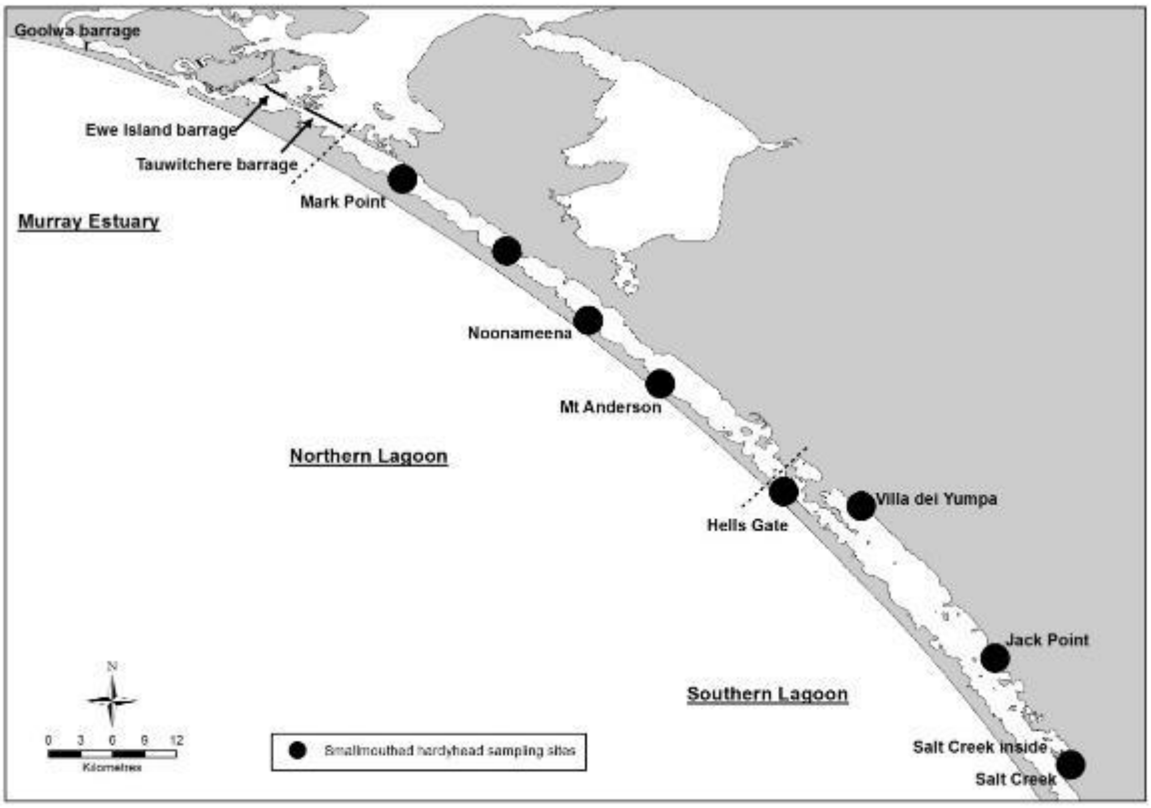

Figure 16. Condition monitoring sites (black dots) for small-mouthed hardyhead in the North Lagoon and South Lagoon of the Coorong.

Table 17. **Sites for Condition Monitoring of small-mouthed hardyhead (UTM zone 54H, GDA94)**

Site	Site description	Eastings	Northings
N1	Mark Point	325756	6054547
N2	Long Point	333861	6047946
N3	Noonameena	340202	6041577
N4	Mt Anderson	245809	6035705
S1	Hells Gate	355353	6025804
S2	Villa dei Yumpa	361288	6024530
S3	Jack Point	371706	6010424
S4	Salt Creek	377586	6000510

4.2.4. Black bream and greenback flounder (Qifeng Ye, Luciana Bucater, George Giatas and David Short)

Preferred citation for the Black bream and greenback flounder chapter:

Ye Q, Bucater L, Giatas G, Short D (2017). Black bream and greenback flounder. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 44-51.

Refined Objective: Restore resilient populations of black bream and greenback flounder in the Coorong (F-4).

Original: Maintain or improve populations of black bream, greenback flounder and mulloway in the Coorong (F-4).

This monitoring and reporting component collects data on commercial fishery catch and effort, age structure, relative abundance and spatial distribution of young-of-the-year (YOY) of black bream (*Acanthopagrus butcheri*) and greenback flounder (*Rhombosolea tapirina*) in the Estuary and North Lagoon of the Coorong (Table 18). Mulloway (*Argyrosomus japonicas*) has been removed from the Condition Monitoring Plan. The assessment of recruitment and population status of Mulloway is best achieved through alternative monitoring coinciding with larger flow releases.

Suitable freshwater flow and salinity regimes and a salinity gradient from freshwater to hypermarine are paramount for fishes in the Coorong. This, in addition to the increased connectivity and productivity by flow, will influence the life history processes and population dynamics of estuarine associated fish species, including black bream and greenback flounder. Black bream is an important commercial and recreational fisheries species which possess a wide environmental tolerance with respect to temperature, salinity and dissolved oxygen concentration. Variability of freshwater inflows has been identified as a key factor influencing recruitment success of black bream (e.g. Sarre and Potter 2000), yet spawning and recruitment processes of the species in the Coorong is not fully understood (Ye et al. 2015b). Greenback flounder also is an important commercial fisheries species. Age structure of greenback flounder in the Coorong is truncated with a dominant class of 1 or 2 year olds (Ferguson et al. 2013; Ye et al. 2013). Temporal and spatial variation of biomass and abundance of greenback flounder could also be related to possible migration of older individuals to the sea (Earl 2014). The spawning behaviour and recruitment success of black bream and greenback flounder are likely to be highly variable due to the dynamic nature of the Coorong.

In the refined condition monitoring methods, the index values for relative abundance, distribution and age structure of black bream and greenback flounder are related to information/samples gained from the commercial fishery. The index values recruitment are calculated using data from additional sampling using fyke nets to capture black bream (Table 19) and seine net to capture greenback flounder (Table 20). Commercial catch and effort data for black bream and greenback flounder from the Lakes and Coorong Fishery are available since 1984-85. Data include catch (kg), effort (fisher days and net days), and spatial reporting of fishing block (Ye et al. 2015a). This information was used to develop the point of references for the condition monitoring targets, which were based on catches during periods of favourable freshwater inflows to the Coorong. Condition monitoring from 2008-09 to 2015-16 provided valuable information on the abundance, distribution, population size/age structures and recruitment ecology of the black bream and greenback flounder populations in the Coorong. The monitoring occurred during an extreme drought period (2008 to 2010), followed by four years with significant barrage releases and two years of reduced water flows, all of which allowed a quantitative assessment of biological responses to flows and an investigation of population dynamics. The point of reference is based on 2008–2014 data and the peak catch-per-unit-effort

(CPUE) value for YOY fish during a year with moderate flow (i.e. 2012-13), which is considered to be beneficial to black bream recruitment. Studies found that the greatest recruitment of this species in estuaries occurred during years of intermediate river flows and poor recruitment following periods of very low and high flows (Jenkins et al. 2010). Adult black bream are sampled from commercial fishery at several sites, and YOY black bream from four regular sites and up to 25 additional sites (Figure 18, Table 21). Adult greenback flounder are collected from commercial fishery across multiple sites, whilst YOY greenback flounder sampling is conducted at nine regular sites (Figure 19, Table 22).

Table 18. Linkages between icon site specific ecological objective and ecological targets for black bream and greenback flounder

Characteristic	Description
Ecological objective	Restore resilient populations of black bream and greenback flounder in the Coorong.
Definition of how objective and targets are interpreted	Restoration of ‘resilient populations’ by ensuring regular recruitment, broadening population age structure, and increasing abundance and distribution.
	‘Ensure regular recruitment’ by increasing the number of young fish through reproduction processes (i.e. spawning, larval development, survival, and growth of the early life stages) which increases population abundances and extent over time.
	‘Regular recruitment’ is defined as annual recruitment in at least eight out of 10 years with at least four of these being strong recruitment events.
	A broad population age structure with several strong cohorts is important for population resilience of long-lived species so that multiple cohorts live through suboptimal conditions and recruit when favourable conditions are restored following environmental improvement.
Ecological target(s)	Black bream 1. Relative abundance: Based on commercial fishery catch (tonnes/year): Annual catch ≥8 tonnes or positive trend over previous 4 years (linear regression). 2. Distribution: >50% of the catch from southern part of Coorong (south of Mark Point). 3. Age structure: Need to meet at least two of the following targets: >20% of fish above 10 years; at least one strong cohort over the last five years; or ≥2 strong cohorts in the population. Strong cohort is defined as a cohort representing ≥15% of the population. 4. Recruitment: Need to meet both targets: Catch per unit effort (CPUE) of young-of-the-year (YOY) >0.77 YOY/fyke net.night; and YOY distribution in the Coorong: >50% of sites with YOY black bream present.
	Greenback flounder 1. Relative abundance: Based on commercial fishery catch (tonnes/year): Annual catch ≥24 tonnes or positive trend over previous 4 years (linear regression). 2. Distribution: >70% of the catch from southern Coorong (south of Mark Point). 3. Age structure: Need to meet one of the following targets: Presence of a very strong cohort (>60%); or at least a strong cohort (>40%) in years 0–2 and >20% of fish >2 years old. 4. Recruitment: Need to meet both targets: CPUE of YOY >1.04 YOY/seine net shot; and YOY distribution in the Coorong >50% sites with YOY greenback flounder present.

CMP monitoring objective	To collect data on commercial fishery catch and effort, age structure, relative abundance and spatial distribution of the YOY of black bream and greenback flounder, along the Estuary and North Lagoon of the Coorong.
Key use of data	The data could inform environmental water delivery to maintain salinity gradient and fish habitat in the Coorong. Both are iconic species for the Murray Estuary and Coorong with significant environmental, social, economic and cultural values.

Table 19. Summary description of sampling strategy and calculation of index for black bream

Characteristic	Description
Sampling strategy	Number of sites: Collect adult black bream from multiple sites, and YOY black bream from four regular sites and up to 25 additional sites.
	Frequency & Timing: Daily catch and effort data from fishery statistics on an annual basis. Collect samples of adult black bream during spring–autumn and YOY black bream during summer-autumn each year.
	Sub-regions covered: Murray Estuary and North Lagoon.
	Method: Adult black bream collected from commercial fishery and opportunistically through seine net sampling (fishery-independent). YOY black bream collected using single-wing fyke nets 8.6 m long (3 m lead plus 5.6 m funnel) with a mesh size of 8 mm and a hoop diameter of 0.6 m.
	Data collected by SARDI Aquatic Sciences.
Index/Indices	1. Relative abundance: Annual commercial fishery catch: Target ≥8 tonnes/year. The trend of catches over 4 years: Target is a positive trend. 2. Distribution: Proportional catch from the southern part of the Coorong (south of Mark Point): Target >50% of the total annual commercial fishery catch of black bream. 3. Age structure: % older fish; Number of strong cohorts over the last five years; and number of strong cohorts in the population. Population age structure includes recent recruits, sub-adults and adults. Need to meet at least two of the following three targets: (1) >20% of fish above 10 years; (2) at least one strong cohort over the last five years; or (3) ≥2 strong cohorts in the population. 4. Recruitment: CPUE of the YOY: Target >0.77 YOY/fyke net.night. YOY distribution in the Coorong: Target >50% of sites with YOY black bream present.
Calculation of index	1. Relative abundance: Point of reference of the annual catch index is established based on the average of the high catch period in recent history (2000-01 to 2005-06); the higher catches in these years are likely associated with recruitments during moderate flow years (1995-96 to 2000-01). An additional index is added using the trend of catches over previous 4 years. 2. Distribution: Point of reference is based on the fishery data that in most of the years prior to the decadal drought (from 2001) >50% of the black bream catch came from the southern part of the Coorong, while <50% came from the southern parts during the drought (2001–2010). 3. Age structure: Based on age composition in the Coorong from 2008–2014, where a strong cohort is defined as a cohort representing ≥15% of the population. The target of proportional abundance of fish older than 10 years is defined with reference to other populations in SA estuaries. 4. Recruitment: Point of reference is based on the peak CPUE value (0.86) for YOY during a year with moderate flow (2012-13), which is considered to be beneficial to recruitment. Previous studies indicate that years of low and high flow are not associated with strong recruitment. The point of reference is based on a single value so an arbitrary error estimate of 10% is adopted to allow for variation (i.e. 0.86 minus

Characteristic	Description
	10% = 0.77). The YOY point of reference is set as an interim target, considering the recruitment data collected from 2008-09 to 2013-14 through Coorong Fish condition monitoring. An additional index is included with respect to the distribution of new recruits. Note: Reference values for recruitment indicator could be revised periodically following collection of further data.
	1. Relative abundance: Use the long-term record of daily catch and effort data from the Lakes and Coorong commercial fishery. Calculate the annual catch (tonnes), and analyse the trend over previous 4 years (linear regression). 2. Distribution: Use spatial reporting data of the greenback flounder catch from the Lakes and Coorong commercial fishery. Calculate proportional catch from fishing blocks (south of Mark Point). 3. Age structure: Analysing age composition, using percentage frequency distribution. 4. Recruitment: Number of YOY/net.night (sampled by fyke net), and proportion (%) of sampling sites that YOY are present (detected) in the Coorong.
	Display graphically how target tracks through time. A summary table of index assessment is presented with the WOISS calculated.
Calculation of whole of icon site score for parameter	Calculation of WOISS is performed by using the combination of proposed population indices and points of reference to assess the condition of black bream in the Coorong during the sampling period. Each indicator will receive 1 point if indices meet the following requirements: Relative abundance – one of the indices meets the reference point. Distribution – meets the reference point. Age structure – two out of the three indices meet the reference points. Recruitment – both indices meet the reference points. WOISS: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, and 4 = Good
Power/Effect size	All indices have been trialed and are sensitive to change in condition. The indices were not statistically assessed for power. However, the multiple lines of evidence approach used is very well justified and the overall fish population condition index is sensitive and it appears that a change in the fish population index is a significant change in icon site condition.

Table 20. Summary description of sampling strategy and calculation of Index for greenback flounder

Characteristic	Description
Sampling strategy	Number of sites: Adult greenback flounder collected from multiple sites, whilst YOY greenback flounder sampling conducted at nine regular sites.
	Frequency & Timing: Daily catch and effort data from fishery statistics on an annual basis. Adult greenback flounder sampled throughout the year and YOY greenback flounder collected during late spring - summer each year.
	Sub-regions covered: Murray Estuary and North and South Lagoons.
	Method: Adult greenback flounder collected from commercial fishery and opportunistically through seine net sampling (fishery-independent). YOY greenback flounder collected by standard seine net 61 m long and consisting of two 29 m-long wings (22 mm mesh) and a 3 m-long bunt (8 mm mesh).
	Data collected by SARDI Aquatic Sciences.
Index/Indices	1. Relative abundance: Annual commercial fishery catch: Target ≥24 tonnes/year. The trend of catches over 4 years: Target at a positive trend. 2. Distribution: Proportional catch from the southern part of the Coorong (south of Mark Point): Target >70% of the total annual commercial fishery catch of greenback flounder.

Characteristic	Description
	3. Age structure: % older fish. Presence of strong cohort(s): Target a very strong cohort (>60%), or at least one strong cohort (>40%) present within first two years and fish >2 years representing >20% of the population. 4. Recruitment: CPUE of the YOY: Target >1.04 YOY/seine net shot. YOY distribution in the Coorong: Target >50% sites with YOY greenback flounder present.
	1. Relative abundance: The reference point is established based on the high catch period in recent history (1995-96 to 2001-02); the higher catches in these years are likely associated with recruitments during high/moderate flow years (1993-94 to 2000-01). 2. Distribution: The reference point is based on fishery data that in most of the years (<2001) prior to the decadal drought >70% of the catch came from the southern part of the Coorong, while during the drought (2001–2010) catch from the southern parts were generally <70%. 3. Age structure: Arbitrarily assigned based on expert knowledge and age composition data from 2009–2013. 4. Recruitment: The reference point is based on the average CPUE of YOY from 2011–2014 minus the standard error (i.e. 1.22–0.18), which followed above average freshwater inflow. The reference point for the distribution of YOY >50% sites is set as a target; considering the data collected from 2010/11–2013/14. Note: Reference values for recruitment indicator could be revised periodically following collection of further data.
Calculation of index	1. Relative abundance: Use the long-term record of daily catch and effort data from the Lakes and Coorong commercial fishery. Calculate the annual catch (tonnes), and analyse the trend over previous 4 years (linear regression), focusing on the catches from the Coorong. 2. Distribution: Use spatial reporting data of the greenback flounder catch from the Lakes and Coorong commercial fishery. Calculate proportional catch from fishing blocks (south of Mark Point) along the salinity gradient in the Coorong. 3. Age structure: Analysing age composition using percentage frequency distribution. Identifying strong cohorts. 4. Recruitment: Number of YOY/ seine shot. Proportion (%) of sampling sites that YOY are present (detected) in the Coorong.
	Display graphically how target tracks through time. A summary table of index assessment is presented with the WOISS calculated.
Calculation of whole of icon site score for parameter	Calculation of whole of icon site score was performed by using the combination of proposed population indices and points of reference to assess the condition of greenback flounder in the Coorong during the sampling period. Each indicator will receive 1 point if indices are meeting the following requirements: Relative abundance – one of the indices meets the reference point. Distribution – meet the reference point. Age structure – one of the indices meets the reference point. Recruitment – both indices meet the reference points. WOISS: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, and 4 = Good
Power/Effect size	All indices have been trialed and are sensitive to change in condition. The indices were not statistically assessed for power. However, the multiple lines of evidence approach used is very well justified and the overall fish population condition index is sensitive and it appears that a change in the fish population index is a significant change in Icon site condition.

Table 21. Sites for Condition Monitoring of black bream (UTM zone 54H, GDA94). Note: sampling sites of black bream are mainly based on commercial fishery data and may vary from year to year

	Sites Description	Eastings	Northings
Sites – adult sampling	Goolwa channel	302550	6066196
	Beacon 19	303450	6065926
	Stuarts Creek	304540	6065626
	Boundary Creek	312644	6062725
	Newells	305383	6064756
	Sugars Beach	307033	6064186
	Mundoo Channel	309313	6064416
	Barkers Knoll	309436	6062946
	Ewe Island	314911	6062306
	Pelican Point	321506	6057961
	Long point	334464	6048245
	Seven Mile	347334	6036174
Regular sites - juvenile sampling	Goolwa Barrage saltwater side HI	301407	6066746
	Goolwa Barrage saltwater side SRP	301378	6066121
	Mundoo Barrage	310076	6064841
	Boundary Creek	312772	6062842
Additional sites - juvenile sampling	Goolwa Barrage freshwater side HI	300860	6067125
	Goolwa Barrage freshwater side SRP	300546	6066384
	Goolwa Channel HI	605844	6064878
	Mundoo Channel	308217	6064980
	Mundoo Channel in front of house	308175	6064297
	Boundary Creek Barrage	313901	6063581
	Godfrey's Landing	312824	6062071
	Ewe Island Causeway	315246	6062666
	Tauwitchere Barrage	319056	6060421
	Pelican Point	321226	6058801
	Pelican Point YHP	322319	6056146
	Pelican Point YHP Phrag. Opposite	322672	6055639
	Cattle Point	324599	6055017
	Mark Point	326026	6055273
	Mark Point beach	326114	6055585
	South Cattle Point	325472	6053769
	Opposite Mark Point YHP	325973	6053289
	Long Point beach	334059	6048540
	Long Point	333724	6048435
	Long Point YHP; opp. Jetty	333550	6047383
	Long Point reef	334054	6046950
	Long Point sand dune	335166	6046339
	Noonameena	339373	6042167
	Robs Point	344771	6039153

Table 22. Sites for Condition Monitoring of greenback flounder (UTM zone 54H, GDA94). Note: sampling sites of greenback flounder are mainly based on commercial fishery data and may vary from year to year

	Sites Description	Eastings	Northings
Sites – adult sampling	Goolwa	302550	6066196
	Mark Point	325216	6055467
	Long Point	333959	6048245
	Sam Island	340729	6043235
	Seven Mile	347334	6036174
	Needles	350784	6032704
Sites – juvenile sampling	Sugars beach	307521	6064006
	Godfrey's Landing	312626	6062013
	Mark Point	325756	6054547
	Noonameena	340202	6041577
	Mount Anderson	345809	6035705
	Hells Gate	355353	6025804
	Villa dei Yumpa	361288	6024530
	Jack Point	371706	6010424
	Salt Creek	377586	6000510

Figure 17. Black Bream caught during seine netting in the Coorong.

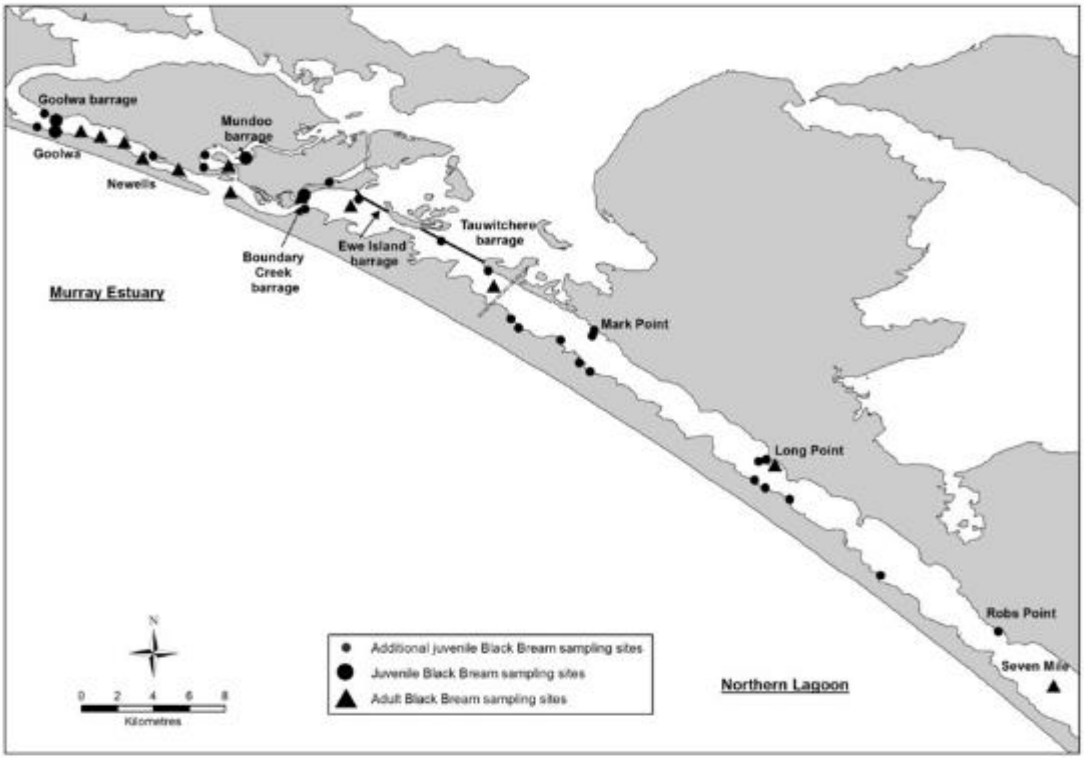

Figure 18. Condition monitoring sites for adult and juvenile black bream at the Coorong. Adult black bream sampling sites represent commercial fishery sampling sites.

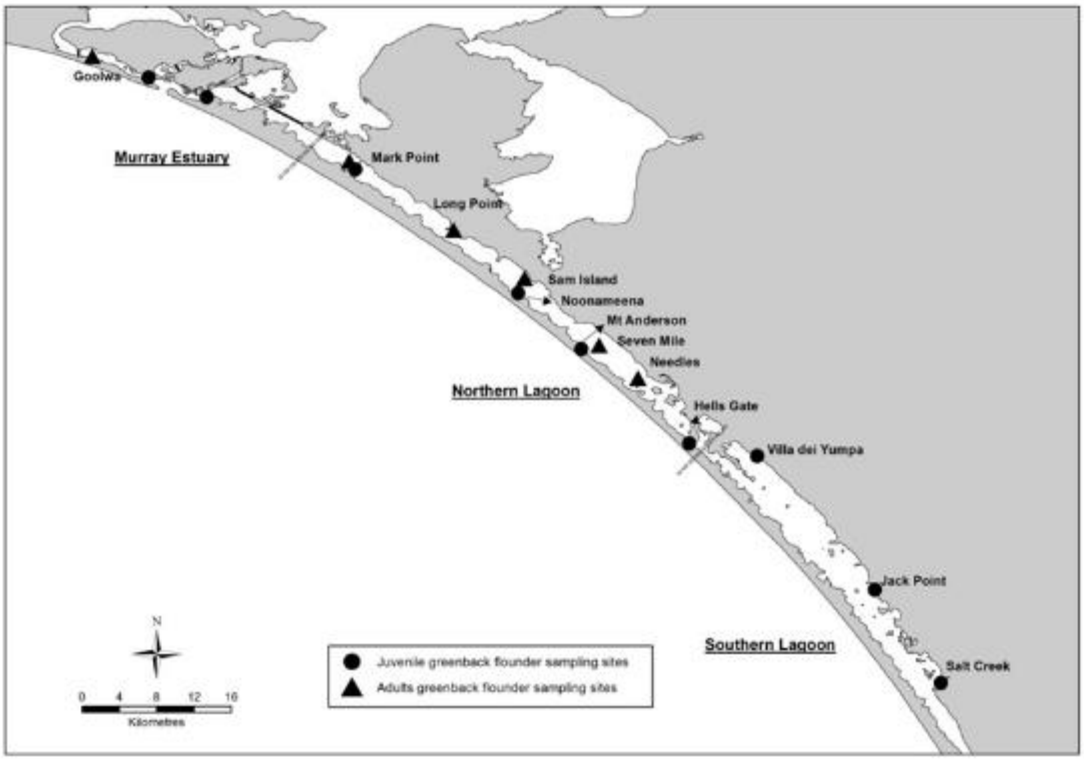

Figure 19. Condition monitoring sites for adult and juvenile greenback flounder at the Coorong. Adult greenback flounder sampling sites represent commercial fishery sampling sites.

4.3. Invertebrates (Sabine Dittmann)

Preferred citation for the Invertebrates chapter:

Dittmann S (2017). Invertebrates. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 52-58.

Refined Objective: Maintain or improve mudflat invertebrate communities that are of high condition relative to southern Australian estuarine mudflat ecosystems (I-1).

Original: Maintain or improve invertebrate populations in mudflats (I-1).

This monitoring and reporting component collects data on macroinvertebrate taxonomic richness, abundance and biomass distribution in mudflats of the Murray Mouth and Coorong lagoons (Table 23). Macroinvertebrates are an intricate part of estuarine and lagoon ecosystems, affected by the environmental conditions (e.g. salinity, water level) and also affecting the environment through bioturbation or biogenic structures such as tubeworm reefs (animal-sediment interactions and ecosystem engineering). Benthic species are interacting with each other through various ecological processes, and are part of the wider estuarine food web by being prey to higher trophic levels (e.g. fish and birds). Their life stages can be part of the zooplankton as pelagic larvae and are affected by hydrodynamics. Macroinvertebrates are thus realising a range of ecosystem functions.

Monitoring of mudflats and macroinvertebrates commenced in 2004 and has since been carried out annually, with one sampling event in late spring–early summer at the start of the overwintering period for migratory shorebirds. Slight variations with regards to the timing and sites had occurred in the monitoring, but since 2006 it has been carried out using a consistent approach and sites for the Murray Mouth and Coorong. Ten years of annual monitoring (since 2004) of benthic communities in the estuary and coastal lagoon of the Murray Mouth and Coorong showed that the Millennium Drought led to decreased taxonomic richness, abundance and biomass of macrobenthos (mudflat invertebrates) as hypersaline conditions developed and water levels dropped (Dittmann et al. 2015). Macroinvertebrate densities dropped and their occurrence contracted during the drought. Macroinvertebrate species also responded differently and recovery was taxon-specific. Macrobenthic communities were distinct before and after the drought and flood event. Communities also varied along the environmental gradient in the Coorong, with distinct communities in areas with salinities >64 ppt. Salinity explained most of the pattern in macroinvertebrate communities, and low dissolved oxygen saturation and sediment properties contributed further to explaining the patterns.

The refined condition monitoring methods focus on mudflats of the Murray Mouth and Coorong to assess the food availability for shorebirds and the overall condition of the system. Refinement of the monitoring methods for invertebrates has taken an approach focussing on indices and their power and/or effect sizes (Table 24-Table 28). Some of the indices which have proven to be most useful to establish benthic quality involve sensitivity or tolerance of benthic species (Borja et al. 2010). For the macroinvertebrate fauna of temperate Australian estuaries, taxonomic expertise and understanding of species specific sensitivities and tolerance are often limited, restricting the adoption of many indices (Tweedley et al. 2014). Several approaches also have been trialled to determine reference conditions for assessing deviations and ecological conditions. For the Murray Mouth and Coorong, where no historical data for macroinvertebrates exist going back to the time before barrage construction, and no sections of the estuary and lagoon are pristine anymore because of the flow regulation, approaches to set up reference values are compromised. Therefore, the approaches taken for the refinement should be treated with care and revisited after further monitoring, to avoid the risk of false baselines or benchmarks. The eleven sampling sites for macroinvertebrate monitoring are arranged along the environmental gradient from the estuary into the lagoons (Table 29).

Table 23. **Linkages between icon site specific ecological objective and ecological targets for macroinvertebrates**

Characteristic	Description
Ecological objective	Maintain or improve mudflat invertebrate communities that are of high condition relative to southern Australian estuarine mudflat ecosystems.
Definition of how objective and targets are interpreted	‘Community’ is defined as a group of macroinvertebrate organisms occurring in a particular environment separable from other groups through ecological surveys of diversity, abundance and biomass.
	‘Mudflat’ is defined as soft sediment habitat episodically emerged and submerged by water through tides, wind seiching, and water level variations subject to flow.
	‘Invertebrate’ is defined as benthic macroinvertebrates living inside or on the surface of sediment and retained in sieves with mesh size >0.5 mm.
	‘Maintain’ is defined as staying within the reference dynamic derived from surveys between 2004 and 2013; a decade encompassing various drought and flow conditions.
	‘Improve’ is defined as (a) a positive trajectory towards communities characteristic of years with average flows, and/or (b) becoming more similar to comparable habitats elsewhere in southern temperate Australia.
Ecological target(s)	1. Macroinvertebrate species richness increases throughout the Murray Mouth and Coorong. 2. Macroinvertebrate occurrence extends along the Coorong into the South Lagoon. 3. The area of occupation for typical estuarine and marine macroinvertebrate species exceeds 60% of the sites sampled (based on the average index of occurrence of the species found in >1% of the samples over the entire monitoring from 2004–2013, considered here as ‘typical’ species for the area). 4. Macroinvertebrate abundance is maintained at, or increases above, reference levels. 5. Macroinvertebrate biomass is maintained at, or increases above, reference levels. 6. Macroinvertebrate communities are similar to those occurring under intermediate continuous flows.
CMP monitoring objective	To collect data on macroinvertebrate taxonomic richness, abundance and biomass distribution.
Key use of data	Data informs on habitat value for migratory waders, food availability for waders and fish, connectivity of Coorong with Lower Lakes and Southern Ocean, response to frequency and volumes of water releases over barrages, and management of water levels in Coorong and Lower Lake wetlands.

Table 24. Summary description of sampling strategy for macroinvertebrates (data obtained from this sampling procedure are used for the analyses outlined in Table 24 to Table 28)

Characteristic	Description
Sampling strategy	Number of sites: Sampling at 11 sites (see Table 29).
	Frequency & Timing: Annually in spring–early summer (November–December).
	Sub-regions covered: Murray Mouth, North Lagoon and South Lagoon. Based on the previous decade of macroinvertebrate monitoring, an ecological boundary occurs in the southern North Lagoon, around Noonameena (site 7), defined by a salinity threshold (South Coorong with salinity >64). Therefore, based on this salinity threshold, the sub-regions 'North Coorong' and 'South Coorong' are proposed.
	Method: Samples are collected between the shore and the water line at the time of sampling, with samples taken in exposed sediment (if available), at the water edge, and up to knee deep water, to capture the spatial gradient across the mudflats and varying water levels. Ten replicate samples are taken at each site using hand-held corers (83 cm^2 surface area) inserted to 15–20 cm depth into the sediment. The sediment is sieved on site through 0.5 mm mesh and samples transferred to the lab, where they are sorted live, identified and counted.
	Data collected by Sabine Dittmann, Flinders University.

Table 25. Summary description of calculation of index for macroinvertebrate diversity

Characteristic	Description
Index/Indices	<u>Species richness</u> S (Range 0–∞): Species richness S (as number of operational taxonomic units) was the most sensitive and indicated significant changes between years. The following indices are less sensitive to change in macroinvertebrate diversity but useful for long-term comparisons: Margalef's Index d (Range 0–1) Shannon Wiener Diversity Index H' (Range 0–∞)
Calculation of index	High species richness and high diversity indicates good condition. Index values indicate high diversity the higher the index value (i.e. closer to 1 for Margalef's Index d, and with no defined upper limit for S and H').
	Species number is the count of taxa per site, which can be identified to different taxonomic levels (mostly species or families) as operational taxonomic units. Species richness S: total number of species recorded per site and survey Margalef's Index d: $d = (S - 1)/logN$ Shannon Wiener Diversity index H': $H' = -\sum i\; pi \log(pi)$, whereby $pi = ni/N$, with n = total count of *i*th species and N total count of all species. The indices can be easily calculated using the PRIMER software.
	Diversity data are presented in table and figure format, comparing indices across sites and over time.
Calculation of whole of icon site score for parameter	Average species richness across sites can be taken as a WOISS. Yet, due to the intrinsic gradient from the Murray Mouth into the Coorong, and the previous data period capturing extreme drought and flood years, reference values for the entire icon site can only be given with caution. Long-term (2004–2013) average species richness for the North Coorong were 6 species, and for the South Coorong 3 species.
Power/Effect size	The sampling method is sensitive to change in condition and the effect size for any two years for species richness is about 3 species.

Table 26. **Summary description of calculation of index for macroinvertebrate occurrence and abundance**

Characteristic	Description
Index/Indices	The following indices were found to be sensitive to the changes in macroinvertebrate distribution and abundance: Index of occurrence (Range 0–1): The index is 1 when a species is found at all sites. Index of relative change in abundance: The ratio is 0 when observed and reference data are the same, positive when observed data exceed reference data, and negative if they are below this reference.
Calculation of index	Index of occurrence: The reference is based on the number of sites a species was found over the 10 year monitoring period from 2004–2013. Index of relative change in abundance: The reference is based on the average abundance per region over the 10 year monitoring period from 2004–2013 (North and South Coorong separately).
	Index of occurrence = SF_i/ST; with SF_i as the number of sites where species *i* was found, and ST the total number of sites sampled on the occasion. The index is similar to the constancy index by Bachelet & Dauvin (1993). For this index, all 11 sites are considered to detect whether distributions extend across regions and, in particularly, into the South Lagoon. The reference value was <1 for several species because their distribution naturally reflects their biological tolerance to environmental conditions and they were, for example, not found at sites in the South Lagoon. The reference values and statistical tolerances for common taxa are: *Capitella* 1±0; Amphipoda 1±0; Chironomidae 1±0; *Simplisetia* 0.82 ±0.23; *Arthritica* 0.73 ±0.26; Nephtys 0.55 ±0.29. Index of relative change in abundance is calculated as a ratio of observed (t_x, any particular year) to reference data (t_r, reference), following standardised time series data analysis: ratio = $\log (t_x/t_r)$ The reference data were based on average abundances of all monitoring years from 2004–2013 for each of the two regions: North Coorong 43,825 individuals m^{-2} South Coorong 1,495 individuals m^{-2} These references should be recalculated based on data from future monitoring years, as the previous 10 year monitoring period encompassed extreme events and did not constitute a typical estuarine situation. The values ranged between 1 and −3.
	The index of occurrence: Plot over time for key species, showing the index value for the year against a reference developed from long-term monitoring (2004–2013). The index of relative change in abundance: Plot in relation to previous years to detect trends of change. The index will be presented for all macroinvertebrates combined (=Total macroinvertebrates), and for key species identified in the previous Condition Monitoring Plan (Maunsell 2009) that were also most abundant over the previous monitoring decade. The index may be plotted for additional species to illustrate any trends in their recovery or decline. The actual abundances will also be presented as individual densities per m^2, to allow comparisons with records from other estuaries in southern temperate Australia and along the flyway of the migratory shorebirds.
Calculation of whole of icon site score for parameter	The index of occurrence gives a score for the whole of icon site, as per calculation described above. The index of relative change in average abundance is also giving a score for the icon site, yet separated for the North and South Coorong which are characterized by different communities.
Power/Effect size	For the index of occurrence, Robinson 2014b gave an overall tolerance limit over the six most prominent species as 0.12. Tolerance limits for the six most prominent species are provided in the inset table above. For the index of relative change in abundance, values for effect size ranged between 0.24 and 1.22.

Table 27. **Summary description of calculation of index for macroinvertebrate biomass**

Characteristic	Description
Index/Indices	Index of relative change in biomass: The ratio is 0 when observed and reference data are the same, positive when observed data exceed reference data, and negative if they are below this reference.
Calculation of index	Index of relative change in biomass: The reference is based on the average biomass per region over the ten year monitoring period from 2004-2013 (North and South Coorong separately) (see below).
	Index of relative change in biomass is calculated as a ratio of observed (t_x, any particular year) to reference data (t_r), following standardised time series data analysis: ratio = log (t_x/t_r) The reference data are based on an average biomass (AFDM = ash free dry mass) of all monitoring years 2004–2013 for each of the two regions: North Coorong 6.56 g AFDM m^{-2} South Coorong 0.25 g AFDM m^{-2} These references should be recalculated based on data from future monitoring years, as the previous ten year monitoring period encompassed extreme events and did not constitute a typical estuarine situation.
	Index of relative change in biomass will be plotted in relation to previous years to detect trends of change. The index will be presented on biomass determined for all macroinvertebrates combined (=Total biomass). The actual biomass values will also be presented as g AFDM/m^2, to allow comparisons with records from other estuaries in southern temperate Australia and along the flyway of the migratory shorebirds.
Calculation of whole of icon site score for parameter	Index of relative change in biomass gives a score for the icon site, but separate for the North and South Coorong. The values ranged between 0.7 and −1.1.
Power/Effect size	For the index of relative change in biomass, values for effect size were 0.51 for the North Coorong and 0.62 for the South Coorong.

Figure 20. Macroinvertebrate sampling using sediment cores at Pelican Point, left image November 2015, right image April 2016.

Table 28. Summary description of calculation of index for macroinvertebrate community

Characteristic	Description
Index/Indices	The Bray-Curtis Index S_{jk}: The most widely used and accepted index for similarity between communities. This index varies between 1 (or 100) (all species in common) and 0 (no species in common). Spearman's rank correlation coefficient δ: Used to detect among sample relationships. For a perfect match δ =1, and δ = 0 if there is no match between sample communities.
Calculation of index	Bray-Curtis index of similarity within a year and across all sites in a sub-region, where a high index value indicates that all these sites have similar communities, in the absence of a strong gradient of environmental change within the sub-region: North Coorong: The target similarity is S_{jk} = 77, with the years 2005 and 2013 used as reference because they had intermediate and/or continuous flows and can indicate good condition, yet are not a baseline. South Coorong: The target similarity is S_{jk} = 45, with the years 2006 and 2010 used as reference when water from flows reached into the South Lagoon. The Spearman rank correlation coefficient δ can indicate whether the ecological target that macroinvertebrate communities are similar to those occurring under intermediate continuous flow is met, when δ between the latest monitoring year and preceding monitoring years from intermediate continuous flows (such as 2005, 2006, 2012, 2013) is high (δ >0.5).
	Description of how to calculate the index: Bray-Curtis Index, in a simple form, is given as $C_N = 2jN/(N_a+N_b)$, with $2jN$ as the sum of the lower of the two abundances for species found in both sites, and N_a and N_b the total number of individuals in site A and B respectively. For comparison between multiple sites and similarities between the *j*th and *k*th samples, more complex formula can be used for Bray-Curtis similarity as S_{jk}. This index is easily calculated and the default resemblance in the PRIMER software. The Spearman rank correlation coefficient δ is obtained from matrix correlation comparing two sets of multivariate data, as carried out in the RELATE routine of the PRIMER software using the Bray-Curtis similarity matrices.
	Bray-Curtis similarity can be plotted as average similarity for each year over the study sites, and the entire similarity matrix can be further displayed as MDS plots or dendrogram from cluster analysis to illustrate spatial and temporal community patterns and trajectories of change between years. The resemblance matrix is also used for multivariate tests, and these test outcomes will be presented in tables. Spearman rank correlation coefficient δ between the similarity matrices of two years (latest monitoring year – each preceding year) is plotted for all yearly comparisons. An accompanying table presents test outcomes and power.
Calculation of whole of icon site score for parameter	No whole of icon site score for a community index can be derived as spatial and temporal variation is high in the Murray Mouth and Coorong, characterised by strong environmental gradients.
Power/Effect size	The Bray-Curtis index S_{jk} is sensitive to change and able to detect similarities between sites and years based on community complementarity. For the North Coorong, effect size was 21 and for the South Coorong 19. The Spearman rank correlation coefficient δ is by itself an index for effect size. The power to detect differences between similarity matrices from related versus totally unrelated communities was high.

Table 29. **Condition monitoring sites for macroinvertebrates in the Coorong lagoons, with new site numbers allocated following refinement of condition monitoring methods**

Region		Site				
		New	Old	Name	Latitude	Longitude
Murray Mouth	North Coorong	1	1	Monument Rd	35°31.526	138°49.741
		2	HC	Hunters Creek	35°32.213	138°53.399
		3	4	Mundoo Channel	35°32.256	138°54.087
		4	6	Ewe Island	35°33.485	138°57.362
		5	20	Pelican Point	35°35.604	139°01.250
North Lagoon		6	22	Mulbin Yerrok	35°40.152	139°08.323
		7	26	Noonameena	35°45.465	139°15.735
	South Coorong	8	24	Parnka Point	35°53.818	139°24.011
South Lagoon		9	19	Villa dei Yumpa	35°54.676	139°27.224
		10	16	Jack Point	36°01.929	139°34.150
		11	14	Loop Road	36°09.855	139°38.954

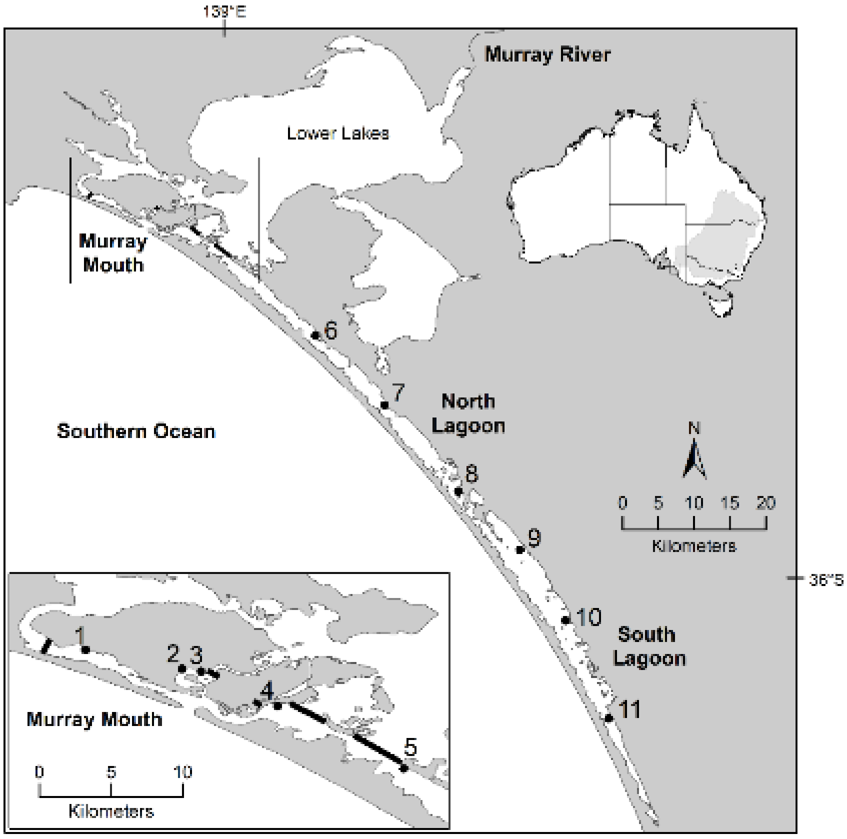

Figure 21. Location of macroinvertebrate monitoring sites for The Living Murray condition monitoring program sampled since 2004.

4.4. Vegetation

4.4.1. *Ruppia tuberosa* (David Paton, Fiona Paton and Colin Bailey)

Preferred citation for the *Ruppia tuberosa* chapter:

Paton D, Paton FL, Bailey C (2017). *Ruppia tuberosa*. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 59-65.

Refined Objective: Maintain or improve *Ruppia tuberosa* colonisation and reproduction (V-2).

Original: Maintain or improve *Ruppia tuberosa* colonisation and reproduction (V-2).

This monitoring and reporting component collects data on the distribution and abundance of sea tassel (*Ruppia tuberosa*) to assess the extent, vigour and resilience of the population (Table 30). *Ruppia tuberosa* essentially is an annual plant that exploits the ephemeral mudflats around the shores of the southern Coorong. During the dry period, when the water levels are lowest (late summer through autumn), the plant remains on or in the mud surface as seeds and turions. When water levels rise again in late autumn and winter, most, if not all, of the turions that survive the dry period sprout and some of the seeds germinate. The plants then grow over winter and, provided water levels remain adequate, reproduce sexually (producing seeds) and asexually (producing turions) during spring and early summer. Core populations of *Ruppia tuberosa* exist in water that is typically 0.3−0.9 m deep during winter and spring within the southern Coorong, with peak performances at the intermediate depths within this range. The extent to which water remains over the ephemeral mudflats during spring and summer is related to releases of water over the barrages. Years with little or no spring releases of water over the barrages are likely to restrict the ability of this annual plant to reproduce, while a sequence of such years is likely to exhaust seed banks and restrict the ability of this plant to maintain its presence in the southern Coorong. Salinities also affect *Ruppia tuberosa*, with higher salinities up to 110 g/L delaying and dampening rates of germination and sprouting. Even though salinities were largely within 60–100 g/L from 2011 to 2015, however, the recovery of populations of *Ruppia tuberosa* was slow following Millennium Drought because of the absence of an effective seed bank.

The monitoring programs for assessing the status of *Ruppia tuberosa* in the Coorong have developed from programs that were established before commencement of The Living Murray program. The monitoring program included the sites that were originally sampled in 1984–5 immediately prior to the Coorong and Lower Lakes being registered as a Wetland of International Importance. Those links provide a solid basis on which to set targets. The implementation of condition and intervention monitoring under The Living Murray program, however, has allowed those initial monitoring programs to be refined to be more effective in documenting changes and, importantly, any recovery.

The refined condition monitoring consists of assessing the distribution, abundance and performance of *Ruppia tuberosa* in the southern Coorong in summer and winter (Table 31). Winter monitoring assesses the plant's ability to survive periods of desiccation during autumn and re-establish once water levels rise and inundate the ephemeral mudflats (Table 32). Summer monitoring assesses the distribution and abundance of the plant at a time when the plant provides resources to waterfowl (Table 33). Measures of turion densities have been added to the original condition monitoring method because asexual reproduction is a key feature of *Ruppia tuberosa*, and there are two types of turions (one type is keenly sought by waterfowl). This additional monitoring component for turions assesses asexual reproductive outputs and is a measure of plant performance over summer. The percentage of cores that contain shoots and the number of shoots present in those cores with shoots also are measured to assess *Ruppia tuberosa* at the local or site level. The target for extent of occurrence for *Ruppia tuberosa* was initially set to 50 km, however, the spread of sites where the species was formerly abundant was 43 km, so the target in the southern Coorong (excluding outliers) is reduced to 43 km based on sampling at least 10 sites. Within a site, the density of *Ruppia tuberosa* varies across the bathymetry of a mudflat. Measures of cover, flowers, seeds and turions need to be taken in the primary areas for the plant at each site. These are typically between 0.4–0.7 m water depth in winter and in water 0–0.6 m deep in summer. The whole of icon site score for *Ruppia tuberosa* entails reporting index scores separately to provide high resolution that can direct and inform management.

Figure 22. Sampling *Ruppia tuberosa* in the Coorong region using a corer (left) to collect a 75 mm diameter x 40 mm deep core to check for presence of *Ruppia tuberosa* (right). Note the turbidity of the water, photos Coby Mathews.

Table 30. **Linkages between icon site specific ecological objective and ecological targets for *Ruppia tuberosa***

Characteristic	Description
Ecological objective	Maintain or improve *Ruppia tuberosa* colonisation and reproduction.
Definition of how objective and targets are interpreted	*Ruppia tuberosa* 'colonisation' is defined by the distribution (area of occupation, extent of occurrence) and abundance of *Ruppia tuberosa* plants (% cores with *Ruppia tuberosa* plants, and density of shoots) in winter and summer. 'Reproduction' is defined as successful flowering and seed production that leads to a net increase in the numbers of seeds in the sediment. The distribution and abundance of *Ruppia tuberosa* was greatly reduced during a period of negligible flows of river water over the Barrages and is still recovering, so the focus is not just maintaining the distribution and abundance of *Ruppia tuberosa* but increasing it.
	'Maintain' means that the distribution and abundance of *Ruppia tuberosa* is at least as good as the previous year, while 'improve' means that the distribution and/or abundance have increased over the last year. The distribution and abundance of *Ruppia tuberosa* in the Coorong was substantially reduced during the millennium drought and the species is still to fully recover, so the emphasis in monitoring is to improve colonisation and reproduction.
Ecological target(s)	Regional level 1. Extent of occurrence (EOO) along the Coorong of 43 km, excluding outliers. 2. Area of occupation (AOO) – within the sampled distribution, 80% of sites have plants present in both winter and summer. 3. Population vigour (VIG) – 50% of sites with *Ruppia tuberosa* should exceed the local site levels for a vigorous population. 4. Resilience (RES) – 50% of sites should exceed 2,000 seeds/m^2 (by 2019). Local (site) level for a vigorous population 5. At least 30% of cores (75 mm diam.) with *Ruppia tuberosa* plants in winter and in summer. 6. At least 10 shoots per core (75 mm diam.) with *Ruppia tuberosa* in winter. 7. At least 50% of surface sediment cores (75 mm diam. x 40 mm deep) with seeds. 8. At least 50 flower-heads/m^2 for 50% of the area sampled with *Ruppia tuberosa* at a site during spring flowering. 9. At least 50% of cores (75 mm diam.) taken across the *Ruppia tuberosa* beds at the end of summer contain turions. Long-term resilience 10. By 2019: 2,000 seeds/m^2 at 50% of sites (≥8 seeds per 75 mm diam. × 40 mm deep core). 11. By 2029: 10,000 seeds/m^2 at 50% of sites (≥40 seeds per 75 mm diam. × 40 mm deep core).
CMP monitoring objective	To collect data on the distribution and abundance of *Ruppia tuberosa* to assess if the populations are widespread, vigorous and resilient and have met the minimum ecological targets.
Key use of data	Data informs on the ability to maintain suitable water levels and salinities in the southern Coorong.

Table 31. **Summary description of sampling strategy and calculation of Indices for *Ruppia tuberosa***

Characteristic	Description
Sampling strategy	Number of sites: 12 (winter); 20 (summer): TBA (spring); TBA (autumn).
	Frequency & Timing: Annual winter (early July) and annual summer (January).
	Sub-regions covered: South Lagoon and southern half of North Lagoon of the Coorong.
	Method: A full assessment of the performance of *Ruppia tuberosa* requires sampling in winter (plants, seeds), spring (flowering), summer (plants, seeds), and autumn (turions). Limited budgets for monitoring should result in monitoring being prioritised in the following order: winter (July), then summer (January), then spring (November), and lastly autumn (March). July sampling: Involves taking 200 cores (75mm diam.) and counting the numbers of shoots present in each core across 12 sampling grids. These samples are taken over the main region supporting *Ruppia tuberosa* at each site in water that is typically 0.4–0.7 m deep (depending on the water level in the Coorong). Assessment of seeds in winter is based on 50 cores (75 mm diam. × 40 mm deep) taken along five permanent transects at each site, sieving these sediment samples through a 500 µm Endecott sieve and counting the seeds (and other biota) in each. For this sampling, two samples are taken at each of the following water depths: 20, 40, 60, 80 and 90 cm; along each of the five transects. January sampling: Involves taking four sets of 25 cores (75 mm diam. × 40 mm deep) across the useable mudflat: dry mudflat, at the water line, and from mudflats covered with 30 cm and 60 cm of water at each of 20 sites. Any shoots present are counted before the samples are sieved through a 500 µm Endecott sieve, and any seeds, turions and other biota detected are then counted. Spring sampling: If undertaken, would count the numbers of flower-heads on or near the surface on 1 m^2 quadrats along a minimum of three 20 m long transects placed over the main *Ruppia tuberosa* bed at each site. Autumn sampling: If undertaken, would follow the same methodology as January sampling.
	Data collected by David Paton and colleagues from The University of Adelaide.
Index/Indices	The indices used for monitoring *Ruppia tuberosa* in the Coorong fit in three categories: (1) regional indices around distribution and abundance; (2) site indices around the vigour of populations; and (3) indices of long-term resilience. The regional indices use International Union for Conservation of Nature (IUCN) criteria for Extent of Occurrence (EOO), Area of Occupation (AOO) and abundance (density) as a basis for setting regional targets. The EOO is set at 43 km based on the distances between long-term monitoring sites that have historically consistently supported *Ruppia tuberosa* along the Coorong. When *Ruppia tuberosa* is in good condition, the EOO is likely to approach or exceed 50 km. The intention is to improve the precision for the EOO only when the 43 km target is not met. This would be done by further sampling at 1km intervals from the southern and northern ends of the distribution to provide 1 km resolution to the EOO. This would change the tolerance from 2.5 km to 0.5 km. The target for AOO is set at 80% of sampling sites within the EOO having *Ruppia tuberosa* present. The resolution for this index is currently 5−10% because the numbers of sites sampled in summer and winter typically ranges from 12−20 sites. The AOO index is also likely to be sensitive to the actual EOO and has a tolerance of around 20%. Historically, all of the sampling sites had *Ruppia tuberosa* present and the target is currently being met. Again, when the target is not being met, additional sites could be sampled to improve the precision of the index. The third component of the regional assessment is 50% of

Characteristic	Description
	populations exceed the local site levels for a vigorous population. Like AOO, this vigour index (VIG) has a modest resolution of 5−10% and tolerance of around 20%. The site indices assess the vigour of the local populations. Vigour is measured as 30% of cores (200 in winter, 25 in summer) at the appropriate water depths having plants, with an average of 10 shoots per core with *Ruppia*, and 50% of cores with seeds (measures the spread of propagules and hence potential to re-establish with similar cover in the subsequent year). The flowering index is set at 50 flower heads/m^2 across 50% of samples with *Ruppia* and is measured in spring. Each flower head produces around 10 seeds, so 50 heads/m^2 has the potential to produce 500 seeds/m^2 or about 2 seeds per 75 mm diameter × 40 mm deep core. At least four years of adequate flowering at that level would be required to reach the 2,000 seeds/m^2 and so provide the plants with an initial level of resilience. Although the field sampling has been tested, flowering was low and well below this level. As most of the *Ruppia tuberosa* beds have become exposed in spring in recent years, there has been little or no opportunity to assess the flowering index further. The final component of the vigour indices is 50% of sediment cores taken over *Ruppia tuberosa* beds containing turions in late summer. Turions are short-lived perenniating tissues that were formerly very abundant in the Coorong and represent an asexual reproductive output for the plants. This index measures spread of these propagules across the *Ruppia tuberosa* beds and is a measure of potential to re-establish the beds with similar cover in the next year. At present this index is not being assessed, but is an important part of overall vigour for this plant. The final series of indices addresses the long-term capacity for resilience for *Ruppia tuberosa* and are based on the numbers of seeds within the seed banks at sites. At present, this is assessed at the individual site level and a regional index still needs to be defined. In keeping with the regional index for vigour, this should be at least 50% of sites having adequate resilience. Seed abundances for local populations are currently based on 50 cores in winter and 100 cores in summer, and the seed densities present in sediments have high variances (standard errors typically 20−30% of means), in part because many of the cores taken have had no seeds (large numbers of zeros). When seed abundances are above the resilience targets, all cores have seeds and the standard errors are typically around 10% of the means. A measure of the ultimate tolerance of these seed density indices can only be provided once the seed banks have recovered, but they are likely to be between 10−20%. At present (i.e. 2014), all sites within the Coorong fall well short of local site resilience targets.
Calculation of index	The targets are based on historical data for the Coorong and the performance of vigorous populations of *Ruppia tuberosa* in nearby ephemeral lakes. Prior to the millennium drought, *Ruppia tuberosa* was distributed along at least 43 km of the southern Coorong, and the four populations that have been monitored within this 43 km EOO since the late 1990s had at least 30% of cores with *Ruppia tuberosa* in early July when monitoring started, and at least 50% of cores had seeds. The density of 10 shoots per core with *Ruppia tuberosa* is based on the minimum number of shoots per core measured in early July over the last 7 years (2009−2015) for the vigorous population of *Ruppia tuberosa* at Lake Cantara. 80% of the populations assessed in the Coorong during the last 17 years have reached this target density of 10 shoots per core in at least one year of the monitoring program. These targets, however, should be viewed as minimum targets for good population vigour and should be placed in context relative to the maximum levels that are possible. For example, populations can have 100% cores with plants and the average densities of shoots can exceed 80 per core (75 mm diam.) in winter. Individual cores can easily exceed 100 shoots. Since sampling in the Coorong in winter takes place prior to further plant growth during spring, the populations growing on the ephemeral mudflats in the southern Coorong in winter are likely to increase their cover and

Characteristic	Description
	shoot densities prior to flowering in spring. Given this, the timing of winter sampling should occur at the same time each year (first week in July). The flowering index is set at 50 flower heads per m^2 for 50% of the area with *Ruppia tuberosa.* Each flower head that sets around 10 seeds, and so 50 heads/m^2 has the potential to produce 500 seeds/m^2 or about two seeds per core (75 diam. x 40 mm deep). Four years of flowering at that level would be required to reach the 2,000 seeds/m^2 to provide an initial level of resilience. The target is set to 'at least 50 flower heads/m^2 across 50% of the area sampled with *Ruppia tuberosa*', so, with such a target, more than four years of adequate flowering will be required to recover seed banks. The 2,000 seeds/m^2 (about 8 seeds per 75 mm diam. x 40 mm deep core) is based on the levels of seeds present on sites in winter in the 1990s. This may seem ample however some of these seeds are not viable, others remain dormant for several years and others may be buried too deep within the sediment to germinate, and would require some disturbance to bring them to the surface to allow germination. Immediately prior to the millennium drought, the population of *Ruppia tuberosa* at Villa dei Yumpa in the northern part of the South Lagoon had a seed bank of a little over 3,000 seeds/m^2 and this population re-established each winter until 2008, unlike other populations in the southern Coorong with much lower accumulated seed banks that disappeared in 2005 and 2006. For comparison, the vigorous population of *Ruppia tuberosa* at Lake Cantara has winter seed densities that have always exceeded 10,000 seeds/m^2. Even this level of seed abundance is lower than once recorded for sites in the southern Coorong in the early 1980s, where sites had >20,000 seeds/m^2. The target for turions is also modest with 50% of cores (75 mm diam.) containing turions in late summer. Like the target for 50% of cores with seeds, this turion target indicates a reasonable spread of asexually produced propagules across the *Ruppia tuberosa* beds that would give a reasonable prospect of establishing a similar percent cover (% cores with shoots) in the following winter. For comparison, 100% of cores with turions were often reported in historical samples.
	The various local indices are calculated from the raw data and consist of either the percent of cores (75 mm diam.) that contain *Ruppia tuberosa* shoots, seeds or turions; or the mean number of these plant items in the cores. In the case of flowering, flower-heads are scored in 1m^2 quadrats. The regional indices are based on the linear distances between sites with *Ruppia tuberosa* and on the percent of local sites with plants, with vigorous populations that have resilience.
	Data should be summarized for each sampling site and then site data used to report on the extent of occurrence (km spread along the Coorong); area of occupation (% of sites with *Ruppia tuberosa*); vigour (based on % cores and shoot abundances) and resilience (based on seed densities). A summary table could be used and the individual components displayed in figures.
Calculation of whole of icon site score for parameter	The whole of icon site score will consist of reporting extent of occurrence (EOO), area of occupation (AOO), vigour (VIG) and resilience (RES).
Power/Effect size	The sampling methods are such that the four regional indices are sensitive to changes with tolerances of around 2.5 km for EOO and around 20% for AOO, VIG and RES. The power regional scale indices could be improved by sampling more sites.

Table 32. Location of monitoring sites for *Ruppia tuberosa* in winter in the Coorong for the start of the third transect at each site (see Sampling strategy; coordinates Datum WGS84, Map 54H)

Site	Site details	Easting	Northing
TTX	5 km south of Salt Creek outlet	378832	5996641
SC	Bay north of Salt Creek entrance	377782	6000984
PP	Bay just north of Policeman's Point	372607	6009074
VDY	Bay just north of shack at Villa dei Yumpa	360339	6025095
NM	Opposite NPWS store shed at Noonameena	342635	6042214
Additional sites added in July 2009			
LC	Lake Cantara (western side)	387124	5978174
MF	Magrath Flat (middle of bay)	354909	6029549
RP	Rob's Point (north of the middle of bay)	345015	6039121
LP	Long Point (2nd bay north of Long Point)	334165	6048619
Additional sites added in July 2012			
S39W	western side of Coorong 3km S of SC	376658	5997276
PS	Princes Soak (western side of Coorong opp PP)	369797	6008099
S21E	Near Woods Well	370410	6013413
S06W	western side of Coorong opposite VDY	357927	6024000

Table 33. **Location of sampling sites for assessing the distribution and abundance of *Ruppia tuberosa* in the Coorong in January, with coordinates representing the average of the locations (water depths) sampled at each site in January 2015 (Datum WGS84, Map 54H). These locations may vary annually because of differences in water levels**

Site	Distance from Mouth (km)	Eastern Shore		Western Shore	
		Easting	Northing	Easting	Northing
N19	37	342533	6042174		
N12	44	347959	6037285		
N08	48	350522	6034249		
N02	54	354684	6029538		
S06	62	360454	6024694	358067	6024263
S11	67	363123	6022500	360914	6020398
S16	72	367049	6018086	363817	6016002
S21	77	370278	6013457	367502	6012315
S26	82	372526	6008937	369874	6007766
S31	87	374401	6004315	372631	6003931
S33	89	376381	6003588		
S36	92	377502	6000803	375476	5999686
S41	97	378547	5996472	377511	5995712

4.4.2. Lower Lakes vegetation (Jason Nicol)

Preferred citation for the Lower Lakes vegetation chapter:

Nicol J (2017). Lower Lakes vegetation. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 66-74.

Refined Objective: Maintain or improve aquatic and littoral vegetation in the Lower Lakes (V-3).

Original: Maintain or improve aquatic and littoral vegetation in the Lower Lakes (V-3).

This monitoring and reporting component collects information regarding the aquatic and littoral vegetation of the Lower Lakes to determine current condition and change through time (Table 34). Generally, there was a diverse submergent, emergent and amphibious plant community in Lower Lakes' wetlands and in aquatic habitats on and around Hindmarsh Island prior to the impacts of the Millennium Drought (Renfrey et al. 1989; Holt et al. 2005; Nicol et al. 2006). The surveys are, however, single snapshots that do not provide an indication of temporal variability. Spatio-temporal variability of native aquatic and littoral vegetation, and the provision of ecosystem services, needs to be taken into consideration when developing targets. Exotic species and potentially invasive native species also need to be taken into consideration. The dominant exotic species in the Lower Lakes are *Cenchrus clandestinus* and *Paspalum distichum* (Frahn et al. 2014), which are rhizomatous and stoloniferous, warm season growing grasses that establish well in the littoral zone throughout the Lower Lakes, except in areas where there is high soil salinity (Frahn et al. 2014). The native *Typha domingensis* and *Phragmites australis* are tall rhizomatous emergent species that are common throughout the Lower Lakes (Frahn et al. 2014) and are adapted to stable water levels (Blanch and Walker 1997). They are an important component of the vegetation in the Lower Lakes, however, they often form undesirable monospecific stands.

Condition monitoring of aquatic and littoral vegetation in the Lower Lakes commenced in spring 2008 and has been undertaken every spring and autumn until autumn 2014. Surveys were not undertaken in spring 2014 but a survey to collect data was funded in autumn 2015. Monitoring sites were grouped on the basis of habitat (lakeshore or wetland), location (Lake Alexandrina, Lake Albert or Goolwa Channel) and permanency (seasonal or permanent wetlands). Due to the large number of plant species present in the Lower Lakes, native species were classified into water regime functional groups using the classification in Gehrig and Nicol (2010).

The refined condition monitoring methods divide the Lower Lakes into different habitats based on hydrology and geomorphology: Lake Alexandrina, Lake Albert, Goolwa Channel (the reach between the former Clayton Regulator site and Goolwa Barrage, including the lower Finniss River and lower Currency Creek), permanent wetlands and seasonal (temporary) wetlands (Table 35-Table 39). Within Lake Alexandrina, Lake Albert and the Goolwa Channel, there are three zones based on elevation: the littoral zone, the aquatic zone and the deep water zone. Permanent wetlands are typically shallow and have no deep water zone; hence they are divided into littoral and aquatic zones. Seasonal wetlands are divided into two zones: the wetland edge and wetland bed. Additionally, there is a seasonal component for seasonal wetlands with targets for spring (high water level) and autumn (low water level) (Table 40). Targets for aquatic and littoral vegetation are based on a minimum proportion of quadrats in each habitat and zone having a minimum cover score of desirable species and a maximum number of quadrats having a maximum cover score of undesirable species in any given survey. The targets are based on expert knowledge, and broadly aim to detect improvements in the abundance of diverse aquatic and littoral vegetation at monitoring sites in the Lower Lakes (Table 41).

Table 34. Linkages between icon site specific ecological objective and ecological targets for Lower Lakes aquatic and littoral vegetation

Characteristic	Description
Ecological objective	Maintain or improve aquatic and littoral vegetation in the Lower Lakes.
Definition of how objective and targets are interpreted	'Maintain' is when the condition scores for the diversity/coverage of vegetation species/communities at each habitat remain at baseline levels (2012).
	'Improve' is when the condition scores for the diversity/coverage of vegetation species/communities at each habitat move towards and/or exceed target levels.
	'Aquatic vegetation' is defined as the plant community that requires the presence of surface water at some point in their life history.
	'Littoral vegetation' is defined as the plant community that occupies the fringes of waterbodies.
	'Amphibious species' is defined as a species that is adapted to wetting and drying and has a requirement for wetting and drying to complete its lifecycle.
	'Emergent species' is defined as a species that requires saturated soil or shallow water but has a requirement for organs above the water level.
	'Aquatic species' is a species that grows entirely under the water and has a requirement of surface water to complete its life cycle.
Ecological targets	Ecological targets are for five habitat zones (Table 36-Table 40).
CMP monitoring objective	To collect information regarding the aquatic and littoral vegetation of the Lower Lakes to determine current condition and change through time.
Key use of data	The data informs management of Lower Lakes' water levels for improved vegetation outcomes and TLM target assessment.

Figure 23. Lower Lakes vegetation monitoring at Clayton Bay, 26/10/2009, photo Susan Gehrig.

Table 35. Summary description of sampling strategy and calculation of index

Characteristic	Description
Sampling strategy	Number of sites: 36 sites.
	Frequency & Timing: Twice yearly in spring and autumn.
	Sub-regions covered: Lake Alexandrina, Lake Albert, Goolwa Channel, permanent wetlands and seasonal wetlands.
	Method: Vegetation surveys at fixed sites. Plants are identified using keys from numerous identification books. Wetlands: At each survey site, a transect running perpendicular to the shoreline and three, 1 x 3 m quadrats, separated by 1 m established at regular elevation intervals that represent the dominant plant communities. Lake shores: With the exception of quadrat placement, lakeshores were surveyed using the same technique as wetlands. At each site, a transect running perpendicular to the shoreline was established and three 1 x 3 m quadrats separated by 1 m at elevation intervals of +0.8, +0.6, +0.4, +0.2, 0 and −0.5 m Australian Height Datum (AHD).
	Data collected by SARDI Aquatic Sciences.
Index/Indices	See Table 36-Table 40.
Calculation of index	Based on expert opinion and pre 2007 data (Nicol et al. 2006; Renfrey et al. 1989).
	See Table 36-Table 40.
	Presentation of results are to be displayed graphically to indicate how the target tracks through time.
Calculation of whole of icon site score for parameter	Whole of habitat condition scores for each survey are calculated using the following equation: Habitat condition score = Σ proportion of targets achieved in each elevation zone/number of elevations zones Whole of icon site condition score for each survey is calculated using the following equation: Whole of system score = Σ habitat scores/number of habitats
Power/Effect size	The index was used for all habitats in the *Lower Lakes Vegetation Condition Monitoring - 2015-16* report (Nicol et al. 2016) and was shown to be sensitive.

Table 36. Vegetation targets for Lake Alexandrina

Zone	Target
Littoral +0.8 to +0.6 m AHD	<40% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 5) of *Typha* and *Phragmites*.
	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 50% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Aquatic +0.4 to 0 m AHD	<40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Typha* and *Phragmites*.
	Minimum of 20% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	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).
Deep water <0 m AHD	Permanent inundation.

Table 37. Vegetation targets for Lake Albert

Zone	Target
Littoral +0.8 to +0.6 m AHD	<40% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 5 or greater) of *Typha* and *Phragmites*.
	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 35% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Aquatic +0.4 to 0 m AHD	<40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Typha* and *Phragmites*.
	Minimum of 20% of quadrats in any given survey contain emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	Minimum of 20% of quadrats in any given survey contain submergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Deep water <0 m AHD	Permanent inundation.

Table 38. Vegetation targets for Goolwa Channel

Zone	Target
Littoral +0.8 to +0.6 m AHD	<50% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 5 or greater) of *Typha* and *Phragmites*.
	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 50% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
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 *Typha* and *Phragmites*.
	Minimum of 20% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	Minimum of 40% of quadrats in any given survey contain native submergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Deep water <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).

Table 39. Vegetation targets for permanent wetlands

Zone	Target
Littoral >+0.6 m AHD	<35% of quadrats in any given survey containing >75% combined cover (Braun-Blanquet score 5 or greater) of *Typha* and *Phragmites*.
	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 50% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Aquatic <+0.6 m AHD	<40% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Typha* and *Phragmites*.
	Minimum of 20% of quadrats in any given survey contain native emergent species (other than *Typha* and *Phragmites*) with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	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).

Table 40. Vegetation targets for a. seasonal wetlands in spring and b. seasonal wetlands in autumn

a. Zone	Target
Edge	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 50% of quadrats in any given survey contain native emergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Bed	Minimum of 20% of quadrats in any given survey contain native emergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	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).
	Minimum of 25% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
b. Zone	**Target**
Edge	<20% of quadrats in any given survey containing >50% combined cover (Braun-Blanquet score 4 or greater) of *Cenchrus* and *Paspalum*.
	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).
	Minimum of 50% of quadrats in any given survey contain native emergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
Bed	Minimum of 20% of quadrats in any given survey contain native emergent species with a combined cover of >5% (Braun-Blanquet score 2 or greater).
	Minimum of 25% of quadrats in any given survey contain native amphibious species with a combined cover of >5% (Braun-Blanquet score 2 or greater).

Table 41. Understorey vegetation site numbers, site name, location, habitat type (wetland or lakeshore), number of survey sites and the year sites were established

Site	Site name	Location	Habitat	Number of survey sites	Year established
1	Bremer Mouth Lakeshore	Lake Alexandrina	lakeshore	1	2008
2	Brown Beach 1	Lake Albert	lakeshore	1	2008
3	Brown Beach 2	Lake Albert	lakeshore	1	2008
4	Clayton Bay	Goolwa Channel	lakeshore	1	2009
5	Currency Creek 3	Goolwa Channel	lakeshore	1	2008
6	Currency Creek 4	Goolwa Channel	lakeshore	1	2008
7	Goolwa North	Goolwa Channel	lakeshore	1	2009
8	Goolwa South	Goolwa Channel	lakeshore	1	2009
9	Hindmarsh Island Bridge 01	Goolwa Channel	lakeshore	1	2009
10	Hindmarsh Island Bridge 02	Goolwa Channel	lakeshore	1	2009
11	Lake Reserve Rd	Lake Alexandrina	lakeshore	1	2008
12	Loveday Bay	Lake Alexandrina	wetland	4	2009
13	Loveday Bay Lakeshore	Lake Alexandrina	lakeshore	1	2009
14	Lower Finniss 02	Goolwa Channel	lakeshore	1	2009
15*	Milang	Lake Alexandrina	wetland	4	pre-2008
16	Milang Lakeshore	Lake Alexandrina	lakeshore	1	2009
17	Pt Sturt Lakeshore	Lake Alexandrina	lakeshore	1	2008
18	Pt Sturt Water Reserve	Lake Alexandrina	lakeshore	1	2008
19	Teringie Lakeshore	Lake Alexandrina	lakeshore	1	2008
20	Upstream of Clayton Regulator	Lake Alexandrina	lakeshore	1	2009
21	Wally's Landing	Goolwa Channel	lakeshore	1	2009
22	Warrengie 1	Lake Albert	lakeshore	1	2009
23	Lower Finniss 03	Goolwa Channel	lakeshore	1	2009
24	Narrung Lakeshore	Lake Alexandrina	lakeshore	1	2008
25	Nurra Nurra	Lake Albert	lakeshore	1	2008
26	Warrengie 2	Lake Albert	lakeshore	1	2009
27	Angas Mouth	Lake Alexandrina	wetland	1	2008
28	Bremer Mouth	Lake Alexandrina	wetland	1	2008
29	Dunns Lagoon	Lake Alexandrina	wetland	4	2008
30	Goolwa Channel Drive	Lake Alexandrina	wetland	3	2008
31	Hunters Creek	Lake Alexandrina	wetland	5	2008
32	Poltalloch	Lake Alexandrina	wetland	2	2008
33	Pt Sturt	Lake Alexandrina	wetland	2	2008
34*	Teringie	Lake Alexandrina	wetland	4	pre-2008
35*	Waltowa	Lake Albert	wetland	2	pre-2008
36*	Narrung	Lake Alexandrina	wetland	3	pre-2008

*Existing SAMDBNRM Board community monitoring site

Table 42. GPS coordinates (UTM format, WGS 84) of vegetation monitoring sites.

Site #	Site name	Easting	Northing
1	Bremer Mouth Lakeshore	323061	6081991
2	Brown Beach 1	350172	6052777
3	Brown Beach 2	350287	6053158
4	Clayton Bay	311301	6070626
5	Currency Creek 3	296772	6074222
6	Currency Creek 4	301013	6071800
7	Goolwa North	303330	6070156
8	Goolwa South	300490	6066366
9	Hindmarsh Island Bridge 01	299670	6068521
10	Hindmarsh Island Bridge 02	299695	6068616
11	Lake Reserve Rd	339298	6089987
12	Loveday Bay	329431	6058407
13	Loveday Bay Lakeshore	326621	6061647
14	Lower Finniss 02	305131	6076401
15	Milang	315964	6079870
16	Milang Lakeshore	316081	6079746
17	Pt Sturt Lakeshore	322811	6069643
18	Pt Sturt Water Reserve	317673	6070784
19	Teringie Lakeshore	327461	6066887
20	Upstream of Clayton Regulator	312281	6069151
21	Wally's Landing	303066	6079631
22	Warrengie 1	347722	6049163
23	Lower Finniss 03	305131	6072406
24	Narrung Lakeshore	333762	6069807
25	Nurra Nurra	341786	6063837
26	Warrengie 2	348487	6049133
27	Angas Mouth	318391	6081206
28	Bremer Mouth	323056	6082019
29	Dunns Lagoon	312417	6070300
30	Goolwa Channel Drive	307024	6064437
31	Hunters Creek	308219	6065526
32	Poltalloch	343248	6071554
33	Pt Sturt	322778	6069794
34	Teringie	327334	6065286
35	Waltowa	353908	6057756
36	Narrung	334542	6068744

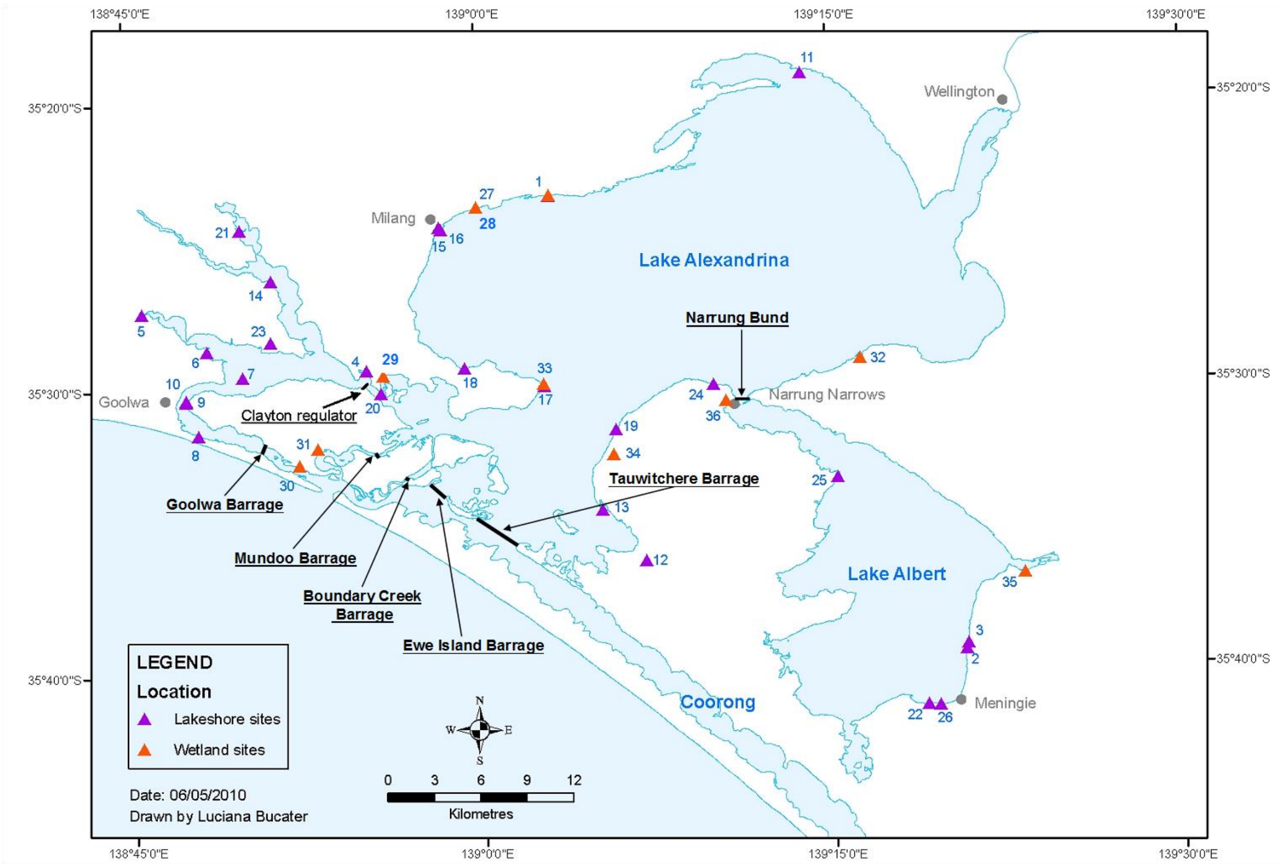

Figure 24. Location of lakeshore and wetland vegetation monitoring sites for The Living Murray condition monitoring program.

Figure 25. Lower Lakes vegetation *Phragmites australis,* Tolderol Point, 22/11/2010, photo Jason Nicol.

4.5. Mudflats (Sabine Dittmann)

Preferred citation for the Mudflats chapter:

Dittmann S (2017). Mudflats. In: *Condition Monitoring Plan (Revised) 2017. The Living Murray – Lower Lakes, Coorong and Murray Mouth Icon Site.* DEWNR Technical report 2016–17. Adelaide: Government of South Australia, through Department of Environment, Water and Natural Resources, p. 75-81.

Refined objective: Maintain or improve habitable sediment conditions in mudflats (M-2 and M-3 combined).

Original: Maintain sediment size range in mud flats (M-2).

Maintain organic content for mud flats (M-3).

This monitoring and reporting component collects data on sediment grain size composition, sediment organic matter content and microphytobenthic biomass (Table 43). The sedimentary variables are meaningful indicators for environmental change and allow to analyse links between the environmental conditions and benthic macroinvertebrates. Sediment properties are prime determinants of benthic organisms, affecting their distribution, abundance, and the size composition of benthic organisms (Sanders 1958; Patrício et al. 2009; Pratt et al. 2014). Grain size composition, nutrient and organic matter load characterise habitat attributes for organisms living inside the sediment, while microphytobenthic biomass, as estimated through Chlorophyll-a values, gives a further insight into food availability for primary consumers (grazer, surface-deposit-feeders). Microphytobenthos is responding to nutrient availability and light (Cahoon 1999; Cebrian et al. 2009).

Changes in sediment properties originate from deposition or erosion. In the Murray Mouth and Coorong, such changes could be caused for example by dredging operations mobilising and suspending sediments, by release of sediment trapped on the lake side of barrages upon opening of gates, or through aeolian deposition of sandier sediment from sand dunes. Smaller scale modifications of sediment properties originate from animal-sediment relationships (Snelgrove and Butman 1994), or trapping of finer sediment amongst macroalgal mats. The organic matter content in sediments can also be affected by algal mats, and by nutrient influxes through changing water quality, often indicative of eutrophication (Heip 1995; Rodil et al. 2013). Sediments with a biogeochemistry that is anoxic are uninhabitable apart from few highly tolerant species (Pearson and Rosenberg 1978).

Monitoring of mudflats began in 2004 and methods have advanced over the years. In the first year, sediment grain size was analysed using a mechanical sieve shaker, but since 2005 samples are processed using laser diffraction methodology with a Malvern Mastersizer. For the sediment organic matter content, dry weight has been initially obtained by using drying ovens, a lengthy procedure over several days to obtain constant dry weight. Since 2013, moisture balances are used and constant dry weight obtained in much shorter times and with higher accuracy. Chlorophyll-*a* was added in the monitoring in 2007 to obtain a measure for microphytobenthic biomass. Findings from the first 10 years of macroinvertebrate monitoring were recently published in Dittmann et al. (2015).

The refined condition monitoring assesses foraging habitat condition (Table 44-Table 47). The 11 sampling sites for mudflat monitoring (also used for monitoring invertebrates) are arranged along the environmental gradient from the estuary into the lagoon (Table 48).

Table 43. Linkages between icon site specific ecological objective and ecological targets for mudflats

Characteristic	Description
Ecological objective	Maintain or improve habitable sediment conditions in mudflats.
Definition of how objective and targets are interpreted	'Mudflat' is defined as soft sediment habitat episodically emerged and submerged by water through tides, wind seiching, and water level variations subject to flow.
	'Habitable sediment conditions' are biogeochemical characteristics that allow sediment to be inhabited by diverse and abundant macroinvertebrate communities. Habitable sediments are located in healthy environments (good water quality, undisturbed and with natural adjacent habitats).
	'Maintain' is defined as staying within the reference dynamic derived from surveys between 2004 and 2013, a decade encompassing various drought and flow conditions.
	'Improve' is defined as deepening the layer of aerobic sediment.
Ecological target(s)	1. Habitable sediments are occurring along the Murray Mouth and Coorong into the South Lagoon. 2. Sediments are maintained as fine to medium sands and are mostly moderately well sorted. 3. Sediment organic matter is maintained. 4. Sediments provide microphytobenthic food for the benthic food web.
CMP monitoring objective	To collect data on sediment grain size composition, sediment organic matter content and microphytobenthic biomass.
Key use of data	Data informs on habitat value for macroinvertebrates, which are a major food source for waders and fish. Sediment conditions in mudflats reflect changes in water quality and water levels.

Figure 26. Coorong Mudflat and Macroinvertebrate sampling, photo Sabine Dittmann.

Table 44. Summary description of sampling strategy for sediment characteristics

Characteristic	Description
Sampling strategy	Number of sites: Sampling at 11 sites.
	Frequency & Timing: Annually in spring–early summer (November–December).
	Sub-regions covered: Murray Mouth, North Lagoon, South Lagoon. For sediment conditions, these regions will continue to be surveyed, while the sub-regions North and South Coorong are used in the context of invertebrate data where an ecological boundary occurs around Noonameena (site 7).
	Method: Samples are collected between the shore and the water line, taken in exposed sediment (if available), at the water edge, and in up to knee deep water, to capture the spatial gradient across the mudflats and varying water levels. Sediment samples are obtained from each site for the analysis of grain size, organic matter content and chlorophyll-*a* (as a proxy for microphytobenthic biomass). For each of these sediment variables, three replicate samples are taken per site to account for small-scale variability. Sediment grain size composition: samples are taken using a cut-off 60 mL syringe (surface area 6.6 cm^2), inserted to ~5 cm into the sediment. Sediment organic matter: samples are also taken using a cut-off 60 mL syringe (surface area 6.6 cm^2), inserted to ~3 cm into the sediment. Chlorophyll-*a*: samples are taken using a 5 mL vial inserted 1 cm into the sediment, giving a 1 cm^3 sample. To extract the chlorophyll, 5 mL of methanol are added, and the vial vigorously shaken before being wrapped in aluminium foil. All sediment samples are stored on ice for transport and frozen upon return to the laboratory until further analysis.
	Data collected by Sabine Dittmann, Flinders University.

Figure 27. Mudflats along the Coorong, photo Sabine Dittmann.

Table 45. Summary description of calculation of index for sediment grain size composition (median and sorting coefficient)

Characteristic	Description
Index/Indices	Index of relative change: The ratio is 0 when observed and reference data are the same, positive when observed data exceed reference data, and negative if they are below this reference.
Calculation of index	Index of relative change: The data on sediment composition from all 11 monitoring sites in the Murray Mouth and Coorong are used, as no significant regional differences were found for previous monitoring periods. Sediments can be considered to be in a good condition when they consist of fine to medium sands and are moderately well sorted.
	Index of relative change: Calculated as a ratio of observed (t_x, any particular year) to reference data (t_r), following standardised time series data analysis by Babcock et al. (2010): ratio = log (t_x/t_r) The reference data are based on an average of the monitoring years 2005–2013: Median grain size: 235 µm (lower–upper bound of confidence interval: 214 µm–256 µm) Sorting coefficient: 0.56 (lower–upper bound of confidence interval: 0.53–0.59) These references should be recalculated based on data from future monitoring years, because the previous 10 year monitoring period encompassed extreme events and did not constitute a typical estuarine situation.
	Index of relative change: Median grain size and sorting coefficient plotted in relation to previous years to detect trends of change. The actual sediment composition values also presented as stacked bar graphs, and a table with metrics for sediment composition to allow comparisons with records from other estuaries.
Calculation of whole of icon site score for parameter	Index of relative change was calculated based on all sampling sites and the index values ranged from −0.1 to 0.14 for median grain size, and from −0.14 to 0.11 for the sorting coefficient.
Power/Effect size	The approach was sensitive to change in condition and effect size for the index of relative change for the median grain size was 0.08, and for the sorting coefficient 0.11.

Table 46. Summary description of calculation of index for sediment organic matter

Characteristic	Description
Index/Indices	Index of relative change: The ratio is 0 when observed and reference data are the same, positive when observed data exceed reference data, and negative if they are below this reference.
Calculation of index	Index of relative change: The data on sediment organic matter are used from all 11 sites, but the index was also calculated by region because average organic matter in the South Lagoon was twice as high as in the Murray Mouth and North Lagoon. Sediments can be considered to be in a good condition when the average organic matter is not exceeding the upper confidence limit for each region.
	Index of relative change: Calculated as a ratio of observed (t_x, any particular year) to reference data (t_r), following standardised time series data analysis by Babcock et al. (2010): ratio = log (t_x/t_r) The reference data and confidence intervals (lower and upper bound) based on an average of the monitoring years 2005–2013 for all sites and each region are: All sites: 1.69 (1.52–1.86) Murray Mouth: 1.29 (1.12–1.46) North Lagoon: 1.29 (1.11–1.47) South Lagoon: 2.76 (2.41–3.10) These references should be recalculated based on data from future monitoring years, because the previous 10 year monitoring period encompassed extreme events and did not constitute a typical estuarine situation.
	Index of relative change: For sediment organic matter will be plotted in relation to previous years to detect trends of change. The actual sediment organic matter values will also be presented as graphs to allow comparisons with records from other estuaries.
Calculation of whole of icon site score for parameter	The index of relative change was calculated based on all sampling sites and the index values ranged from −0.1 to 0.15 for all sites. These ranges in the index were different for each region.
Power/Effect size	The approach was sensitive to change in condition and effect size for the index of relative change for organic matter was 0.10 for all sites. Effect sizes for each region separately were slightly higher (0.12 for the South Lagoon, 0.13 for the North Lagoon, and 0.15 for the Murray Mouth).

Table 47. Summary description of sampling strategy and calculation of Index for sediment chlorophyll-a

Characteristic	Description
Index/Indices	Index of relative change: The ratio is 0 when observed and reference data are the same, positive when observed data exceed reference data, and negative if they are below this reference.
Calculation of index	Index of relative change: The data on sediment chl-*a* were used from all 11 sites, but the index was also calculated by region as average sediment chl-*a* was higher in the Murray Mouth mudflats than in the South Lagoon. Sediments can be considered to be in a good condition when the average sediment chl-*a* is above the lower bound of the confidence interval for each region.
	Index of relative change: Calculated as a ratio of observed (t_x, any particular year) to reference data (t_r), following standardised time series data analysis by Babcock et al. (2010): ratio = log (t_x/t_r) The reference data and confidence intervals (lower and upper bound) based on an average of the monitoring years 2005–2013 for all sites and each region are: All sites: 2.05 (1.64–2.45) Murray Mouth: 2.48 (1.81–3.16) North Lagoon: 2.18 (1.38–2.98) South Lagoon: 1.19 (0.63–1.75) These references should be recalculated based on data from future monitoring years, because the previous 10 year monitoring period encompassed extreme events and did not constitute a typical estuarine situation.
	Index of relative change: For sediment chl-*a* will be plotted in relation to previous years to detect trends of change. The actual sediment chl-*a* values will also be presented as graphs to allow comparisons with records from other estuaries.
Calculation of whole of icon site score for parameter	The index of relative change was calculated based on all sampling sites and the index values ranged from −0.97 to 0.38 for all sites. These ranges in the index were different for each region.
Power/Effect size	The approach was sensitive to change in condition and effect size for the index of relative change for organic matter was 0.77 for all sites. Effect sizes for each region separately were 0.68 for the South Lagoon, 0.73 for the North Lagoon, and 0.88 for the Murray Mouth.

Table 48. Condition monitoring sites for mudflats in the Coorong lagoons, with new site numbers allocated following refinement of condition monitoring methods

<table>
<tr><th colspan="2"></th><th colspan="3">Site</th><th colspan="2"></th></tr>
<tr><th colspan="2">Region</th><th>New</th><th>Old</th><th>Name</th><th>Latitude</th><th>Longitude</th></tr>
<tr><td rowspan="5">Murray Mouth</td><td rowspan="7">North Coorong</td><td>1</td><td>1</td><td>Monument Rd</td><td>35°31.526</td><td>138°49.741</td></tr>
<tr><td>2</td><td>HC</td><td>Hunters Creek</td><td>35°32.213</td><td>138°53.399</td></tr>
<tr><td>3</td><td>4</td><td>Mundoo Ch.</td><td>35°32.256</td><td>138°54.087</td></tr>
<tr><td>4</td><td>6</td><td>Ewe Island</td><td>35°33.485</td><td>138°57.362</td></tr>
<tr><td>5</td><td>20</td><td>Pelican Point</td><td>35°35.604</td><td>139°01.250</td></tr>
<tr><td rowspan="3">North Lagoon</td><td>6</td><td>22</td><td>Mulbin Yerrok</td><td>35°40.152</td><td>139°08.323</td></tr>
<tr><td>7</td><td>26</td><td>Noonameena</td><td>35°45.465</td><td>139°15.735</td></tr>
<tr><td rowspan="4">South Coorong</td><td>8</td><td>24</td><td>Parnka Point</td><td>35°53.818</td><td>139°24.011</td></tr>
<tr><td rowspan="3">South Lagoon</td><td>9</td><td>19</td><td>Villa dei Yumpa</td><td>35°54.676</td><td>139°27.224</td></tr>
<tr><td>10</td><td>16</td><td>Jack Point</td><td>36°01.929</td><td>139°34.150</td></tr>
<tr><td>11</td><td>14</td><td>Loop Road</td><td>36°09.855</td><td>139°38.954</td></tr>
</table>

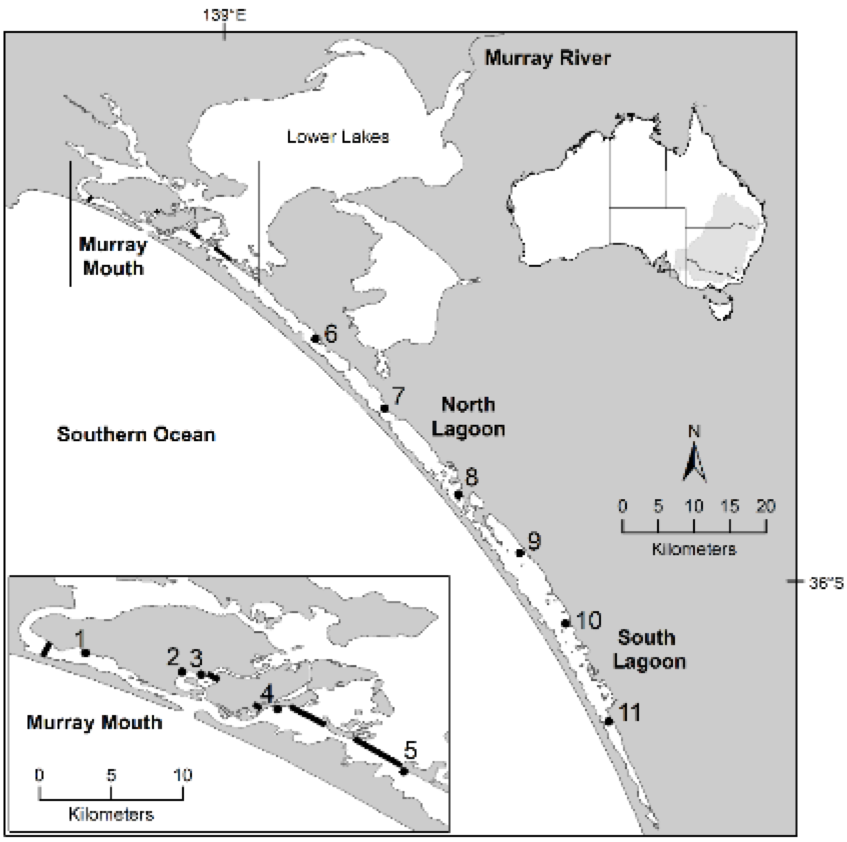

Figure 28. Location of macroinvertebrate monitoring sites for The Living Murray condition monitoring program sampled since 2004.

4.6. Water

Refined Objective: Support aquatic habitat by establishing and maintaining variable salinity regimes in the Murray Mouth Estuary, North Lagoon and South Lagoon (W-1).

Original: Establish and maintain variable salinity regime with >30% of area below sea water salinity concentrations in Murray Mouth Estuary and North Lagoon (W-1).

The objective and targets are a form of compliance monitoring related to environmental water management, particularly barrage releases. This monitoring component uses existing water quality stations along the estuary and Coorong to assess the extent, timing and duration that the salinity targets are met.

The Coorong receives river inflows at the northern end from Lake Alexandrina, and at times to the southern end via Salt Creek (DEWNR 2015). Sea water also enters the northern Coorong from the Southern Ocean when river inflows to the Murray Mouth are absent. It is a 'reverse estuary' (i.e. salinity increases with distance from the Mouth), with salinities ranging from fresh to brackish in parts of the Murray Mouth estuary to hyper-saline in the areas of the Southern Lagoon (DEWNR 2015).

The Murray Mouth Estuary is an important transitional area for many species of fish that rely on estuarine conditions to complete their lifecycles (MDBA 2014). Historically, the North Lagoon was mainly estuarine and provided rich, sheltered waters for fish and lifecycle cues required for aquatic seed germination (MDBA 2014). Evidence suggests that the South Lagoon was historically fresher (Krull et al. 2009) but more recent years has seen increase salinities and unfavorable water levels that have led to a severe decline of keystone species such as *Ruppia tuberosa* (MDBA 2014).

Reporting on this objective will support the assessment of other objectives and targets, in particular F-3, F-4, I-1, M-2, M-3 and V-2.

Table 49. Linkages between icon site specific ecological objective and ecological targets for estuarine conditions

<table>
<tr><th>Characteristic</th><th>Description</th></tr>
<tr><td>Ecological objective</td><td>Support aquatic habitat by establishing and maintaining variable salinity regimes in the Murray Mouth Estuary, North Lagoon and South Lagoon.</td></tr>
<tr><td rowspan="6">Definition of how objective and targets are interpreted</td><td>'Murray Mouth Estuary' is defined as the area on the ocean side of barrages extending from Goolwa barrage to Pelican Point.</td></tr>
<tr><td>'North Lagoon' is defined as the area from Pelican Point and Parnka Point.</td></tr>
<tr><td>'South Lagoon' is defined as the Lagoon below Parnka Point.</td></tr>
<tr><td>'Variable salinity regime' within the Murray Mouth Estuary is defined as conditions where a shallow salinity gradient ranges between ~1 ppt and < 35 ppt.</td></tr>
<tr><td>'Variable salinity regime' within the North Lagoon is defined as conditions where salinity gradient remains < 45 ppt.</td></tr>
<tr><td>'Variable salinity regime' within the South Lagoon is defined as conditions where salinity gradient ranges between 60 ppt to 100 ppt.</td></tr>
<tr><td>Ecological target(s)</td><td>1. A salinity gradient ranging between ~1 ppt to <35 ppt is established between Goolwa barrage and Pelican Point (estuary) for 100% of days.*
2. A salinity gradient where < 45 ppt is established between Pelican Point and Parnka Point (North Lagoon) for 100% of days.
3. A salinity gradient ranging between 60 ppt to 100 ppt is established south of Parnka Point (South Lagoon) for 100% of days.</td></tr>
<tr><td>CMP monitoring objective</td><td>Assessment of the salinity gradient along the Murray Mouth Estuary, North Lagoon and South Lagoon.</td></tr>
</table>

Key use of data	Data informs the connectivity between the Lakes and Coorong, and the extent and duration of salinity conditions, which influence benthic macroinvertebrates, fish and waterbirds. The resultant conditions is highly influenced by the volumes and timing of water releases through the barrages, and management of water levels in the Lower Lake wetlands. Links to the following objectives: F-4 and F-3 and F-1. Reporting and data collection incorporated into reporting for Target I-1.

* short-term deviations from this prescribed gradient may be expected, particularly in periods of low barrage releases and fluctuations in weather and natural variability.

Table 50. **Summary description of sampling strategy and calculation of Indices for estuarine conditions**

Characteristic	Description
Sampling strategy	Desktop method. Daily time step data is downloaded from the WaterConnect website: https://www.waterconnect.sa.gov.au/Systems/SWD/Pages/Default.aspx The following surface water data locations may be used for assessing the Murray Mouth Estuary: • A4260525 Goolwa Barrage DS • A2461036 Beacon 17 (or 12?) – adjacent Reedy Island • A4261037 Port Pullen • A4261039 Adjacent Barker Knoll • A4261043 Beacon 1 – near Ewe Island Shacks • A4261134 Beacon 19 Pelican Point The following surface water data locations may be used for assessing the North Lagoon: • A4260664 Mark Point • A4261135 Long Point The following surface water data locations may be used for assessing the South Lagoon: • A4260633 Parnka Point • A2461209 near Cattle Island • A4261165 NW Snipe Island
Index/Indices	Salinity in parts per thousand (ppt) at each location over the year on a daily time step. The 'area' of the estuary and North Lagoon will be expressed as kilometers (km) along the estuary, North Lagoon and South Lagoon, where existing stations are located, that are within the target salinity range.
Calculation of index	Electrical conductivity (µ/cm) is sampled at the water quality stations on a daily basis, and is converted to ppt.
Calculation of whole of icon site score for parameter	Not identified for this objective.
Power/Effect size	n/a

Refined Objective: Maintain a permanent Murray Mouth opening through freshwater outflows to improve water quality and maximise connectivity (W-2).

Original target: Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity (W-2).

This is an assessment of physical rather than ecological condition. The objective assesses the percentage of days that the Murray Mouth remains open through adequate River Murray discharge and without mechanical intervention (e.g. dredging). To maintain a permanent Murray Mouth opening through freshwater outflows, it is estimated that 730-1090 GL/year (or 2-3 GL/day) of barrage releases is required (MDBA 2014). A required annual volume of 2 GL/day barrage releases is the minimum volume required to minimise sand ingress (O'Connor et al. 2015).

The targets are also designed to be a measure of the percentage of days dredging was required.

Diurnal variations were removed from the objective as they are not adequately monitored to enable an assessment of the Murray Mouth opening.

Table 51. Linkages between icon site specific ecological objective and ecological targets for Murray Mouth Opening

Characteristic	Description
Ecological objective	Maintain a permanent Murray Mouth opening through freshwater outflows to improve water quality and maximise connectivity.
Definition of how objective and targets are interpreted	'Permanent' relates to 365 days in the year where there is an open Murray Mouth.
	'Freshwater outflows' relates to the discharges made through the barrage bays and fishways, calculated as ML/day.
	'Maximise connectivity' is assumed to be achieved on days where there is an open Murray Mouth.
	'Improve water quality' relates to the targets within ecological objective W-1.
Ecological target(s)	1. A minimum of 2000 ML/day of water is discharged through the Lower Lakes barrages and fishways for 356 days. 2. Murray Mouth is open 100 % of days in 95% of years as a result of freshwater releases from the barrages. 3. Where freshwater releases are not adequate to maintain an open Murray Mouth, the Mouth is maintained open for the remainder of year as a result of dredging.
CMP monitoring objective	Assessment of connectivity between Southern Ocean and Murray Mouth Estuary through assessment of Murray Mouth Opening.
Key use of data	Murray Mouth openness informs the connectivity between the Southern Ocean and the Murray Mouth Estuary, Coorong and Lower Lakes.

Table 52. **Summary description of sampling strategy and calculation of Indices for Murray Mouth Opening**

Characteristic	Description
Sampling strategy	Desktop method Desktop approach. Data available from SA Water, DWLBC, MDBA.
Index/Indices	1) Barrage Discharge index is the total volume of water discharged through the Lower Lakes barrages and fishways, ML/day.

Characteristic	Description
	2) The Murray Mouth Open index is the percentage of days the Murray mouth has remained open without requiring dredging. 3) The Dredging index is the percentage of days in the year that dredging was undertaken.
Calculation of index	Barrage Discharge index: = total ML/day (i.e. from all barrage bays and fishways) for each day of the year calculated in the Barrage Dashboard Murray Mouth Open Index: = number of days Murray Mouth is open without dredging / 365 (366 in leap years) x 100 Dredging index: = number of days Murray Mouth is open with dredging / 365 (366 in leap years) x 100
Calculation of whole of icon site score for parameter	Not identified for this objective.
Power/Effect size	n/a

Refined Objective: Maximise fish passage connectivity between the Lower Lakes and Coorong (W-3).

Original target: Maximise fish passage connectivity the Lower Lakes and Coorong (W-3).

This objective reports on the timing and number of barrage bays and fishways open throughout the year, as a measure of connectivity, which also helps to promote upstream and downstream fish passage. It is closely linked to the fish objective F-1: promote the successful migration and recruitment of diadromous fish species in the Lower Lakes and Coorong.

Table 53. Linkages between icon site specific ecological objective and ecological targets for fish passage between Lower Lakes and Coorong

Characteristic	Description
Ecological objective	*Maximise fish passage connectivity the Lower Lakes and Coorong.*
Definition of how objective and targets are interpreted	'Maximise fish passage connectivity' means the number of days the fishways and barrage bays are open at each barrage. 'Attractant flows' include barrage releases that provide both upstream and downstream fish migration opportunities.
Ecological target(s)	1. Fishways are open at each barrage every day. 2. Attractant flows, via the operation of barrage bays adjacent to fishways, are provided every day.
CMP monitoring objective	Assessment of fish passage and connectivity between the Lower Lakes and Coorong.
Key use of data	The assessment of fishways and barrage bays, and resultant barrage discharges, are an assessment of the connectivity between the Lower Lakes and Coorong, which promotes fish passage.

Table 54. Summary description of sampling strategy and calculation of Indices for fish passage between Lower Lakes and Coorong

Characteristic	Description
Sampling strategy	This is a desktop assessment using operational data on the number of fishways, barrage bays, and discharge volumes for each barrage is collected by DEWNR and SA Water.
Index/Indices	The indices used are the proportion of weeks in a year that were compliant in terms of providing open fishways and attractant flows. A week is considered compliant with maintaining fishways open where fishways are open every day of that week. A week is considered compliant with open fishways and attractant flows where fishways are open in conjunction with adjacent barrage bays (providing attractant flows for upstream migration and connectivity for downstream migration) for every day of that week. Compliance is calculated for each barrage separately. The proportion of weeks compliant with fishways open and fishways + attractant flows are then calculated for each of the barrages.
Calculation of index	For every week of the reporting period collate the following data for each of the five barrages: • The number of days the fishways are open. • The number of days the fishways are open with attractant flows. For each week, for each barrage, identify if that week was compliant with: • Providing open fishways every day of that week. • Providing open fishways with attractant flows adjacent the fishways (enabling upstream and downstream fish movement) every day of that week.

Characteristic	Description
	Note: times of the year that are more important for fish movement across the barrages (upstream and downstream): mid-winter and spring/early summer. For each barrage, calculate the proportion of weeks that were compliant with: • fishways open • fishways open with attractant flows
Calculation of whole of icon site score for parameter	Average the five fishway scores for fishways and fishways + attractant flows to give an overall icon site score for: • fishways open • fishways open + attractant flows
Power/Effect size	n/a

Figure 29. Tauwitchere rock ramp.

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