Technical information supporting the South Australian Basin Plan Environmental Outcome Evaluation

Coorong, Lower Lakes and Murray Mouth Priority Environmental Asset

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A special thanks to the following technical experts for their continued support, access to data and ongoing contributions to the evaluation: Chris Bice, Luciana Bucater, George Giatas, Jason Nicol, David Paton, Michelle Waycott, Qifeng Ye.

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Summary

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

Theme	Indicator	Trend	Information reliability	Key findings
Flow & Ecosystem Function	Murray Mouth Openness (annual barrage flows)	↗ Trend Getting better	★★★★☆ Reliability Very good	The number of days the mouth is open has increased since Basin Plan adoption, but remains heavily reliant on dredging.
Vegetation	Aquatic and littoral vegetation	↗ Trend Getting better	★★★★☆ Reliability Very good	Vegetation condition in the Lakes is getting better and is expected to be maintained in the future.
	Ruppia	↗ Trend Getting better	★★★★★ Reliability Excellent	The health of Ruppia has improved, however the community is still not considered to be resilient.
Fish	Black bream and greenback flounder	↗ Trend Getting better	★★★★★ Reliability Excellent	Whilst bream and flounder populations have improved, the condition of both populations remains very poor.
	Diadromous fish	↗ Trend Getting better	★★★☆☆ Reliability Good	Recruitment of diadromous fish has improved due to increased system connectivity.
	Small-mouthed hardyhead	↗ Trend Getting better	★★★★★ Reliability Excellent	Small-mouthed hardyhead recruitment is improving, and is better than we expected at this point in time.
Birds	Lakes Waterbirds	↗ Trend Getting better	★★★★☆ Reliability Very good	Lakes waterbirds are showing signs of recovery, however condition of the community is still considered to be poor.
	Coorong Waterbirds	↙ Trend Getting worse	★★★★☆ Reliability Very good	The abundance of Coorong waterbirds is getting worse, particularly for resident and migratory shorebirds.

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

- Following the impacts of the Millennium Drought and adoption of the Basin Plan, the CLLMM has shown positive signs of recovery.

- Water for the environment and high (unregulated) flows are both critically important for maintaining the ecological health and function of the asset.

- Implementation of the Basin Plan to date has supported:
    - improved connectivity between the Lakes, Coorong and Murray Mouth with 10 years of continuous flow and increased barrage flows
    - maintenance of lake levels and salinities within optimal ranges
    - increased resilience of fish populations in dry times
    - improved health of Ruppia in the Coorong

- Remaining challenges include:
    - the current state of the Southern Coorong is degraded due to prolonged hyper-saline and hyper-eutrophic conditions, and if we do nothing it is at risk of no longer supporting key biota such as waterbirds, fish, plants and invertebrates
    - Recovery of water bird populations to the Coorong, particularly migratory and resident shorebirds
    - Improving the resilience of Ruppia in the southern Coorong
    - Maintaining Murray Mouth openness without the ongoing need for dredging.

- continued effort and investment is required to improve the health of the CLLMM through:
    - striving for full implementation of the Basin Plan
    - undertaking research and works planned through the Healthy Coorong Healthy Basin sub-program of Project Coorong
    - continued involvement of the local community and First Nations to find enduring solutions.

1 Introduction

1.1 Basin Plan Schedule 12

The reporting requirements outlined in Schedule 12 of the Basin Plan provide the Murray–Darling Basin Authority (MDBA) with the information necessary to evaluate the effectiveness of the Basin Plan against its objectives and outcomes (s13.05).

Matter 8 (achievement of environmental outcomes at an asset scale) is a state-based reporting obligation that is central to communicating the environmental outcomes achieved through the implementation of the Basin Plan.

1.2 South Australia's approach to 2020 Basin Plan Environmental Outcome Evaluation and Reporting (Matter 8)

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

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

The South Australian Department for Environment and Water (DEW) has developed an approach to reporting on the achievement of environmental outcomes required for the Matter 8 reporting. This approach recognises the linkages between the Basin Plan environmental objectives, environmental watering plans and strategies (state and Basin-wide) and asset-scale environmental outcome reporting (Matter 8).

South Australia considers Matter 8 an evaluation of the achievement of environmental outcomes at an asset scale, and the reporting of that evaluation to the Authority.

This evaluation is guided by 3 key evaluation questions:

- To what extent are expected environmental outcomes being achieved?
- If expected environmental outcomes are not being achieved, why not?
- To what extent is the provision of environmental water, in line with environmental water requirements, contributing to the achievement of expected environmental outcomes?

For the South Australian River Murray, this evaluation is underpinned by the assessment of expected environmental outcomes (see section 3) for prioritised targets for each of the priority environmental assets within the South Australian River Murray Long-Term Watering Plan. The prioritisation of targets was undertaken against the following key criteria:

1. capability to track environmental trends at a range of spatial scales
2. environmental value
3. response to flow

4. consistency with the Basin-wide Environmental Watering Strategy
5. scientific credibility and reproducibility.

Some additional post-check considerations were then applied to ensure that the prioritised targets:

1. represent all of the key biotic groups (i.e. vegetation, fish and waterbirds), and key ecosystem processes
2. do not over represent any of the key biotic groups or processes
3. resulted in large positive contributions towards the achievement of the targets under the Environmental Water Requirements (EWRs) (as shown in Wallace et al. 2014; Kilsby et al. 2015; O'Connor et al. 2015)
4. include all of the key hydrological and water quality drivers.

This resulted in a total of 21 prioritised targets from the SA River Murray Long Term Environmental Watering Plan (LTWP) for the development of expected environmental outcomes.

1.2.1 South Australian River Murray expected environmental outcomes

Targets in the South Australian River Murray LTWP (DEWNR 2015) represent what a 'healthy, functioning ecosystem' might look like. Targets also vary in when they are expected to be achieved due to patterns in responses, including responses to environmental watering, and other management actions, over time. In the absence of complete knowledge and data around ecosystem responses, the quantitative expected environmental outcomes (and associated assumptions and limitations) were developed through a structured expert elicitation process (DEW in prep). These outcomes then give a more nuanced approach to evaluation and reporting, as they allow us to track the trajectory towards outcomes and targets and demonstrate progress towards our objectives, rather than passing or failing the targets.

Expected environmental outcomes quantify the extent to which we expect to meet the LTWP targets over 3 time points following the adoption of the Basin Plan in 2012 (2019, 2029 and 2042). These time points were chosen to align with key Basin Plan implementation activities and reporting.

This document presents the assessment of achievement of short-term (i.e. the 2019) expected environmental outcomes for the SA River Murray CLLMM PEA, and supporting data and information to evaluate why these outcomes have been met or not met since the adoption of the Basin Plan and actions to achieve environmental outcomes in the future.

2 Coorong, Lower Lakes and Murray Mouth Priority Environment Asset

2.1 Context

The Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environment Asset (Figure 2-1) is located in South Australia at the mouth of the River Murray, approximately 75 kilometres south east of the city of Adelaide. It is the terminus of the Murray–Darling Basin, which extends across South Australia, Victoria, New South Wales, the Australian Capital Territory and Queensland. The CLLMM PEA is the equivalent to the Coorong and Lakes Alexandrina and Albert Wetland (Ramsar Wetland of International Importance) and the Lower Lakes, Coorong and Murray Mouth Icon Site (as part of The Living Murray Program).

The CLLMM PEA comprises a series of freshwater, estuarine and hypersaline habitats with the freshwater habitats of Lakes Alexandrina and Albert (the Lakes) upstream of the barrages and the estuarine to hypersaline habitats of the Murray estuary and Coorong Lagoons downstream of the barrages. The fresh waters of Lake Alexandrina are separated from the more saline waters by a series of 5 barrages which were completed in the 1940s between Goolwa on the mainland and Hindmarsh, Mundoo, Ewe and Tauwitchere Islands. They were built to prevent seawater entering the Lower Lakes to maintain freshwater conditions during times of low flows (Blackmore 2002), ensuring water supplies for agricultural productivity in the surrounding areas.

The lagoons of the Murray estuary and Coorong are connected to the sea via the Murray Mouth, which is the only connection to the sea in the Murray–Darling Basin. The Murray estuary and Coorong are the only estuarine areas within the Murray–Darling Basin. Salinity increases with distance from the Mouth, but not in a uniform gradient. The Murray estuary and North Lagoon, which are directly influenced by freshwater flows over the barrages, are estuarine. The South Lagoon is influenced by flows over the barrages, through the impact of these flows on North Lagoon salinity and water levels, as wells as flows from the Upper South East. The South Lagoon is predominately saline to hypersaline.

The Murray Mouth is a tidal inlet restricted by the accumulation of dune material on the flanking spits of Sir Richard Peninsula and Younghusband Peninsula. It is located in a high energy environment and is extremely dynamic. The location, size and shape of the mouth and the adjacent estuary are dictated by a combination of river flows, tidal flows and ocean and coastal processes (Harvey 2002).

Also included within the CLLMM PEA is the Younghusband Peninsula, a peninsula of dunes and beach front that protects the Coorong from the Southern Ocean. The CLLMM PEA incorporates the entire Coorong National Park which, in addition to the Coorong lagoons, includes woodlands, shrublands and swamps. The CLLMM PEA supports extensive and diverse waterbird, fish and plant assemblages as well as threatened ecological communities and species.

2.2 Hydrology

The primary source of fresh water inflows into the CLLMM PEA are from the River Murray into the north of Lake Alexandrina, near Wellington (Figure 2-1). The volume and pattern of River Murray flows are determined by the water sharing arrangements in the Murray–Darling Basin Agreement 2008 and the delivery of water for the environment. In addition to the River Murray, small seasonal inflows are provided by tributary streams draining the Eastern Mount Lofty Ranges (i.e. Currency Creek and Finniss, Angus and Bremer Rivers) which are typically less than 2% of the overall inflows into the Lakes; and from the Upper South East which drains into the Coorong South Lagoon at Salt Creek. Rainfall and groundwater inputs at the site are also minor when compared to River Murray inputs. Given the location of the CLLMM PEA at the bottom of the catchment, it is strongly influenced by rainfall across the whole Murray–Darling Basin as well as local rainfall. The connection to the Southern Ocean exposes the site to strong winds and tides. Wind, sea level and tide actions are important climatic drivers within the site and change seasonally and annually.

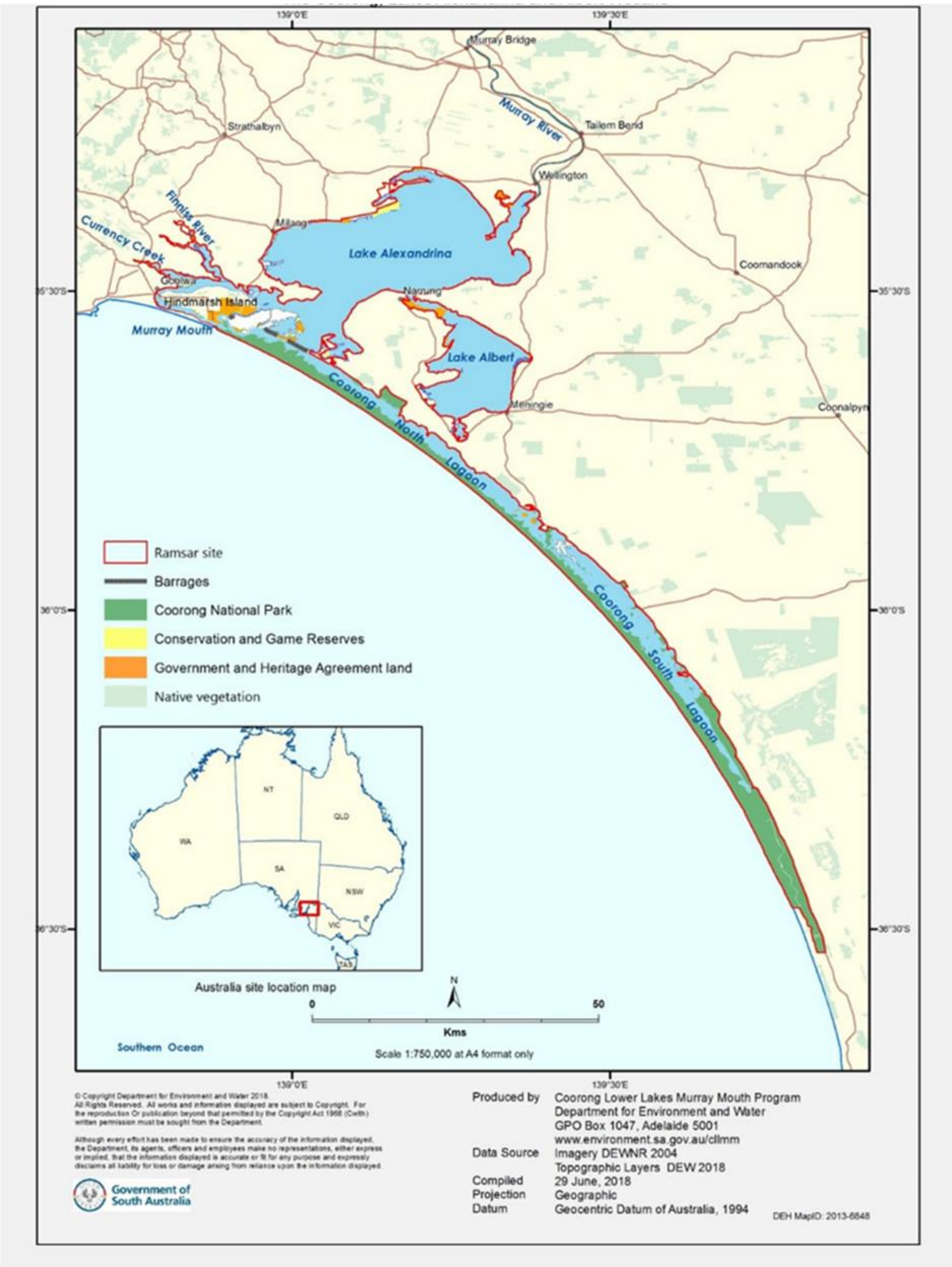

Figure 2-1. Location and extent of the CLLMM PEA.

The magnitude and timing of River Murray inflows to the CLLMM PEA have changed significantly since European settlement, with water consumption across the Murray–Darling Basin reducing average annual flow at the Murray Mouth by 61% (CSIRO 2008). Murray–Darling Basin Authority (MDBA) modelling during development of the Basin Plan has shown that under 'without development' conditions (a near-natural scenario approximating river flows without dams, weirs or extraction), an average of 12,500 gigalitres per year would flow out of the Basin through the Murray Mouth. Under current diversion limits (including all water that is recognised under water resource plans as pumped, diverted or intercepted for consumptive purposes including irrigation, urban supplies, stock water, domestic supplies and industry) this reduces to 5100 gigalitres per year, which is around 41% of 'without development' outflows (MDBA 2010).

Within South Australia's Entitlement of 1850 gigalitres, a Dilution and Loss Entitlement of 696 gigalitres per year (58 gigalitres per month) is provided to meet conveyance losses and salinity dilution to Wellington and provides a small inflow into the Lakes. While the Lakes receive some benefit from this entitlement, there is no specific provision for dilution and losses to maintain the condition of Lakes Alexandrina and Albert and the Coorong in South Australia's Entitlement, which is approximately 1,850 gigalitres in a hot dry year. South Australia's Entitlement of up to 1850 gigalitres by itself, does not provide sufficient water to maintain the health of the CLLMM PEA, which is highly dependent on the delivery of water for the environment (Figure 2-2). High (unregulated) flows and water for the environment are strategically important for maintaining the ecological health and function of the CLLMM PEA.

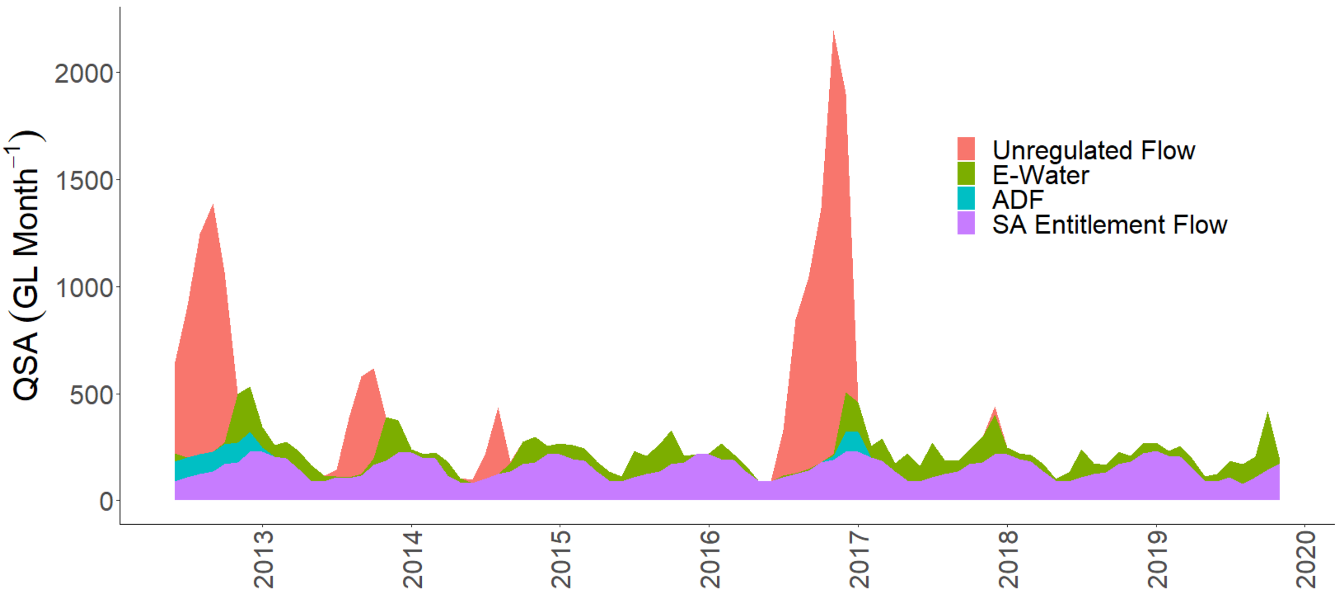

Figure 2-2. Contribution of unregulated flow, water for the environment (E-Water), additional dilution flow (ADF) and SA entitlement flow to flow (GL Month^{-1}) to the South Australian border (QSA) from June 2012 (Basin Plan implementation) to November 2019 (Data source: MDBA 2019).

2.2.1 Lakes hydrology

River Murray flows enter the CLLMM PEA at the northern end of Lake Alexandrina immediately downstream from Wellington. Flows move southward through Lake Alexandrina with a portion funnelled through the narrows and into the terminal wetland of Lake Albert. The remainder of the water moves further southward and leaves Lake Alexandrina through 5 barrages (Goolwa, Mundoo, Boundary Creek, Ewe Island and Tauwitchere) connecting the islands (Hindmarsh, Mundoo, Ewe and Tauwitchere) in the southern section of the lake. These flows are required to maintain stable salinities in the Lakes, maintain connectivity with the River Murray and contribute to the maintenance of waterbird populations, fish communities and aquatic and littoral vegetation of the Lakes.

Inflows to Lake Alexandrina from the Eastern Mount Lofty Ranges tributaries are relatively small but are important to the CLLMM PEA because of the biodiversity, habitat and ecological connectivity the tributaries support.

Lakes water levels

Lake levels are determined by inflows into Lake Alexandrina, releases through the barrages and climatic factors. Lake Alexandrina levels vary across years and seasons but generally rise in winter and fall in summer between +0.85m AHD and +0.5m AHD annually. The nature of Lake Albert as a terminal wetland, with its narrow connection with Lake Alexandrina, means levels in Lake Albert rise in winter and fall in summer in accord with the levels in Lake Alexandrina (Heneker 2010). Factors such as wind direction and speed, water extraction rates and local rainfall to evaporation rates affect water levels in and transfer between both lakes.

Variable lake levels are required to maintain or improve the diversity of aquatic and lakeshore vegetation and provide available habitat (e.g. for feeding, refuge, or breeding) for key biota including waterbirds and fish.

The pattern of gradually raising and lowering water levels is driven by the seasonal requirements of the ecology in and around the Lakes. Winter-spring filling of the Lakes supports the growth of new vegetation while ensuring that fauna have access to vegetation for food, shelter and recruitment. Water levels are kept high in spring to ensure fauna access to habitat (Lester et al. 2011). A gradual drawdown over the summer and autumn aims to expose mudflats and support diverse vegetation, while allowing fishways and some gates at each barrage to remain open over summer during the low flow period.

Prior to 2007, the water level in the Lakes varied seasonally from +0.4 m to +0.8 m AHD and surface water electrical conductivity was lower than 2,000 $\mu S.cm^{-1}$ (Kingsford et al. 2011). Prolonged drought and upstream diversion led water levels falling below sea level between 2007 and 2010 (Kingsford et al. 2011) (Figure 2-3), and due to the cessation of barrage flows that flush salt from the lakes, electrical conductivity exceeded 5,000 $\mu S.cm^{-1}$ in Lake Alexandrina and 15,000 $\mu S.cm^{-1}$ in Lake Albert (Figure 2-4). A high flow event that commenced in October 2010 reinstated lake levels and flushed saline water from the lakes (Figure 2-3). Since 2011–12, water levels have been managed to cycle between +0.4 and +0.9 m AHD (Figure 2-3). Managed and variable lake level cycling have helped to further reduce surface water salinity to concentrations reflective of pre-drought conditions in Lake Alexandrina (<1000 $\mu S.cm^{-1}$) and Lake Albert (1500 $\mu S.cm^{-1}$) (Figure 2-4) (Gibbs et al. 2018).

Figure 2-3. Mean monthly lake levels (m AHD) at Lake Albert (A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2003 to 2019 with respect to adoption of the Basin Plan (BP) in November 2012 as shown by the dashed blue line.

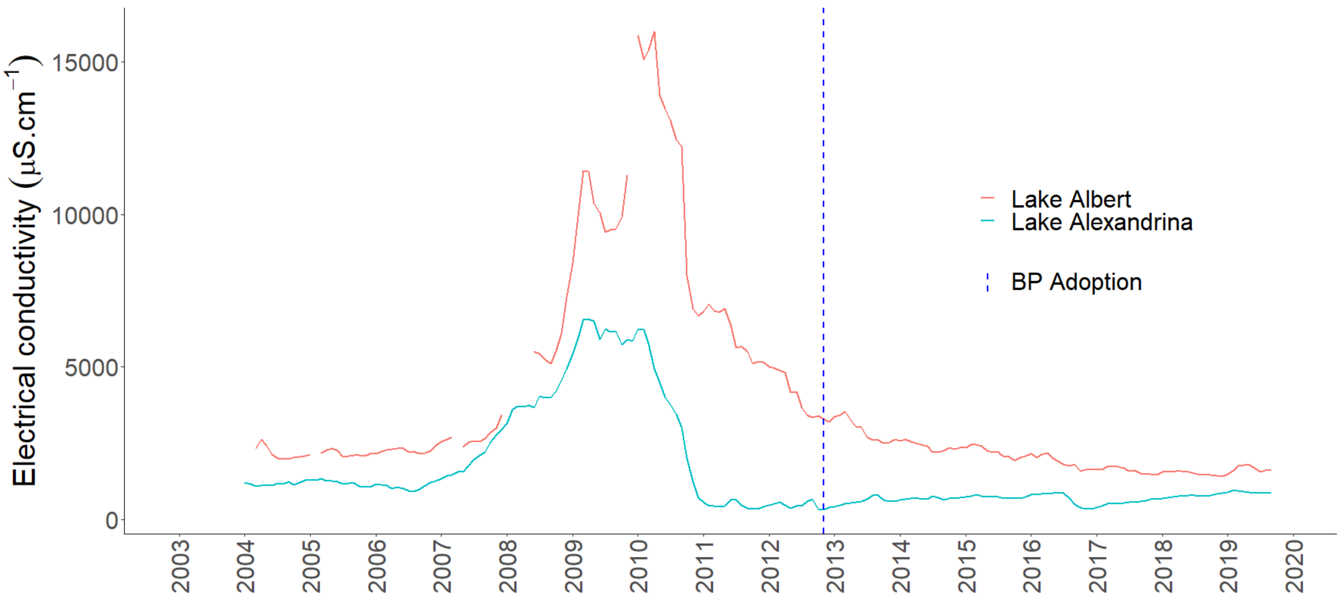

Figure 2-4. Mean monthly electrical conductivity (µS.cm-1) in Lake Albert (A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2003-2019 with respect to the adoption of the Basin Plan (BP) in November 2012 as shown by the dashed blue line.

2.2.2 Barrage flows

Barrage flows are required to maintain hydrological and ecological connectivity between the River Murray, the Coorong and the Southern Ocean to discharge salt and other nutrients out to sea and to maintain healthy ecosystems in the Coorong. Flow through the barrages is the result of lake inflows and losses and diversions across the Lakes and is affected by lake level, tide and wind conditions. Mean annual discharge from the barrages is dependent on the magnitude of inflows into Lake Alexandrina and net evaporative losses. During times of high inflows from the River Murray, significant volumes of fresh water can pass through the barrages.

Barrage flow was highly variable from 2000–01 to 2018–19 (Figure 2-5). High flows were recorded over 2000–01 with a total of 5095 GL discharged. During the Millennium Drought from 2001–02 to 2009–10, annual outflow was low (mean 288 GL), with no outflow from 2007/08 to 2009/10. This led to led to greater volumes of seawater entering the Coorong (Brookes et al. 2009). Water levels were low during this period, despite the ingression of seawater, and salinities in the southern lagoon exceeded 150 $g.L^{-1}$ (Brookes et al. 2009; Gibbs et al. 2018) (Figure 2-7). Dredging of the Murray Mouth was required over this period to prevent closure caused by sand deposited from the Southern Ocean (Higham 2012).

Extensive flooding over the Murray–Darling Basin greatly improved outflow, with 12808 GL in 2010/11 discharged. High flows continued in 2011/12 and 2012/13, with 8813 GL and 5410 GL of outflow, respectively. More moderate volumes were flow from the barrages in 2013/14 (2130 GL) and further reductions in annual outflow were recorded in 2014/15 (1364 GL) and 2015/16 (815 GL). Flood throughout the Murray–Darling Basin in 2016/17 led to substantial increases in outflow, with 7717 GL discharged. Dry conditions over the Murray–Darling Basin led to low outflows of 1305 GL in 2017/18 and 684 GL in 2018/19. Since the adoption of the Basin Plan, there has been outflow in all months with the exception of December 2015, January and May 2016.

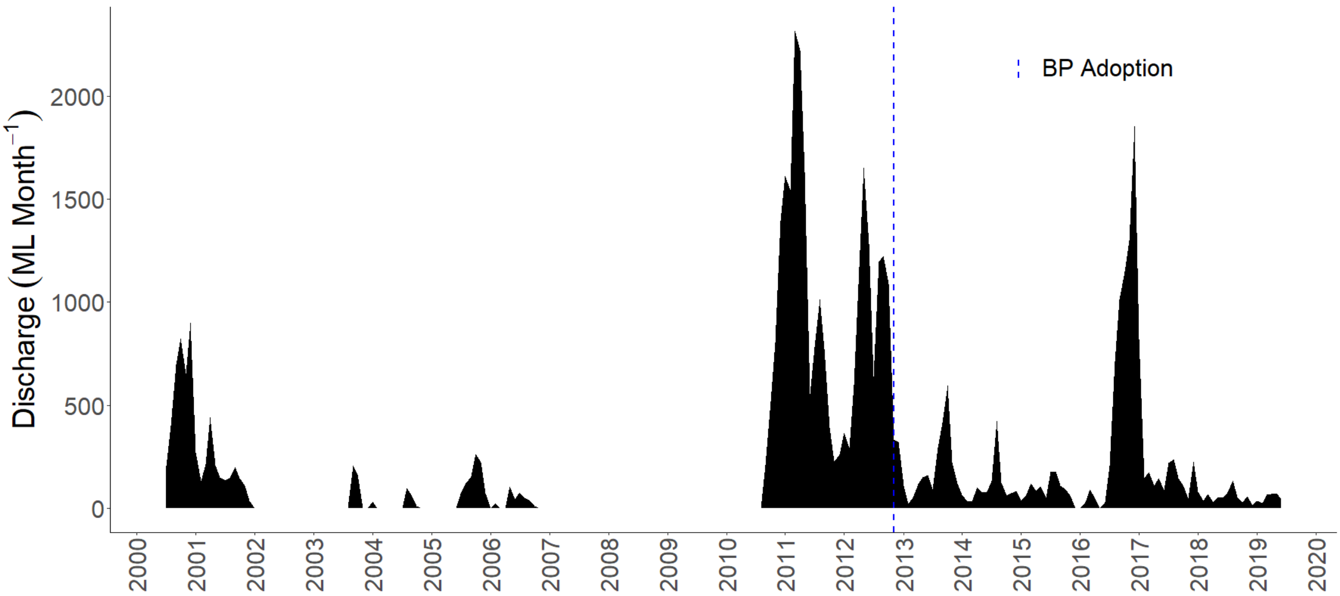

Figure 2-5. Monthly discharge from the barrages (ML Month-1) from 2000–01 to 2018–19.

2.2.3 Tidal signal

The coast at the Murray Mouth has a high off-shore gradient that results in only a 20% loss of wave power, resulting in a high energy system capable of influencing the influx of marine sediment into the Murray Mouth. Sea water enters the system via the Murray Mouth under tidal influence and wave dynamics, mixing with the freshwater from Lake Alexandrina, groundwater and rainfall to create the estuarine environment. The degree of Murray Mouth openness is influenced by barrage flows and in the other direction by flow driven by tides and waves. An open Murray Mouth allows tidal exchange and connectivity between the ocean and estuary. The tidal signal in water level is mainly visible in the North Lagoon closer to the Murray Mouth, where it can reach up to 0.2 metres. Most of the time, the tidal signal does not persist more than 30 kilometres from the Murray Mouth.

The ingression of sea water into the Murray estuary, in conjunction with evaporation, causes salinities in the Coorong to greatly increase during low flow periods (Kingsford et al. 2009; Higham 2012). Water levels in the Coorong are influenced by wind and sea level variations (such as tides) in Encounter Bay (Webster 2005; Brookes et al. 2009;

Higham 2012). The rise and fall of water levels are critical to the Murray estuary and Coorong, as it provides a mechanism for salt export through the Murray Mouth caused by oscillatory flow and subsequent long-channel mixing in the Coorong (Webster 2005; Brookes et al. 2009; Higham 2012).

2.2.4 Coorong hydrology

The hydrology of the Coorong is driven by barrage outflow, Murray Mouth openness, water level variation in Encounter Bay and meteorological conditions such as evaporative rates, precipitation and wind (Webster 2005; Brookes et al. 2009; Higham 2012; Gibbs et al. 2018). Modelling of Coorong hydrodynamics and ecosystem states has determined a series of flow targets for the Coorong. Flows of at least 2500 gigalitres over 2 years are described as a minimum target to prevent degraded states, and flows of at least 6000 gigalitres per year and 10 000 gigalitres per year, maintained every 3 and 7 years respectively to ensure healthy ecosystem states (Lester et al. 2011). High River Murray inflows provide targeted opportunities to scour the Murray Mouth and the opportunity to maintain and/or improve estuarine salinity conditions to support the provision of habitat, available food resources and recruitment of estuarine fish populations.

Small inflows also enter the Coorong South Lagoon at Salt Creek. A number of drainage networks have been constructed in the upper south-east of South Australia to restore some of the natural flow paths toward the Coorong. As a result, limited inflows (modelled average annual volume of 56.2 gigalitres per year) from the south-east of South Australia into the Coorong South Lagoon can occur under regulated conditions to periodically freshen the hypersaline waters (Natural Resources South East 2014).

As with the Lakes, water levels and salinity in the Coorong have a strong influence on ecosystem variability and the habitat conditions for aquatic plants, fish and birds (Paton et al. 2009; Ye et al. 2015). Water levels also influence particle resuspension and turbidity generated by wind and wave action in the shallow lagoons, and thereby reducing the light conditions necessary for plankton and aquatic plants. Variation in water levels in the Murray estuary and Coorong exposes and inundates extensive areas of mudflats for invertebrates. Water levels in the Coorong vary over timescales of seasons down to hours. A combination of wind, sea level, evaporation and barrage releases all influence water levels in the Coorong, which undergo a seasonal cycle of up to approximately +0.7m AHD in range; higher water levels tend to occur in late winter-early spring, with lower water levels in late summer-early autumn (Figure 2-6) (Webster 2010).

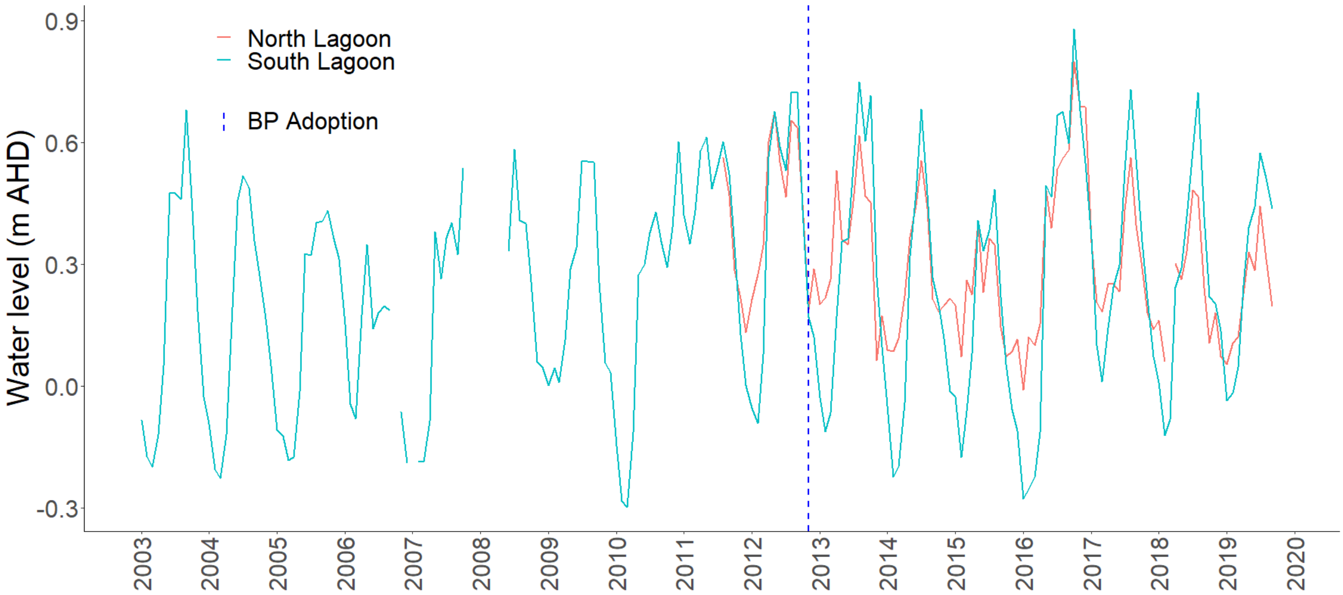

Figure 2-6. Mean monthly water level (m AHD) in the North Lagoon (A4261134, A4261135, A4260572) and South Lagoon (A4260633, A4261209, A4261165) of the Coorong from 2003 to 2019 with respect to the adoption of the Basin Plan (BP) in November 2012 as shown by a dashed blue line.

Coorong salinity

The connected Murray estuary and Coorong sub-units of the CLLMM PEA have a natural gradient from estuarine to marine conditions (up to 36 ppt) in the Murray estuary to hypersaline conditions in the South Lagoon at the terminal end of the system (Geddes and Butler 1984; Brookes et al. 2009; Fairweather and Lester 2010; Webster 2010). This salinity gradient characterises the diversity of habitats and biota across the system (Paton et al 2009).

Salinity levels in the Murray estuary are governed by the balance between freshwater flows through barrage releases, seawater inflows through the Murray Mouth and evaporation. High salinity tends to be associated with periods of reduced barrage flows and closure of the Murray Mouth. During periods of high freshwater discharge from the barrages, salinity in the Murray estuary and North Lagoon can range from fresh to brackish (5–30 ppt) (Geddes 1987; Bice et al. 2012).

The North Lagoon is estuarine-saline with lower salinity in the north-west and higher salinity towards the south-east at the connection with the South Lagoon. Salinity in the North Lagoon is controlled by freshwater inflows from primarily the Tauwitchere Barrage; tidal exchange through the Murray Mouth; rainfall; evaporation; and flows of hypersaline water from the South Lagoon. Salinity in the North Lagoon undergoes a seasonal cycle with maximum salinity occurring in mid-summer. Barrage flows in the Millennium Drought were small and salinities in the North Lagoon exceeded 100 ppt.

The South Lagoon is saline-hypersaline. Similar to the North Lagoon it has a salinity gradient with lower salinity in the north-west and higher salinity towards the south-eastern end. Salinity in the South Lagoon is not directly controlled by River Murray inflows but rather by water exchange with the North Lagoon, openness of the Murray Mouth, rainfall, evaporation, groundwater inputs and inflows from the South East of South Australia. The South Lagoon also undergoes a seasonal cycle with peak salinity occurring after the North Lagoon near the end of March. In the Millennium Drought salinity in the South Lagoon exceeded 200 ppt.

Figure 2-7. Mean monthly salinity (g.L-1) in the North Lagoon (A4261134, A4261135, A4260572) and South Lagoon (A4260633, A4261209, A4261165) of the Coorong from 2003 to 2019 with respect to Basin Plan (BP) implementation in November 2012 as shown by a dashed blue line.

3 Objectives, targets and expected environmental outcomes

3.1 Ecological objectives and targets

Objectives and targets identified in the SA River Murray Long-term Environmental Watering Plan (DEWNR 2015) represent what is required to support each of the priority environmental assets in a *healthy, functioning* state. As such, the objectives and targets within the LTWP were not constrained to those considered to be achievable under the Basin Plan. The ecological targets provide a means to assess and report on changes in condition over time, tracking progress towards ecological objectives.

A total of 6 ecological objectives and 29 nested ecological targets are described for the CLLMM PEA within the SA River Murray LTWP. These objectives and targets focus on abiotic processes, water quality, vegetation, macroinvertebrates, fish and waterbirds.

Of these targets, a total of 15 prioritised ecological targets across 5 ecological objectives (Table 3-1) were used as the basis for this assessment and evaluation of expected environmental outcomes for the CLLMM PEA. It is important to note that these targets have been refined since the LTWP was published, with an independent review of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017), including the targets undertaken. The refined *LLCMM Icon Site Condition Monitoring Plan* targets have been used for the basis of the development of expected environmental outcomes.

Table 3-1. Ecological objectives and targets for the CLLMM PEA (DEWNR 2015).

Ecological objective	Ecological targets
Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the sea	Maintain a minimum annual flow required to keep the Murray Mouth open (730-1090 GL/year)
Maintain or improve diversity of aquatic and littoral vegetation in the Lower Lakes as quantified using the LLCMM vegetation indices	Maintain or improve diversity of aquatic and littoral vegetation in (1) Lake Alexandrina, (2) Lake Albert, (3) Goolwa Channel, (4) permanent wetlands, (5) seasonal spring wetlands and (6) seasonal autumn wetlands as quantified using the LLCMM vegetation indices
Restore *Ruppia tuberosa* colonisation and reproduction in the Coorong at a regional and local scale	Extent of occurrence (EOO) along the Coorong of 43 km, excluding outliers
	Area of occupation (AOO) – within the sampled distribution, 80% of sites have plants present in both winter and summer
	Population vigour (VIG) – 50% of the sites with *R. tuberosa* should exceed the local site levels for a vigorous population

Ecological objective	Ecological targets
	Long-term resilience: i. By 2019: 2,000.m^2 at 50% of sites (≥ 8 seeds per 75 mm diam. × 40 mm deep core) ii. By 2029: 10,000.m^2 at 50% of sites (≥ 40 seeds per 75 mm diam. × 40 mm deep core)
Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the lower lakes and Coorong	Annual detection of juvenile catadromous fish at abundances ≥ that of defined 'Recruitment Index' values (44.5 for congolli; 6.1 for common galaxias)
	Maintain or improve abundances, distribution and recruitment of black bream and greenback flounder with a population condition score ≥ 3
	Maintain or improve abundances, distribution and recruitment of small-mouthed hardyhead with a population condition score ≥ 3 (max 5)
Maintain or improve waterbird populations in the Coorong and Lower Lakes	Exceed the recent (2013–2015) median value for abundance of each bird guild in the Lower Lakes in 2 of the last 3 years
	Exceed the 75% threshold for the recent (2013–2015) AOO for each bird guild in the Lower Lakes
	Exceed the 75% threshold for the recent (2013–2015) EOO for each bird guild in the Lower Lakes
	Exceed the long-term (2000–2015) median value for abundance of each bird guild in the Coorong in 2 of the last 3 years
	Exceed the 75% threshold for the long-term (2000–2015) AOO for each bird guild in the Coorong.
	Exceed the 75% threshold for the long-term (2000-2015) EOO for each bird guild in the Coorong.

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

3.2 Methods

For Matter 8 reporting, assessments included:

- achievement of expected environmental outcomes
- trend (as described in section 3.2.1)

- information reliability (as described in section 3.2.2)
- evaluation of environmental outcomes using expert elicitation supported by available data and information (DEW in prep), including the identification of actions to achieve environmental outcomes in the future.

South Australian Trend and Condition Report Cards include:

- trend (as described in section 3.2)
- condition assessments specific to each of the indicators (as described in each section of this report)
- information reliability (as described in section 3.2.2).

3.2.1 Trend

A Bayesian modelling approach was used to assess trend in the time series data collected for ecological indicators. This modelling approach was used as it provides more information surrounding the results and allows for a more detailed assessment of trend based on variability inherent in the data. Bayesian models provide an estimate of the likelihood of the trend in the time series data assessed. Bayesian trend analysis was undertaken in R Studio (R version 3.5.0, R Core Team 2018) using Bayesian Generalised Linear Models models and Mixed Models (using the stan-glm and stan-glmer functions in the rstanarm package, Goodrich et al. [2020], 4000 runs). If both fixed and random effects were included within a model then mixed models were used. Slope (trend) was estimated from the posterior distribution resulting from the Bayesian analysis. Trend direction was assessed using calculated probability (as per McBride 2019) using a graduated scale to present results. Alignment of trend outcomes with the categories used for the South Australian Trend and Condition Report Cards (herein referred to as Report Cards) are presented in Table 3-2.

Table 3-2. Alignment of trend outcomes based upon the likelihood of an increase or decrease (modified from Mastrandrea et al. 2010) with categories used for Report Cards.

Outcome	Likelihood of outcome	Report Card
Virtually certain increase	>+99 – +100%	Getting better
Extremely likely increase	>+95 – +99%	
Very likely increase	>+90 – +95%	
Likely increase	>+66 – +90%	
About as likely as not	-66 – +66%	Stable
Likely decrease	<-66 – -90%	Getting worse
Very likely decrease	<-90 – -95%	
Extremely likely decrease	<-95 – -99%	
Virtually certain decrease	<-99 – -100%	

This trend is then summarised as the following:

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

3.2.2 Information reliability

The reliability of data to assess the achievement of environmental outcomes and the progression towards the LTWP targets were scored based upon the method devised by Battisti et al. (2014) with modifications to improve its applicability to Matter 8 reporting and the Report Card process. This scoring system assesses answers to questions relating to the method used for data collection, representativeness and repetition. A scoring system as shown in Table 3-3 was used to determine a final score for data reliability that ranges between 0 and 12. Final scores are then converted into an information reliability rating that ranges between poor and excellent using the matrix in Table 3-4.

Table 3-3. Scoring system for the reliability of data used to assess and analyse trend, condition and the expected environmental outcomes for Matter 8 reporting.

Methods	Question	Scoring system		
		Yes	Somewhat	No
Methods used	Are the methods used appropriate to gather the information required for evaluation?	2	1	0
Standard methods	Has the same method been used over the sampling program?	2	1	0
Representativeness				
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	2	1	0
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	2	1	0
Repetition				
Space	Has sampling been conducted at the same sites over the assessment period?	2	1	0
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	2	1	0

Table 3-4. Conversion of the final score (0-12) of data reliability to an information reliability rating that ranges from poor to excellent for Matter 8 reporting and Report Cards.

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

4 Murray Mouth openness: annual flow

4.1 Introduction

The Murray Mouth is located the end of the River Murray system, where the Coorong estuary meets the Southern Ocean. The environment at the Murray Mouth is dynamic, with freshwater flow from the River Murray, through barrage releases, and tidal movement of the Southern Ocean changing the location of the Mouth as well as its width and depth ('openness') (Harvey 1988; Webster 2005). The openness of the Murray Mouth varies based upon the flow volumes within and between years (Higham 2012). To reverse the direction of net sand transport from inflow to outflow, and subsequently, potentially maintain an open Murray Mouth, a Tauwitchere barrage flow of ~2,000 $ML.day^{-1}$ is required (BMT WBM 2009). When barrage releases are low, sand is deposited at the Murray Mouth from the Southern Ocean, leading to the constriction of the Mouth (Harvey 1988; Webster 2005; Higham 2012). To naturally clear constriction of the Mouth, a high flow event is required where barrage outflows exceed ~60,000 $ML.day^{-1}$ (DEW 2018). Sand deposition during periods of low flow led to the complete closure of the Mouth in 1981 and dredging of the Mouth has occurred during low flow periods since 2002 to prevent closure (DEW 2018).

An open Murray Mouth provides connection between the River Murray, Coorong and Southern Ocean (Higham 2012). This connection is important for the export of nutrients, salts and sediments from the system, maintenance of water quality in the Coorong, passage for diadromous fish and tidal mudflat that support foraging habitat for shorebirds (Webster 2005; Higham 2012; Paton et al. 2015). The Murray Mouth is the only landscape feature within the River Murray system that allows for the export of nutrients, salts and sediments (MDBA 2018a). The export of excess salt is particularly important for the River Murray system to ensure water is suitable for drinking, agriculture and the environment (MDBA 2018b), with the structure and function of freshwater ecosystems adversely affected by increased salinity (Nielsen et al. 2003).

The water quality of the Coorong and subsequently the health of the ecosystem is dependent upon an open Murray Mouth. Constriction of the Murray Mouth affects water levels and salinity in the Coorong, especially during low flow periods (Webster 2005; Kingsford et al. 2009; Higham 2012). The intrusion of seawater not only provides a source of water for the Coorong that is critical during periods of low flow (Kingsford et al. 2009), but also mixes water within the Coorong and causes a rise and fall in water levels, which in turn, provides a mechanism for the lagoons to export accumulating salt (Webster 2005; Higham 2012). As water levels and salinity are 2 key drivers of the health of the Coorong ecosystem, the maintenance of an open Murray Mouth is critical to function of the system.

4.2 Ecological objective, target and expected environmental outcomes

The LTWP ecological objective and targets for Murray Mouth openness are presented in Table 4-1 (DEWNR 2015).

Table 4-1. Ecological objective and target for the Murray Mouth openness.

Characteristic	Description
Ecological objective	Maintain a permanent Murray Mouth opening through freshwater outflows with adequate tidal variations to improve water quality and maximise connectivity between the Coorong and the sea.
Ecological target	Maintain a minimum annual flow required to keep the Murray Mouth open (730-1090 $GL.year^{-1}$).

The expected environmental outcome for Murray Mouth openness is based on the percentage (%) of years that barrage outflow will meet or exceed the minimum outflow required to keep the Murray Mouth open (730 GL.year^{-1}) (Table 4-2). Over time, it is expected that the percentage of years that the minimum outflow volume is met will remain stable over time (Table 4-2; Figure 4-1). However, the confidence in predictions attenuates with time.

Table 4-2. Expected environmental outcomes for the percentage of years that barrage outflow will meet or exceed the minimum outflow required to keep the Murray Mouth open (730 GL.year^{-1}) in 2019, 2029 and 2042.

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

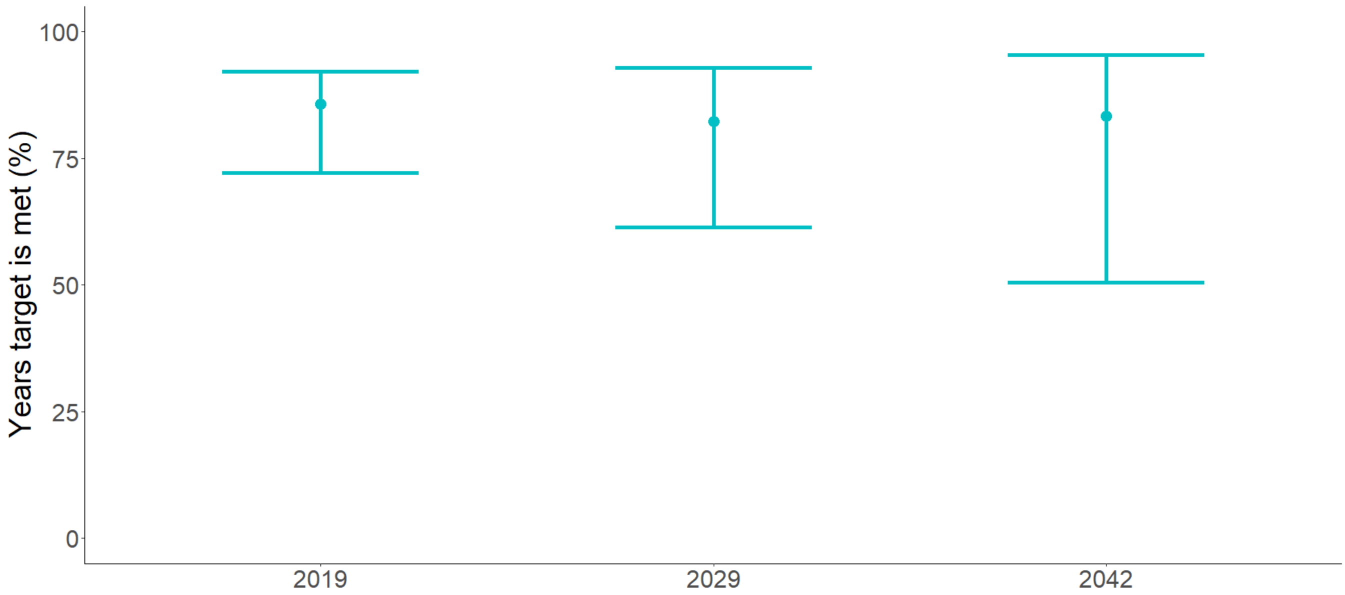

Figure 4-1. Percentage (%) of years that the LTWP target (730 GL.Year^{-1}) is met following Basin Plan adoption (2012) in 2019, 2029 and 2042 under modelled water recovery conditions.

4.3 Method

4.3.1 Barrage outflow

Direct measures of outflow through the Murray Mouth are not possible due its shifting and dynamic nature. Therefore, the accepted method for estimating outflow through the Murray Mouth is based on modelled barrage outflow, as the majority of barrage outflow exits directly out of the Murray Mouth (Auricht et al. 2018).

Modelled estimates of barrage outflow were sourced from the MDBA. The MDBA calculates barrage outflow from a water balance below Lock 1 using the BIGMOD model (MDBA 2014a). This approach is outlined in MDBA (2013) and is based on recorded flows at Lock 1, recorded or estimated diversions for supply to Metropolitan Adelaide and other consumptive purposes, changes in storage volume within Lakes Alexandrina and Albert based on recorded water levels, and estimated net evaporation from the water surface. The remainder from the water balance is the barrage flow. In some months, the estimates are filtered based on the barrage gate settings, for example when the water balance calculates some flow occurred. However, it is known that the barrage gates were shut.

The South Australian Matter 8 reporting for 2019 has selected the water years of 2000/01 and 2018/19 as the bounds for data collection and analysis. Therefore, while barrage outflow data is available prior to 2000/01, data from 2000/01 to 2018/19 has been used to assess the achievement of the expected environmental outcome in 2019.

4.3.2 Supplementary datasets

The following supplementary datasets were used to support the assessment of the achievement of the Murray Mouth openness expected environmental outcome and to inform the evaluation:

- Dredging data were provided by DEW Water Infrastructure and Operations (K Williamson Pers. Comm. 2019). The dredging data included the date range over which one or two dredges were in operation at the Murray Mouth.
- Diurnal Tide Ratio (DTR) data were resourced through DEW Water Infrastructure and Operations (K Williamson Pers. Comm. 2019) and provided by SA Water. The DTR is a ratio of the tidal energy between Goolwa Barrage, in the Coorong estuary, and Victor Harbor, in the Southern Ocean (DEW 2018). The ratio of tidal energy in the Coorong estuary provides an index for Murray Mouth openness, with a ratio of 0.3 indicative of an open Mouth and 0.2 suggestive of a constricted Mouth that requires dredging (DEW 2018).

4.3.3 Trend assessment

The analysis was undertaken as per section 3.2.1 using a Bayesian Generalised Linear Model. Trend was assessed based upon the success or failure of the LTWP target over time, with success representative of annual outflow ≥730 GL. As such, a binary dataset was used for the the trend analysis, with water years where annual outflow was ≥730 GL allocated a 1 and years where this did not occur allocated a 0. Time step (years since the commencement of the assessment period) was included as a random effect within the model. A binomial family was fitted to the Bayesian generalised linear model as binary data were used.

4.3.4 Condition

The condition of the Murray Mouth was assessed based upon DTR values and whether dredging has occurred for any length of time over the past 5 years from 2014/15 to 2018/19 (Table 4-3).

Table 4-3. Criteria used to assess the condition of the Murray Mouth over the past 5 years.

Condition rating	Criteria
Very good	DTR >0.4 without the use of dredges over the past 5 years.
Good	DTR >0.3 without the use of dredges over the past 5 years.
Fair	DTR >0.2 without the use of dredges over the past 5 years.
Poor	DTR <0.2 or the use of dredges over the past 5 years.

4.3.5 Information reliability

The information reliability assessment for Murray Mouth openness was conducted as per section 3.2.2.

4.4 Limitations of assessment

The minimum annual outflow required to keep the Murray Mouth open is assessed as 730-1090 $GL.year^{-1}$. These volumes were based on daily barrage outflow volumes of 2-3 $GL.day^{-1}$ required to prevent sand deposition inside the Murray Mouth. As outflow is not consistent over the year, there will be periods where barrage flow is less than 2 $GL.day^{-1}$ and likely to lead to the accumulation of sand inside the Murray Mouth and cause its constriction. As such, the ecological objective of maintaining a permanent Murray Mouth opening through freshwater outflows may not be achieved despite the minimum outflow volume being met.

To more appropriately assess whether the ecological objective was met following the adoption of the Basin Plan, dredging and DTR data were used in conjunction with barrage outflow data. The congruent use of these datasets helped to determine whether dredging was initiated due to constriction of the Murray Mouth in association with insufficient outflow. Therefore, multiple lines of evidence were used to ensure robust assessment of Murray Mouth openness.

4.5 Results

Outflow from the barrages fluctuated greatly from 2000/01 to 2018/19 (Figure 4-2). During the Millennium Drought, 9 consecutive years (2002/03 to 2009/10) of low to no outflow were recorded, with the last 3 water years prior to the break of the drought having no outflow recorded (2007/08 to 2009/10). The Millennium Drought broke in September 2010 and led to widespread flooding and subsequently 12,808 GL of barrage outflow in 2010/11. High outflow continued from 2010/11 to 2012/13 after which low outflow persisted until 2015/16. High outflow returned in 2016/17 due to high (unregulated) flows, however, low outflow prevailed in 2017/18 and 2018/19.

4.5.1 Environmental outcome assessment

The expected environmental outcome was met in 2019, as 6 of 7 water years had an annual outflow greater than the minimum annual outflow volume of 730 GL since the adoption of the Basin Plan (Figure 4-2).

Since the adoption of the Basin Plan, the minimum flow requirement (730 $GL.year^{-1}$) was exceeded on 6 of 7 years (86%) (Figure 4-2). In contrast, prior to the adoption of the Basin Plan (i.e. from 2000/01 to 2011/12) the minimum flow requirement was exceeded in 5 of 12 years (42%). As a result, progression towards the LTWP was greater following the adoption of the Basin Plan (noting though influence of drought conditions prior to the adoption of the Basin Plan), with the target minimum outflow volume met/exceeded more frequently.

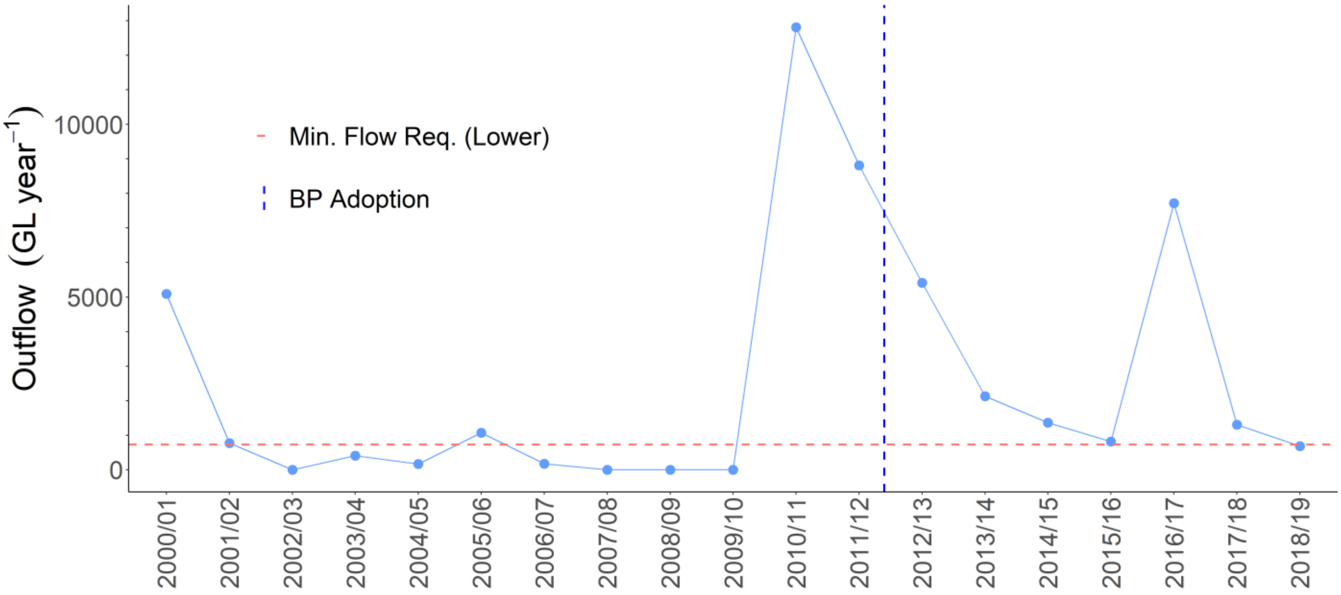

Figure 4-2. Outflow (GL.year-1) from the barrages for each water year from 2000/01 to 2018/19 with respect to the lower and upper bound LTWP minimum flow thresholds (red dashed lines) since the adoption of the Basin Plan (dashed blue line). Outflow data was sourced from the MDBA.

4.5.1 Assessment of the influence of dredging of the Muray Mouth

While barrage outflows since the adoption of the Basin Plan have contributed to an increase in the frequency of years that exceeded the minimum annual outflow required to keep the Murray Mouth open (Figure 4-2), volumes were inadequate to maintain an open Murray Mouth through outflows alone. As a result, dredging of the Murray Mouth has occurred during periods of low flow since the adoption of the Basin Plan. Two dredges have been in operation for the most of the past 5 water years, in operation between January 2015 and October 2016, and August 2017 and June 2019 (end date for data collection; noting dredges continue to operate), due to prolonged periods of low flow (Figure 4-3). The commencement on dredging was associated with the Murray Mouth becoming constricted, as evidenced by the decline of DTR to 0.2 (Figure 4-4). Since Basin Plan adoption, DTR declined below 0.2 at times in 2015, 2016 and 2017 (Figure 4-4).

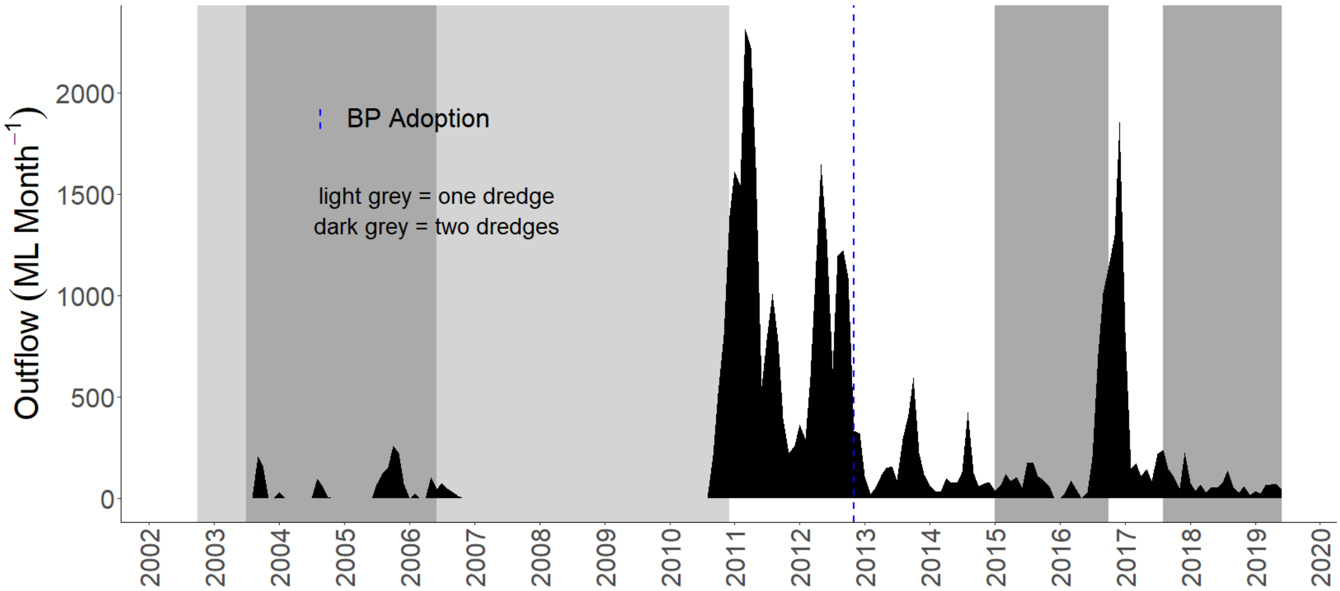

Figure 4-3. Monthly barrage discharge (ML.Month-1) (black fill) from June 2002 to June 2019 with respect to dredge operations (no shading for no dredges, light grey for one dredge and dark grey for 2 dredges) and Basin Plan adoption (November 2012) (dashed blue line).

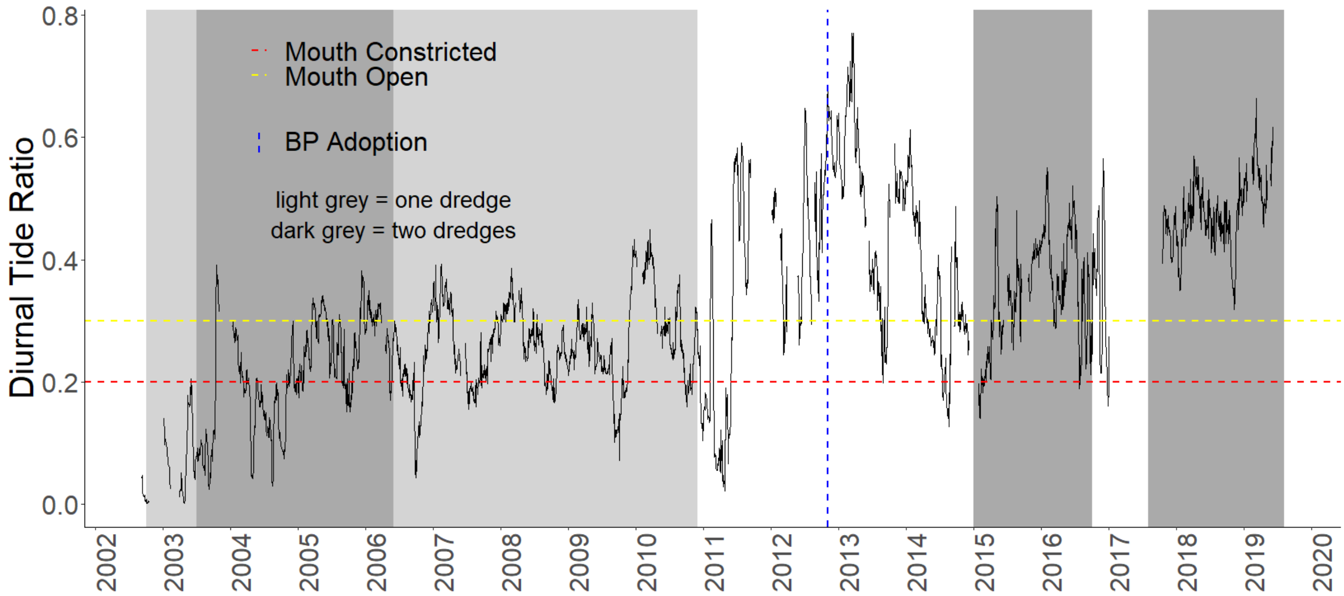

Figure 4-4. Diurnal Tide Ratio (DTR) at Goolwa from September 2002 to June 2019. DTR values of below 0.2 (red dashed line) are reflective of a constricted Mouth and values above 0.3 (yellow dashed line) are reflective of an open and functional Mouth. Basin Plan adoption (November 2012) is shown by the vertical blue dashed line. Caution needs to be taken when examining DTR data recorded during high unregulated flow events (i.e. 2010/11 and 2016/17), as

during such periods flow rather than tides are largely influencing water levels downstream of the barrages and therefore the amplitude of the tidal signal is reduced.

4.5.2 Trend assessment

It is very likely (91% likelihood) that the frequency of years that annual outflow meets the minimum flow requirements (>730 GL.year^{-1}) is getting better (Figure 4-5).

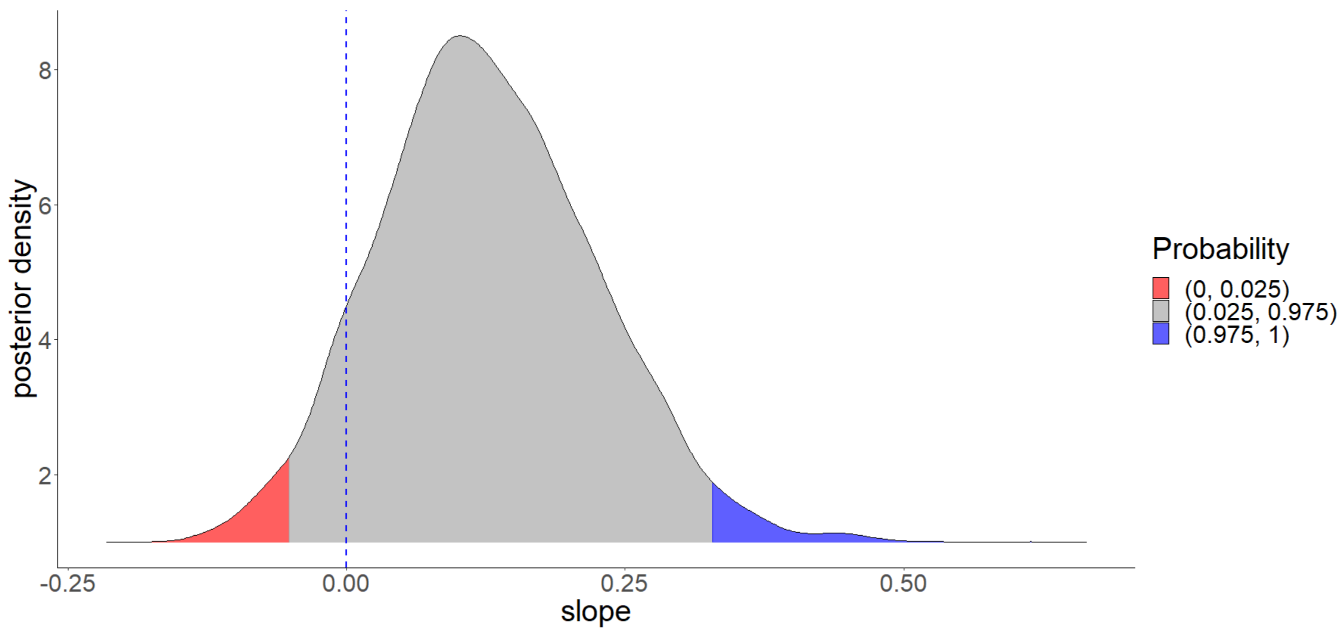

Figure 4-5. Estimated values for the slope generated from Bayesian modelling for the frequency of years from 2000/01 to 2018/19 meeting the requirements of the LTWP target (> 730 GL.year-1). Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

4.5.3 Condition

The condition of the Murray Mouth is considered to be **poor**. Two dredges were in operation for most of the past 5 water years and DTR declined below 0.2 in 2014/15 and (Figure 4-4), which triggered reinstatement of the dredging program. DTR also fell below 0.2 in 2016/17, however, this result was recorded during high regulated flows which diminished the tidal signal, and therefore, does not reflect the level of Murray Mouth constriction.

4.5.4 Information reliability

The information reliability rating for Murray Mouth openness was **very good** (final score of 11). Justification for the scoring of Murray Mouth openness data reliability is provided in Table 4-4.

Table 4-4. Reliability of MDBA barrage outflow data to assess the expected environmental outcome for Murray Mouth openness. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Somewhat.** The LTWP target and expected outcomes were assessed using modelled estimates of barrage outflow using the BIGMOD model (MDBA 2014a), which does not directly assess the openness of the Murray Mouth. However, supplementary datasets of DTR and dredging over the assessment period have been used to help assess our ecological objective.	**1**
Standard methods	Has the same method been used over the sampling program?	**Yes**. Modelled estimates of barrage outflow were sourced from the BIGMOD model (MDBA 2014a) to cover the assessment period (2000/01 to 2018/19).	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	**Yes.** The BIGMOD model estimates barrage outflow from a water balance below Lock 1 (MDBA 2014a). Therefore, the BIGMOD model is representative of barrage outflow from the Lower Lakes	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes**. Modelled estimates of barrage outflow were sourced from the BIGMOD model (MDBA 2014a) to cover the assessment period (2000/01 to 2018/19).	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes**. Modelled estimates of barrage outflow were sourced from the BIGMOD model (MDBA 2014a) to cover the assessment period (2000/01 to 2018/19).	**2**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Yes**. The LTWP target required an assessment of annual outflow volumes, which were estimated using the BIGMOD model (MDBA 2014a).	**2**
Final score			**11**
Information reliability			**Very good**

4.6 Evaluation

The Murray Mouth has threatened to close over the evaluation period for this assessment (2000/01 to 2018/19) (Bourman et al. 2018), with dredges used from October 2002 to December 2010, January 2015 to October 2016 and August 2017 to June 2019 (end date for data collection; noting dredges continue to operate). As freshwater outflows alone were insufficient to restore an open Murray Mouth, dredging was required to maintain the openness and function of the Murray Mouth following the adoption of the Basin Plan,

Water delivered, including water for the environment, through the implementation of the Basin Plan has supported barrage outflows. Water delivered has contributed to an increase in the frequency of water years that exceeded the minimum annual outflow volume required (730 $GL.year^{-1}$) to keep the Murray Mouth open between 2000/01 and 2018/19, but these volumes alone have been insufficient to maintain an open Murray Mouth.

As the Murray Mouth requires approximately 2,000 $ML.day^{-1}$ of outflow to prevent sand accumulation (BMT WBM 2009; MDBA 2014b), days of sand deposition inside the Murray Mouth would have been particularly frequent in 2015/16 and 2018/19, which had annual outflow volumes of 815 GL and 684 GL, respectively. The factors associated with inability to maintain an open and functional Murray Mouth through freshwater outflow were reduced rainfall conditions, along with the upstream extraction of water (see section 4.6.1), prolonged periods of barrage outflows less than approximately 2,000 ML/day, which have resulted in the accumulation of significant amounts of sand within the estuary, and the lack of high flows that scour the Murray Mouth (see section 4.6.2). Actions required to maintain an open Murray Mouth in future years and improve its function are provided in section 4.7.

4.6.1 Reduced rainfall conditions and upstream extraction of water

Reduced rainfall conditions across the assessment period has contributed to the reduced inflows to the CLLMM PEA and subsequent barrage outflows. The rainfall decile maps of the Basin from 2006 to 2019 (BOM 2020) show prolonged dry periods broken by years of above average to record rainfall (Figure 4-6). The Millennium drought that commenced in 1996 was broken in 2010 by 2 consecutive years (2010 and 2011) of significant rainfall. Between 2012 and 2015, average to record lower rainfall were recorded over the Basin, dependent on location, with the far south most severely affected. In 2016, above average rainfall was recorded for much of the Basin, with most significant relative rainfall within the southern Basin. Drought conditions commenced in 2017 and continued throughout 2019. The lack of rainfall during this period (2017 to 2019) was notable across the entire Basin, however, was most prominent in the north near the New South Wales and Queensland border.

Upstream extraction of water and river regulation has, over the prevailing decades, led to the entrance of the Murray Mouth becoming more shoaled and prone to closure without intervention (BMT WBM 2009). Barrage outflows have reduced by ~60% when compared to natural flows due to upstream abstraction of water, primarily for agriculture (CSIRO 2008a). As a result, modelling indicates that water ceases to flow through the Murray Mouth 40% of the time in contrast to 1% under natural flow conditions (CSIRO 2008b). As a barrage outflow of 2,000 $ML.day^{-1}$ is the minimum flow required to prevent sand accumulation inside the Murray Mouth (BMT WBM 2009; MDBA 2014b), prolonged periods with no or low barrage outflow increase the risk of the Murray Mouth constriction or closure without intervention.

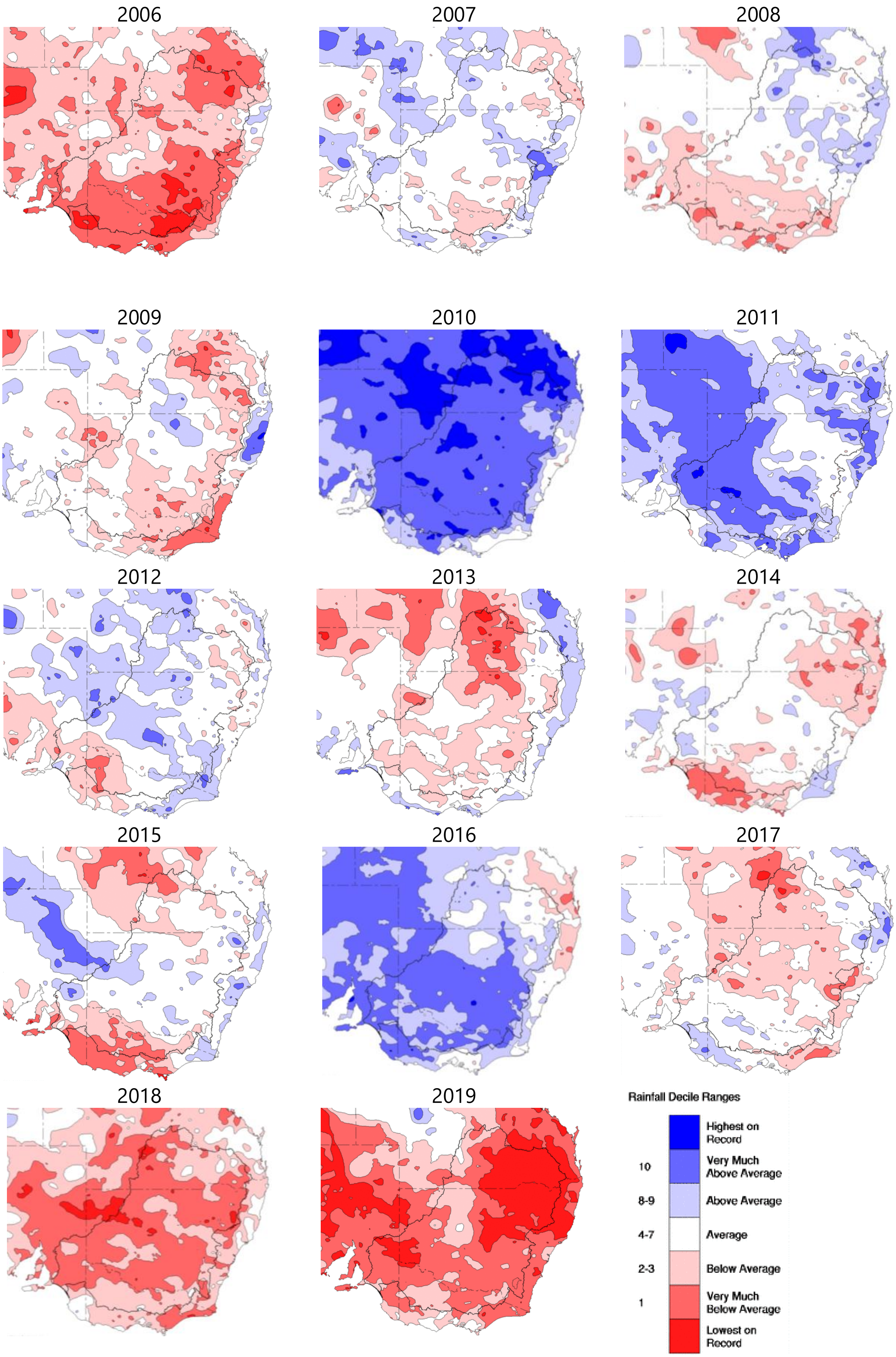
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
Rainfall Decile Ranges
Highest on Record
10
Very Much Above Average
8-9
Above Average
4-7
Average
2-3
Below Average
1
Very Much Below Average
Lowest on Record

Figure 4-6. Murray–Darling Basin rainfall deciles from 2006 to 2019 (BOM 2020).

4.6.2 Scouring flows

High River Murray inflows provide targeted opportunities to scour the Murray Mouth and the opportunity to maintain and/or improve estuarine salinity conditions to support the provision of habitat, available food resources and recruitment of estuarine fish populations. Sand may be scoured from the Murray Mouth when barrage outflows are ~60-70,000 $ML.day^{-1}$, similar to those that occurred during the high (unregulated) flow event in 2010/11 (DEW 2018). However, since the adoption of the Basin Plan, such flows were only recorded for short periods between October and December 2016. The return interval of flows that scour the Murray Mouth have been too great to maintain an open Murray Mouth through freshwater outflow. This is demonstrated by the operation of 2 dredges from August 2017 to June 2019 (end date for data collection; noting dredges continue to operate). Therefore, both mechanical and natural clearance of sand from the Murray Mouth are required to maintain its function.

4.7 Actions to achieve environmental outcomes

Targeted delivery of water for the environment to the Murray Mouth is unlikely to be of sufficient volume and frequency to maintain its openness without dredging, due to current water recovery volumes and the physical and operational constraints to water delivery.

The achievement of the Murray Mouth openness environmental outcome is also reliant on large prolonged high flow events. The management of the Lakes' water levels and barrage outflows during these events will be important to improve the directionality of the flow to the Murray Mouth to ensure scouring of sand and mitigate constriction of the Mouth. To prime the Murray Mouth for a high (unregulated) flow event, water may be discharged from Goolwa and Mundoo barrages to improve directionality of flow towards the Murray Mouth in an effort to try to scour sand (A Rumbelow Pers. Comm. 2020). Targeted dredging may be undertaken in association with such actions to lessen constriction at the Murray Mouth and improve function (A Rumbelow Pers. Comm. 2020).

4.8 Conclusion

Despite meeting the minimum annual outflow as expected, the delivery of water and subsequent freshwater outflows were insufficient to prevent the Murray Mouth becoming constricted since the adoption of the Basin Plan, particularly during low flow periods. As a result dredging is required to maintain its function.

In future years, it is expected that the percentage of years with barrage outflow exceeding the minimum annual outflow volume will be maintained. However, water for the environment is unlikely to be of sufficient volume to maintain an open Murray Mouth without high flows to scour sand that has accumulated inside the Murray Mouth. Therefore, it is expected that dredging of the Murray Mouth will be required in the future during prolonged low flow conditions.

Key messages:

- Water delivered through the implementation of the Basin Plan has supported barrage outflows. Water for the environment has also contributed to barrage outflow, especially in low flow years.
- Volumes of freshwater outflows alone were insufficient to restore an open Murray Mouth, with dredging required to maintain its openness and function.
- Prolonged periods of barrage outflows less than approximately 2,000 ML/day resulted in the accumulation of significant amounts of sand within the estuary, which has increased the risk of sand deposition and accumulation inside the Murray Mouth.

- Barrage outflows of ~60-70,000 $ML.day^{-1}$ are considered to scour sand from the Murray Mouth in the absence of dredging.

5 Aquatic and littoral vegetation

5.1 Introduction

Aquatic and littoral vegetation are comprised of plant species that grow from within a waterbody to its high water mark. These plant species play an important ecological role through primary production (Hart and Lovvorn 2000; Noges et al. 2010), water quality enhancement (Verhoeven et al. 2006), shoreline stabilisation (Nicol et al. 2016) and the provision of habitat for invertebrates (Paukert and Willis 2003), birds (O'Connor et al. 2013), frogs (Mason and Durbridge 2015) and fish (Wedderburn and Barnes 2018). Aquatic and littoral vegetation communities in good condition have high species richness, structural diversity and limited cover from invasive exotic and over-abundant native species (Nicol et al. 2019). These communities are particularly important for the conservation of threatened fauna in the Lakes, including the southern bell frog (Mason 2017), Australasian bittern (O'Connor et al. 2013) and southern pygmy perch (Wedderburn and Barnes 2018).

The primary driver of aquatic and littoral vegetation community structure and condition in the Lakes is water regime (Gehrig and Nicol 2010). Water regime drives changes in the species composition and diversity of aquatic and littoral vegetation communities, as each functional group responds differently to water residence time, depth and level fluctuations based upon their life histories (Gehrig and Nicol 2010; Nicol et al. 2018). Water level fluctuations in the Lakes are important for establishing diverse aquatic and littoral plant communities, by providing opportunities for germination, growth and reproduction (Nicol et al. 2019). Fluctuations in water level also help to reduce the dominance of over-abundant native species, such as *Typha domingensis* and *Phragmities australis*, that form monotypic stands when water levels are relatively stable (Deegan et al. 2007). Therefore, to maintain or improve the aquatic and littoral vegetation condition in the Lakes, it is imperative that there are variable water levels, from high (+0.7-0.9 m AHD) in spring and early summer, falling to no lower than (+0.4 m AHD) in autumn, to protect submergent plant species from desiccation and enhance species richness and diversity (Nicol et al. 2019).

Although water regime is the primary driver of species composition in aquatic and littoral vegetation communities in the Lakes, salinity is also considered to be an important driver (Gehrig and Nicol 2010). The impact of salinity on aquatic and littoral vegetation is less well understood (Nicol 2016), with a range of submergent and emergent species considered to have low salinity tolerances having colonised and/or persisted in the Goolwa Channel through 2009/10 when salinities at times exceeded 30,000 EC (Gehrig et al. 2011). However, over this period in the Goolwa Channel, the species diversity of submergent plants was low (Gehrig et al. 2011), growth of emergent species was likely impaired (Gehridg et al. 2011) and there was no recruitment from *T. domingensis* and *Schoenoplectus tabernaemontani* (Nicol 2016). To maintain the condition of aquatic and littoral vegetation in the Lakes system, it is considered to be important that salinities preferably remain below 1000 EC and do not exceed 2,000 EC in Lake Alexandrina (Nicol 2016).

5.2 Ecological objective, target and environmental outcomes

The ecological objective for aquatic and littoral vegetation in the Lakes from the SA River Murray LTWP is presented in table 5-1. The ecological targets for aquatic and littoral vegetation are those within the Lakes vegetation chapter (Nicol 2017) as part of the LLCMM Icon Site Condition Monitoring Plan (DEWNR 2017) and are also presented in table 5-1.

Table 5-1. Ecological objective (DEWNR 2015) and targets (Nicol 2017) for littoral and aquatic vegetation in the Lakes.

Characteristic	Description
Ecological objective	Maintain or improve aquatic and littoral vegetation in the Lakes (O'Connor et al. 2015; DEWNR 2015)
Ecological targets	Maintain or improve diversity of aquatic and littoral vegetation in (1) Lake Alexandrina, (2) Lake Albert, (3) Goolwa Channel, (4) permanent wetlands and (5) seasonal wetlands as quantified using the LLCMM TLM vegetation indices (Nicol 2017).

The expected environmental outcomes for whole of icon site scores (referred to herein as icon site score) in 2019, 2029 and 2042 were determined by elicitation with key experts. These form the basis of the assessment of aquatic and littoral vegetation environmental outcomes in the SA River Murray CLLMM PEA.

Table 5-2. Expected environmental outcomes for aquatic and littoral vegetation in the Lakes in 2019, 2029 and 2042.

Year	Expected environmental outcome
2019	The whole of icon site score for Lakes littoral and aquatic vegetation will be **0.50** (80% confidence interval of 0.40-0.06)
2029	The whole of icon site score for Lakes littoral and aquatic vegetation will be **0.51** (80% confidence interval of 0.33-0.62)
2042	The whole of icon site score for Lakes littoral and aquatic vegetation will be **0.53** (80% confidence interval of 0.27-0.72)

It was expected that the icon site score will slightly increase between 2019 and 2042, however, the confidence of this prediction attenuates with time (Table 5-2; Figure 5-1).

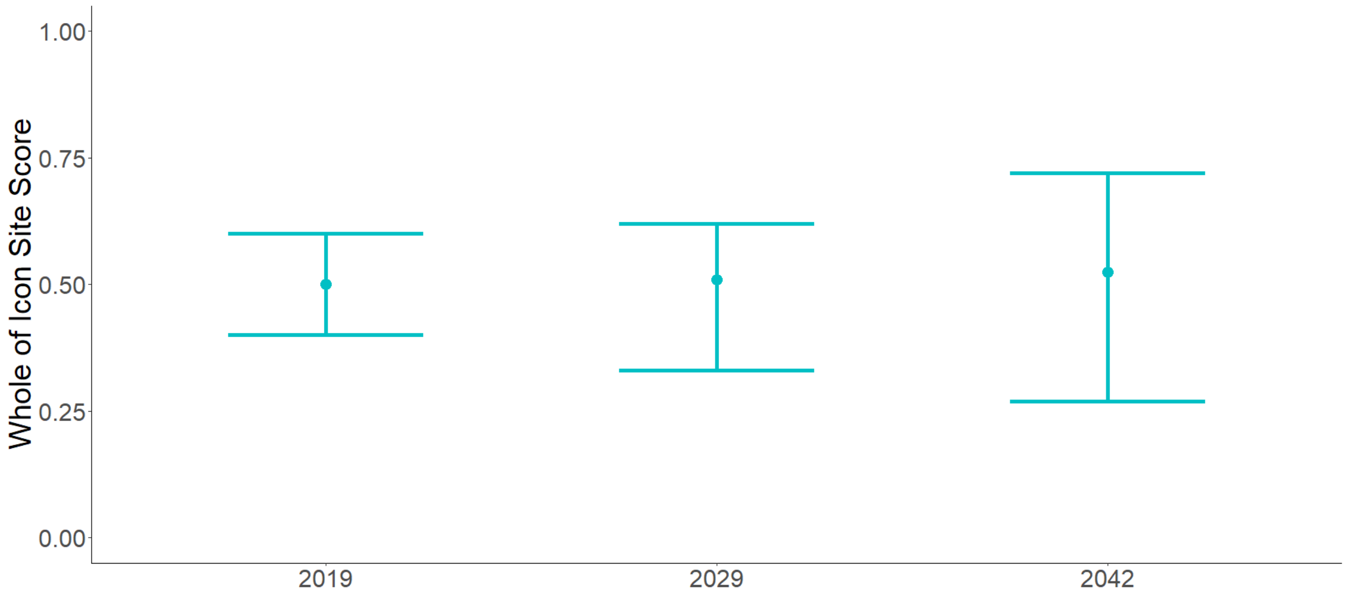

Figure 5-1. Expected environmental outcomes for aquatic and littoral vegetation in the Lakes in 2019, 2029 and 2042.

5.3 Method

The methodology for the Lakes vegetation condition monitoring followed the Lakes vegetation chapter (Nicol 2017) of the LLCMM Condition Monitoring Plan (DEWNR 2017). Nicol et al. (2019) summarised the method: 'Vegetation condition monitoring is conducted at selected wetland and lakeshore sites across the lakes Alexandrina and Albert, Goolwa Channel, lower Finniss River, lower Currency Creek and the mouths of the Angas and Bremer Rivers. Sites established in spring 2008 and 2009 were re-surveyed. At each site, transects were established perpendicular to the shoreline and three, 1×3 m quadrats, separated by 1m were located at regular elevation intervals (defined by plant community) for wetlands or elevations (+0.8, +0.6, +0.4, +0.2, 0 and -0.5 m AHD) for lakeshores. The cover and abundance of each species present in quadrats were estimated using a modified Braun-Blanquet (1932) cover abundance score.'

5.3.1 Calculation of habitat and icon scores

Habitat scores were determined by multiplying the proportion of targets met for each habitat zone by one divided by the number of habitat zones, i.e. all habitat zones were allocated equal weighing to the overall habitat score (Nicol 2017).

Habitat scores were calculated using the following equation for:

Lake Alexandrina, Lake Albert and Goolwa Channel habitats:

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

Permanent wetlands:

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

Spring and autumn (temporary) wetlands:

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

Whole of icon site scores were calculated by multiplying habitat scores by 1 divided by the number of habitats (5), i.e. all habitats were allocated equal weighting to the overall icon score.

The **whole of icon site score** was calculated using the following equation:

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

5.3.2 Trend assessment

Trend analysis for the icon site and each habitat was undertaken as per section 3.2.1 using a Bayesian generalised linear model. Trend was assessed based upon the proportion of targets met in each assessment period. Time step (years since the commencement of the assessment period) was included as a random effect within the model and an interaction effect between time step and habitat was included to enable slopes to be derived for each habitat (i.e. trend to be assessed for each habitat). A beta family was fitted to the Bayesian linear model to account for proportional data.

5.3.3 Condition assessment

A condition rating for aquatic and littoral vegetation was allocated based on the icon site score in the last condition monitoring assessment (spring 2018). The matrix used in the conversion of an icon site score to a condition rating is provided in Table 5-3.

Table 5-3. The alignment of icon site scores for aquatic and littoral vegetation Lakes with a condition rating used.

Icon site score	Condition rating
0.80-1.00	Very good
0.60-0.79	Good
0.40-0.59	Fair
<0.40	Poor

5.3.4 Information reliability

The information reliability assessment for aquatic and littoral vegetation condition in the Lakes was conducted as per section 3.2.2.

5.4 Results

5.4.1 Environmental outcome assesssment

The expected environmental outcome (whole of icon site score of 0.5) was not met in 2019, as in spring 2018 the icon site score was 0.43 (Figure 5-2). This was lower than what was expected and was the lowest icon site score recorded following the restoration of lake water levels and salinities after the Millennium drought. Progression towards the achievement of the LTWP target has varied. Aquatic and littoral vegetation condition in Lake Alexandrina and Albert was virtually certain to have improved over the assessment period, but with condition likely to have declined in the Goolwa Channel and permanent wetlands, a decline in condition was virtually certain in temporary wetlands (spring and autumn) (Figure 5-3; Table 5-4).

Icon site scores varied between 0.32 and 0.36 during the Millennium drought from spring 2008 to autumn 2010 (Figure 5-2), when lake levels fell below sea level (0 m AHD). Lake levels were restored (>0.4 m AHD) in spring 2010 and the icon site score increased to 0.50. Icon site scores remained >0.50 until autumn 2012. Icon site scores were relatively stable between autumn 2012 and autumn 2014, varying between 0.48 and 0.50. In autumn 2015, the icon site score increased to 0.55. Icon site scores declined to 0.45 between spring 2015 and spring 2017, before increasing to 0.53 in autumn 2018.

The habitats that positively contributed to the icon site score were Lake Albert and Lake Alexandrina lakeshores, which both had minor long-term increases in their respective habitat scores (Figure 5-3). The habitat score for permanent wetlands were consistent for most of the monitoring program, while the habitat scores for Goolwa Channel and temporary wetlands were dynamic and the source of variability in icon site scores between assessments, including periods of reduced icon site scores.

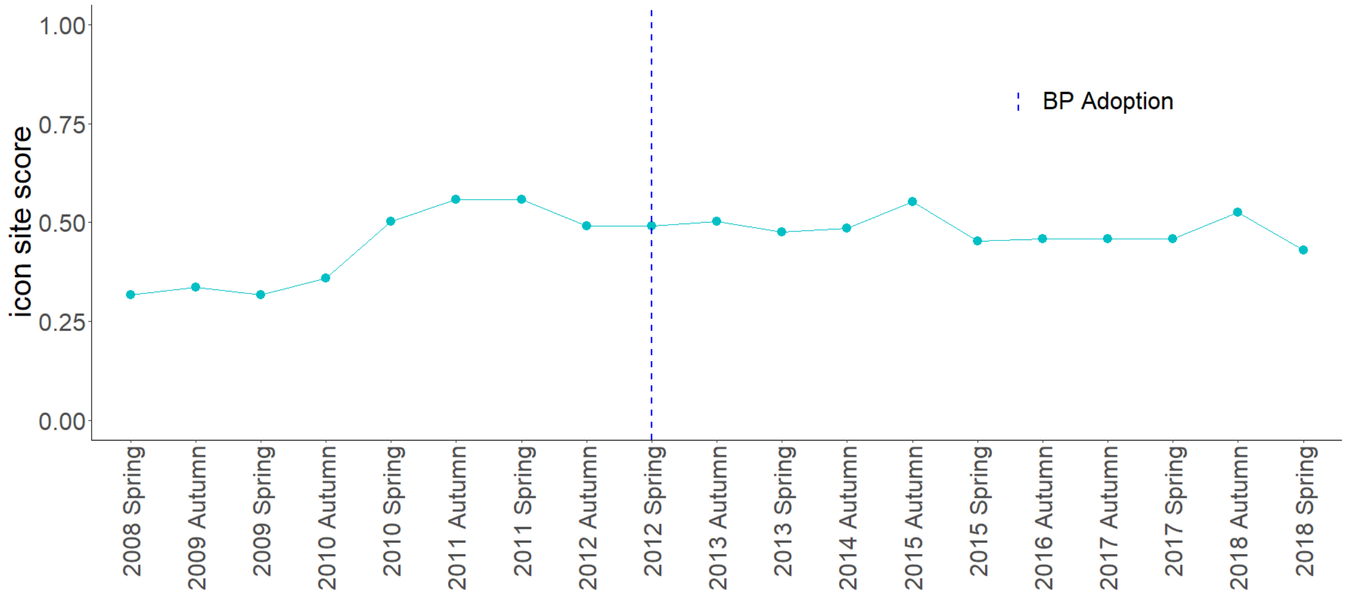

Figure 5-2. Icon site scores for the condition of aquatic and littoral vegetation in the Lakes from spring 2008 to spring 2018. The adoption of the Basin Plan is marked by a vertical dashed blue line.

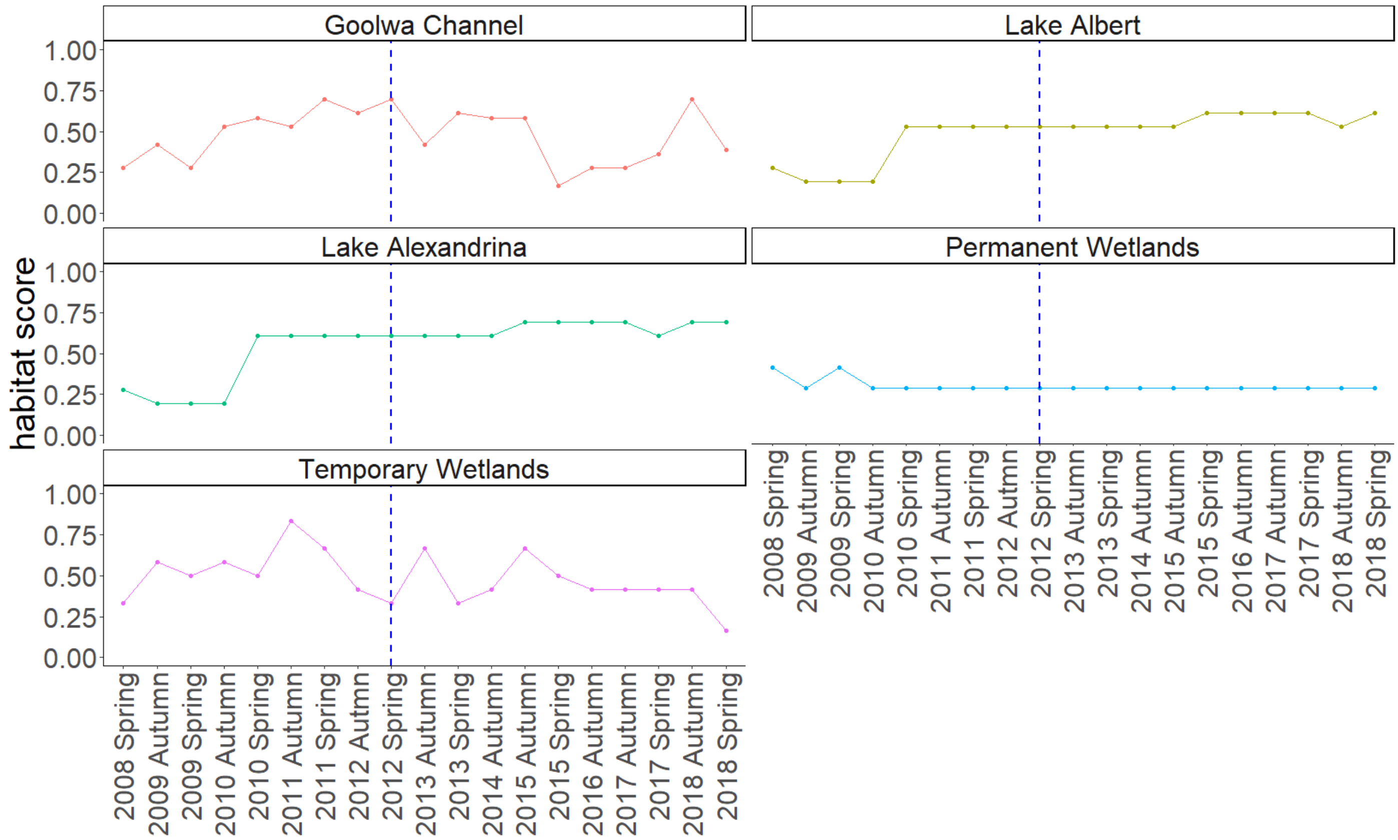

Figure 5-3. Habitat scores for each wetland type: Goolwa Channel, Lake Albert, Lake Alexandrina, Permanent Wetlands, Temporary Wetlands from spring 2008 to spring 2018. Note: Temporary wetlands includes autumn and spring wetlands. The adoption of the Basin Plan is marked by a vertical dashed blue line.

5.4.2 Trend

Overall, the icon site score for aquatic and littoral vegetation condition has likely increased over the sampling program (Table 5-4). The habitats that comprise the icon site had variable trends over the monitoring program, with the habitat scores for Lake Albert and Lake Alexandrina virtually certain to have increased, Goolwa Channel and permanent wetlands likely to have decreased and temporary wetlands extremely likely to have decreased (Table 5-4).

Table 5-4. Outcomes from the Bayesian modelling assessment of trend for the icon site and each location. The likelihood of improvement in the icon site score and habitat scores are provided in addition to their associated confidence rating (as per Mastrandrea et al. 2010).

Location	Outcome	Likelihood of outcome	Report card category
Icon site	Likely increase	83%	Getting better
Lake Albert	Virtually certain increase	100%	Getting better
Lake Alexandrina	Virtually certain increase	100%	Getting better
Goolwa Channel	Likely decrease	69%	Getting worse
Permanent wetlands	Likely decrease	73%	Getting worse
Temporary wetlands	Extremely likely decrease	98%	Getting worse

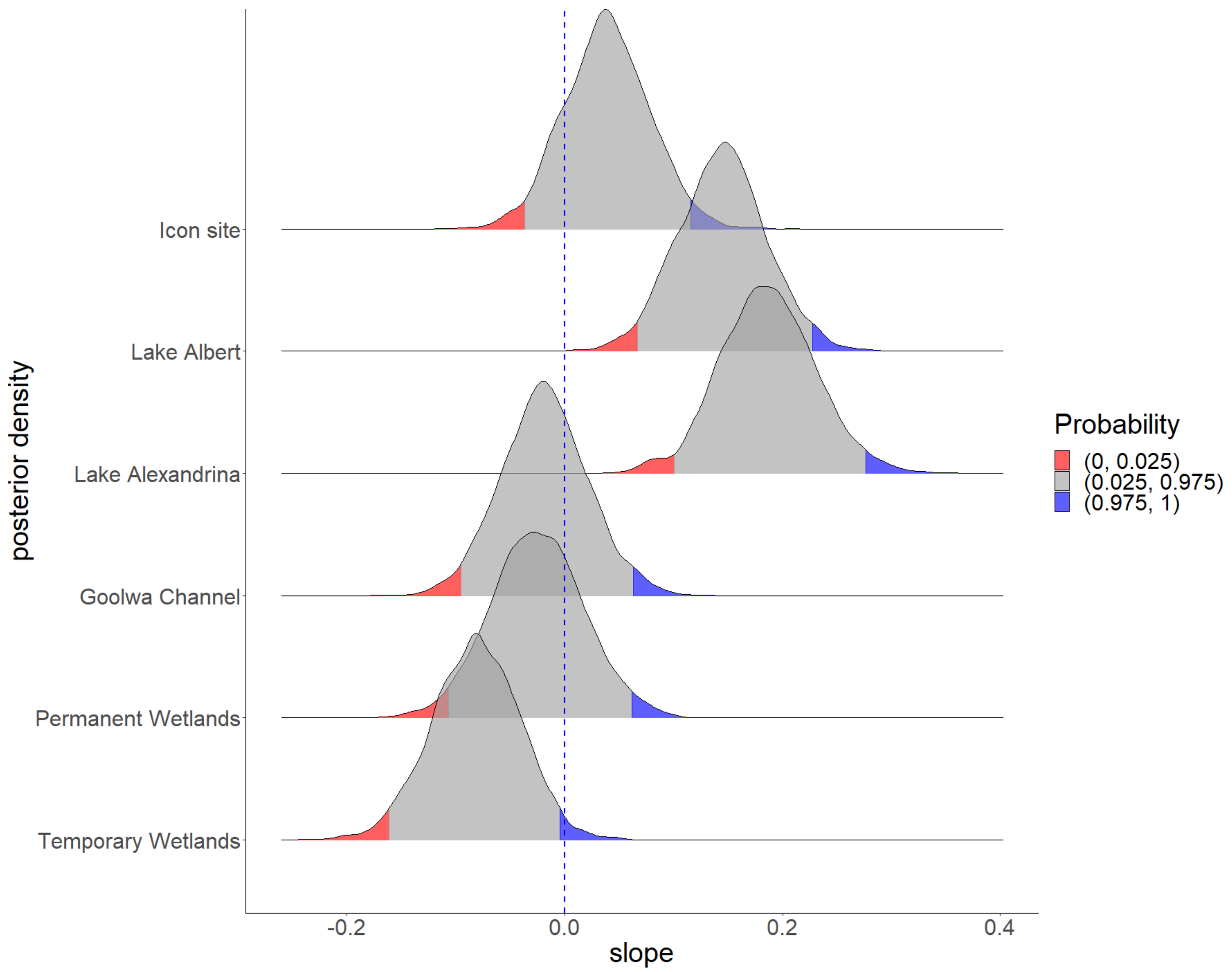

Figure 5-4. Estimated values for the slope generated from Bayesian modelling for the icon site score and habitat scores of the whole icon site and each location within the icon site from spring 2008 to spring 2018. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse). Note: Temporary wetlands includes autumn and spring wetlands.

5.4.3 Condition

The condition of aquatic and littoral vegetation in the Lakes in the most recent monitoring event (spring 2018) was considered to be **fair**, given an icon site score of 0.43.

5.4.4 Information reliability

The information reliability rating for aquatic and littoral vegetation was **very good** (final score of 11). Justification for the scoring of aquatic and littoral vegetation data reliability is provided in Table 5-5.

Table 5-5. Reliability of aquatic and littoral vegetation data to assess the expected environmental outcome for aquatic and littoral vegetation condition in the Lakes. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *Condition Monitoring Plan* (DEWNR 2017).	**2**
Standard methods	Has the same method been used over the sampling program?	**Yes.** The same method has been used over the monitoring program (spring 2008 to spring 2018).	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	**Somewhat.** Sampling effort has been spread over the PEA, however, is greater in Goolwa Channel than the other habitats.	**1**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Sampling has been conducted from 2008 to 2018, and therefore, the 11 years of monitoring includes pre- and post-Basin Plan adoption years and range of hydrological conditions.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** All sites were established by 2009 and were monitored during each assessment period.	**2**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Yes.** Sampling has been conducted annually at a minimum and bi-annual data (autumn and spring) collected in most years.	**2**
Final score			**11**
Information reliability			**Very good**

5.5 Evaluation

Over the duration of the assessment period from 2008 to 2018, the condition of aquatic and littoral vegetation in the Lakes was likely to have improved. However, there were discrepancies in the trends between habitats within the icon site. It is expected that aquatic and littoral vegetation condition in the Lakes will be maintained from 2019, with peak benefits to condition likely to occur from now over the next 10 years due to greater water recovery. This will be achieved through addressing water delivery constraints and because 'there was progress towards achieving most of the targets that require an increase in the abundance of desirable taxa in most zones of most habitats' (Nicol et al. 2019).

The likely improvement in aquatic and littoral vegetation condition over the assessment period was influenced by the breaking of the Millennium drought in 2010 and the return of the Lakes to normal operating levels, and the maintenance of these conditions through the delivery of water and management of the Lakes (see section 5.5.1). Additionally, complementary management actions (see section 5.5.2) have also influenced the condition of the aquatic and littoral vegetation in the Lakes within the assessment period.

5.5.1 Water regime and Lake level management

The delivery of water has enabled the return of the Lakes to normal operating levels and subsequent improvements in the condition of aquatic and littoral vegetation in the Lakes since the Millennium drought to be sustained. Lake operating levels are maintained through the planned (not licensed) environmental water (PEW) component of South Australia's Entitlement and unregulated flows.

The delivery of water has enabled the improvements in condition to be sustained through the management of lake levels, including seasonal lake level management and the maintenance of lake levels above critical thresholds and the restoration of salinities in the Lakes.

Seasonal lake level management

Seasonal water level management between +0.4 m AHD and +0.85 m AHD provides water level variability to support growth and reproduction of aquatic plants. Variations in lake level were relatively small between 2010/11 and 2012/13 due to high flow conditions that maintained high lake levels. Seasonal lake levels became more pronounced after 2013/14 and since 2015/16 the annual hydrograph has varied seasonally between +0.5 and +0.9 m AHD (Nicol et al. 2019). Seasonal water level fluctuations between +0.5 m AHD and +0.9 AHD contributed to improvements in the habitat scores for Lake Alexandrina and Albert (e.g. in 2015), compared to more constant lake levels observed between 2010 and 2014.

Fluctuations in water level exposed lake and wetland fringes during draw-down periods (+0.5 m AHD) (Nicol et al. 2019). The exposure of littoral habitats were important for the germination of amphibious taxa, which increased species richness at +0.6 m AHD (Nicol et al. 2019). However, the germination and recruitment of amphibious taxa were limited within areas exposed to wave action or located within dense reed beds of *Phragmities australis* and *Typha domingensis* (Nicol et al. 2019). Furthermore, surcharges of the Lakes above +0.8 m AHD for short periods facilitated recruitment of *Melaleuca halmaturorum* (Frahn et al. 2014). Overall, the influence of seasonal lake level management has improved the condition of aquatic and littoral vegetation in the Lakes (Nicol et al. 2019).

Maintenance of lake levels

Lake water levels have been maintained above +0.4 m AHD since 2010/11, which has ensured that habitats are permanently inundated to support aquatic vegetation (Nicol et al. 2019). Lake level is a primary driver of aquatic and littoral vegetation condition in the Lakes. When water levels receded to below 0 m AHD between 2008 and 2010, submergent plants were extirpated and terrestrial plants colonised the littoral zone (Nicol et al. 2019). A return of flow conditions (due to the high unregulated flow event) below Lock 1 in late August 2010 resulted in significant improvement in aquatic and littoral vegetation condition. The recolonisation of submergent, emergent and amphibious taxa was associated with the extirpation of terrestrial taxa (Nicol et al. 2019).

Salinity

The restoration of salinities in the Lakes following the Millennium drought have contributed to supporting the diversity and condition of the aquatic and littoral vegetation. Electrical conductivity (EC) during the peak of the Millennium Drought (used to describe salinity) exceeded 5,000 EC in Lake Alexandrina and 15,000 EC in Lake Albert (Figure 2-4). The impact of elevated EC during this period on aquatic and littoral vegetation is difficult to determine, as lake levels were also below sea level, disconnecting water from fringing habitats. However, elevated salinities may have largely prevented the colonisation of submergent taxa in the remaining areas of open water (Marsland and Nicol 2009). The high (unregulated) flow event and high flows between 2010/11 and 2012/13 greatly reduced salinities in Lake Alexandrina and Lake Albert, however, the EC of Lake Albert continued to decline after the adoption of the Basin Plan and as of June 2019 (end of reporting period) reflective of conditions pre-2007 (Gibbs et al. 2018). The reduction in EC of Lake Albert was likely in response to the maintenance of its connection with Lake Alexandrina (noting this had to be constructed during the Millennium Drought) (Nicol et al. 2019), seasonal lake level management (Wedge et al. 2014; Nicol et al. 2019), high (unregulated) flow events and the enhancement of barrage outflow with water for the environment (Ye et al. 2020). Magnitudes of change in EC of Lake Albert since the adoption of the Basin Plan are not considered to be biologically significant for the plant species present (Nicol et al. 2019).

5.5.2 Complementary actions

Lakeshore fencing

A total of 22% of the shoreline of the Lakes was fenced under the Vegetation Program as part of the CLLMM Recovery Project in 2012 (DEW 2019). Fences were established in areas where stock threatened the condition of littoral vegetation. Overall, 42% of the lakeshore was fenced where stock grazing threatened littoral vegetation (DEW 2019). Fences prevent the impacts of stock, which included over-grazing, pugging and erosion of lakeshores, to the benefit of aquatic and littoral vegetation condition (DEW 2019). Most fences were established prior to the adoption of the Basin Plan; however, they likely influenced the recovery of aquatic and littoral vegetation following the adoption of the Basin Plan. Despite the overwhelming positive impact of fencing, *P. distichum* and *C. clandestinus* have increased in cover with the exclusion of grazing.

Aquatic plant revegetation

Schoenoplectus tabernaemontani stands were planted over 30 km of shoreline in the Lakes by community groups since 1996 and under the CLLMM Recovery Project from 2012 to 2016 (Nicol et al. 2016). The plantings aimed to reduce shoreline erosion and enhance aquatic and littoral vegetation condition (Nicol et al. 2016). Stands of *S. tabernaemontani* enhance the condition of aquatic and littoral vegetation by providing a barrier to wave action, which provided sheltered habitats for aquatic flora, such as *Myriophyllum* spp., *Potamogeton* spp., *Certophyllum demersum* and *Vallisneria australis* (Nicol et al. 2016). Furthermore, *S. tabernaemontani* does not form monotypic stands, and therefore can grow as a component of a diverse flora community (Nicol et al. 2016). Three of the 24 lakeshore monitoring sites overlapped with lakeshore where *S. tabernaemontani* were planted (J Nicol Pers. Comm. 2019). Therefore, given the minor overlap of *S. tabernaemontani* plantings with monitoring sites, the impact of planted *S. tabernaemontani* stands to the icon site score are expected to be minor.

5.6 Actions to achieve environmental outcomes

The likely improvement of icon site scores over the assessment period suggests that current hydrological and salinity regimes are helping aquatic and littoral vegetation recover from the period of low water levels (<0.4 m AHD) from 2007 to 2010 (Nicol et al. 2019). Therefore, it is recommended that current hydrological and salinity regimes, especially seasonal lake level management, need to be maintained to provide conditions for the continual improvement of aquatic and littoral vegetation condition in the Lakes (Nicol et al. 2019). Outside of the current management influence, periodic high (unregulated) flow events are also important and are needed more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes.

The lower condition scores observed in permanent and temporary wetlands over the assessment period highlight the need to investigate opportunities to improve hydrological management through on-ground works initiatives, in order to generate improved vegetation outcomes. Land management changes and direct vegetation management including weed control may also aid in improving the condition of littoral vegetation.

5.7 Conclusion

The delivery of water following the adoption of the Basin Plan has enabled the return of the Lakes to normal operating levels, including the seasonal management of lake levels and maintenance of lake levels above critical thresholds. Lake operating levels have been maintained through the planned (not licensed) environmental water (PEW) component of South Australia's Entitlement and unregulated flows. These conditions have been crucial in protecting aquatic environments and providing opportunities for recruitment by aquatic plant species. In future years, it is expected that aquatic and littoral vegetation condition in the Lakes will be maintained from 2019.

Key messages:

- The delivery of water has contributed to seasonal lake level management between +0.5 and +0.9 m AHD, the maintenance of lake levels above +0.4 m AHD, and the restoration of salinities in Lakes to those reflective of pre-drought conditions. These hydrological management actions have been integral to the sustained improvements in aquatic and littoral vegetation condition since the Millennium drought.
- Periodic high (unregulated) flow events are important and are needed more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes that in turn support the diversity and condition of aquatic and littoral vegetation in the Lakes.
- Maintaining current hydrological and salinity regimes, especially seasonal lake level management, will be important to provide conditions for the continual improvement of aquatic and littoral vegetation condition.

6 Ruppia tuberosa

6.1 Introduction

Ruppia tuberosa is a species of submerged macrophyte that historically is distributed throughout the southern Coorong (Paton et al. 2019b). *R. tuberosa* plays an important role in the structure and function of the southern Coorong, where it modifies the physical environment (i.e. water velocity) and biogeochemical processes (Rogers and Paton 2009). *R. tuberosa* is one of the most important primary producers in the southern Coorong, as it provides longer-term capture of nutrients and directly and in-directly provides critical habitat and food resources for higher trophic organisms (Nicol 2005; Rogers and Paton 2009; Waycott et al. 2020). Higher trophic organisms that directly benefit from *R. tuberosa* include small-mouthed hardyhead (Brookes et al. 2009), which adhere their eggs to *R. tuberosa* shoots (Molsher et al. 1994), and waterbirds that consume *R. tuberosa* (Paton and Rogers 2009). *R. tuberosa* is an important food resource for waterbirds, as plant material and turions are grazed by herbivorous waterfowl and turions and seed are foraged upon by shorebirds (e.g. *Calidris* spp.) (Paton 1986).

Water depth is a primary driver of *R. tuberosa* population health in the southern Coorong (Paton et al. 2019b). Optimal water depths are dependent upon the life stage of *R. tuberosa* (Figure 6-1), with seed germination and turion sprouting occurring in late autumn when exposed mudflats are re-inundated. In order for annual populations of *R. tuberosa* to complete reproduction and increase vigour (i.e. total plant material), plants need to be covered by 30 cm of water to prevent wind seiches exposing plants to desiccation (Paton et al. 2019b). As most *R. tuberosa* beds in the southern Coorong that establish in winter are at elevations between 0.0 and 0.2 m AHD, a fall in water level below 0.3 m AHD over spring and into summer means that *R. tuberosa* beds are not covered by 30 cm of water. Consequently, plants are therefore prone to desiccation before they have set seed or produced turions (Paton et al. 2019b). Populations of *R. tuberosa* that maintain shoots throughout the year occur at lower elevations and have limited capacity to grow during periods of higher water levels (i.e. winter) due to poor light availability, however, will grow when water levels fall and light availability improves (Figure 6-1).

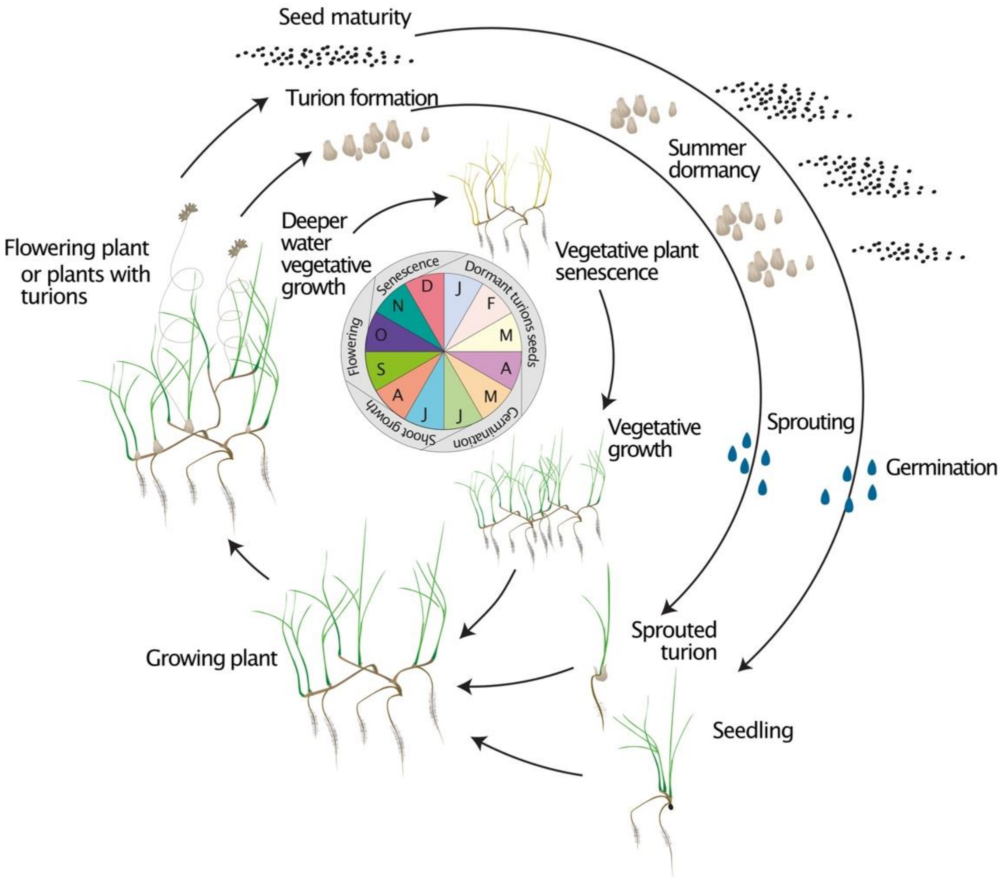

Figure 6-1. Illustration of *the R. tuberosa* life cycle showing annual growth from seeds and turions and depicting the vegetative persistence growth cycle for deeper water locations where water clarity contains adequate light (adapted from Waycott et al. 2020).

Salinity is another key driver of *R. tuberosa* population health in the southern Coorong (Collier et al. 2017; Paton et al. 2019b). The sensitivity of *R. tuberosa* to salinity is dependent upon the life stage and reproductive strategy, i.e. asexual or sexual reproduction (Figure 6-1, Figure 6-2) (Collier et al. 2017). Salinities >100 $g.L^{-1}$ impede the germination of seeds, sprouting of turions, growth of seedlings and flowering (Paton and Bailey 2010, 2012; Kim et al. 2013; Collier et al. 2017), however, such salinities are more tolerable for adult growth and the dormancy of seeds and turions over the summer months (Collier et al. 2017). Population health of *R. tuberosa* in the southern Coorong is also adversely impacted when salinities fall below 80 $g.L^{-1}$, which is the upper tolerance threshold for filamentous algae (Collier et al. 2017).

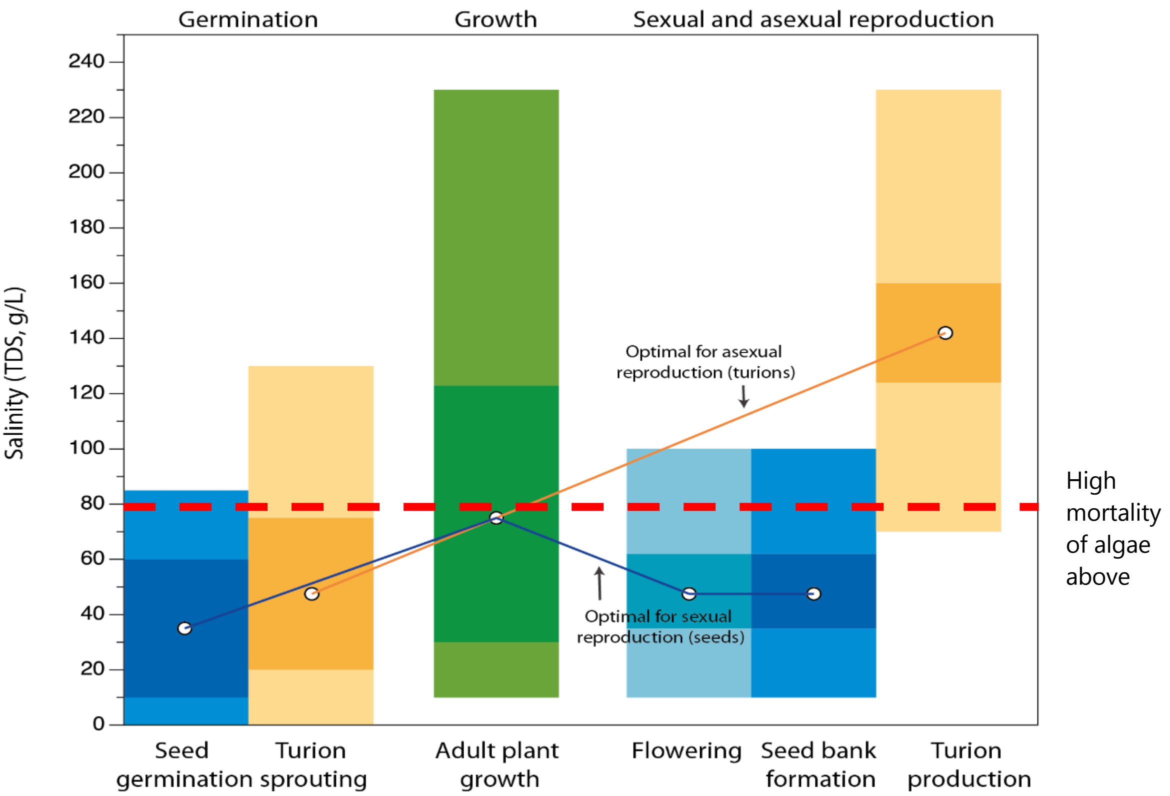

Figure 6-2. Summary of optimal (darker shades) and sub-optimal (lighter shades) salinity ranges for different stages of the *R. tuberosa* life cycle, with conditions separated for sexual reproduction shown in blue and asexual reproduction shown in orange. Salinity ranges for seed germination and turion sprouting were derived from laboratory experiments, and salinity ranges for adult growth, flowering, seed bank formation and turion production were derived from a combination of in-situ, laboratory and mesocosm data. As such, the salinity ranges for seed germination and turion sprouting for which in-situ data is unavailable should be treated with caution. It should be recognised that under current hyper-eutrophic conditions in the southern Coorong that excessive filamentous algal growth when salinities are below 80 g.L-1 means that *R. tuberosa* flowering and seed bank formation are adversely impacted. Unsuitable conditions are not included in this figure (Source: Collier et al. 2017).

Seasonal periods of excessive filamentous algal growth are a tertiary driver of *R. tuberosa* population health (Paton et al. 2015b; Collier et al. 2017). Excessive filamentous algal growth adversely impact *R. tuberosa* by causing (1) light limitation, (2) senesce of *R. tuberosa* attributed to high organic loads and associated sulphide intrusion from sediments that become anoxic during the decay of the algae and (3) flowering and fruiting stalks of plants are removed or broken, resulting in low seed development even when there is high flowering density (Collier et al. 2017; Paton et al. 2019b). Excessive growth of filamentous algae is thought to be in response to the hyper-eutrophic conditions that now persist in the Coorong (Mosley and Hipsey 2019; Waycott et al. 2020). Nutrients in the Coorong can accumulate from the inputs of freshwater inflows from the barrages (River Murray) and Salt Creek (South-East), although it's the lack of flows to flush the system that are thought to be the primary driver of the current hyper-eutrophic conditions (Mosley and Hipsey 2019). Recent research (Mosley 2020; Waycott 2020) has been investigating the likelihood that the loss of *R. tuberosa* during the Millennium Drought likely led to a shift in ecosystem state, where slow-growing *R. tuberosa* that retain nutrients for relatively long periods (weeks to months) were replaced by fast-growing phytoplankton and filamentous algae that retain nutrients for short periods (days to weeks).

The population health of *R. tuberosa* in the southern Coorong declined prior to the Millennium Drought, due to increased upstream extraction and diversion of water for human use that contributed to inadequate water levels for reproduction and growth (Paton et al. 2015b). Adverse impacts to *R. tuberosa* were exacerbated during the Millennium Drought, with low water levels and salinities consistently above 100 $g.L^{-1}$ and at times exceeding 150 $g.L^{-1}$ in the South Lagoon. This caused a northward shift in the distribution of the plant in the Coorong (Paton and Bailey 2012). The distribution and abundance of *R. tuberosa* in the South Lagoon declined significantly between 2000 and 2010, with no *R. tuberosa* detected between 2008 and 2010 (Paton and Bailey 2012). However, from 2006 to 2010, *R. tuberosa* established extensive beds in the central section of the North Lagoon (Paton and Bailey 2012). A high flow event in 2010 improved the health of *R. tuberosa* populations in the South Lagoon, however, *R. tuberosa* did not recover to its condition prior to 2000 (Paton and Bailey 2013a). Furthermore, the extensive beds of *R. tuberosa* in the central section of the North Lagoon established during the Millennium Drought were completely lost by July 2011, likely due to impacts associated with excessive filamentous algal growth (Paton and Bailey 2012). The limited recovery of *R. tuberosa* since the Millennium Drought is considered to be in response to falling water levels in spring and into summer that prevent the completion of the *R. tuberosa* reproductive cycle and filamentous algae interfering with the productivity of the plant (Paton et al. 2019b).

6.2 Ecological objective, targets and environmental outcomes

The ecological objective for *R. tuberosa* in the Coorong from the SA River Murray LTWP (DEWNR 2015) is presented in Table 6-1. The ecological targets for *R. tuberosa* are from the *Ruppia tuberosa* chapter (Paton et al. 2017b) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and are also presented in Table 6-2. The targets formed the basis for the development of expected environmental outcomes for this assessment.

Table 6-1. Ecological objective and targets for *R. tuberosa* in the southern Coorong.

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

The expected environmental outcomes for *R. tuberosa* in 2019, 2029 and 2042 were determined by elicitation with key expert (Table 6-2;

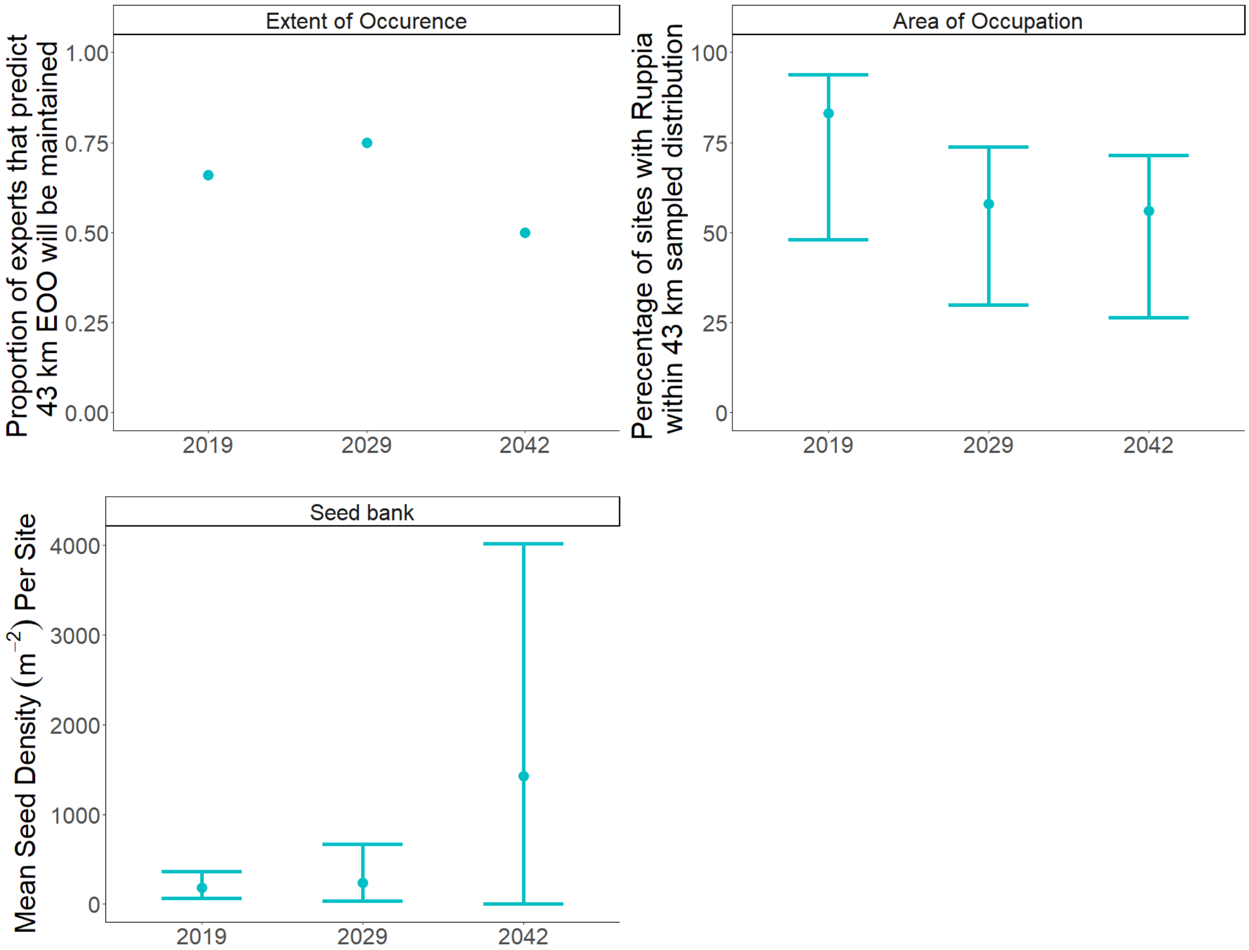

Figure 6-3). These form the basis of the assessment of *R. tuberosa* environmental outcomes in the SA River Murray CLLMM PEA.

Table 6-2. Expected environmental outcomes for *R. tuberosa* distribution – extent of occurrence (EOO), area of occupation (AOO) and long-term resilience (seed bank) across the 43 km sampling distribution in the Coorong in 2019, 2029 and 2042.

	Year	Expected environmental outcomes
Extent of occurrence (EOO)	2019	66% experts expected that the historical occurrence (43 km extent) of *R. tuberosa* would be maintained.
	2029	75% experts expected that the historical occurrence (43 km extent) of *R. tuberosa* would be maintained.
	2042	50% experts expected that the historical occurrence (43 km extent) of *R. tuberosa* would be maintained.
Area of occupation (AOO)	2019	83% of sites (within the sampled 43 km distribution) will have *R. tuberosa* plants present in both winter and summer, with an 80% confidence interval of 48 to 93% of sites.

	Year	Expected environmental outcomes
	2029	58% of sites (within the sampled 43 km distribution) will have *R. tuberosa* plants present in both winter and summer, with an 80% confidence interval of 29 to 73% of sites.
	2042	56% of sites (within the sampled 43 km distribution) will have *R. tuberosa* plants present in both winter and summer, with an 80% confidence interval of 27 to 72% of sites.
Long term resilience (seed bank)	2019	*R. tuberosa* seed density (seeds.m^{-2}) across the 43 km sampling distribution in the Coorong is expected to be 181 seeds.m^{-2}, with an 80% confidence interval of 68-363 seeds.m^{-2}.
	2029	*R. tuberosa* seed density (seeds.m^{-2}) across the 43 km sampling distribution in the Coorong is expected to be 238 seeds.m^{-2}, with an 80% confidence interval of 35-668 seeds.m^{-2}.
	2042	*R. tuberosa* seed density (seeds.m^{-2}) across the 43 km sampling distribution in the Coorong is expected to be 1425 seeds.m^{-2}, with an 80% confidence interval of 0-4016 seeds.m^{-2}.

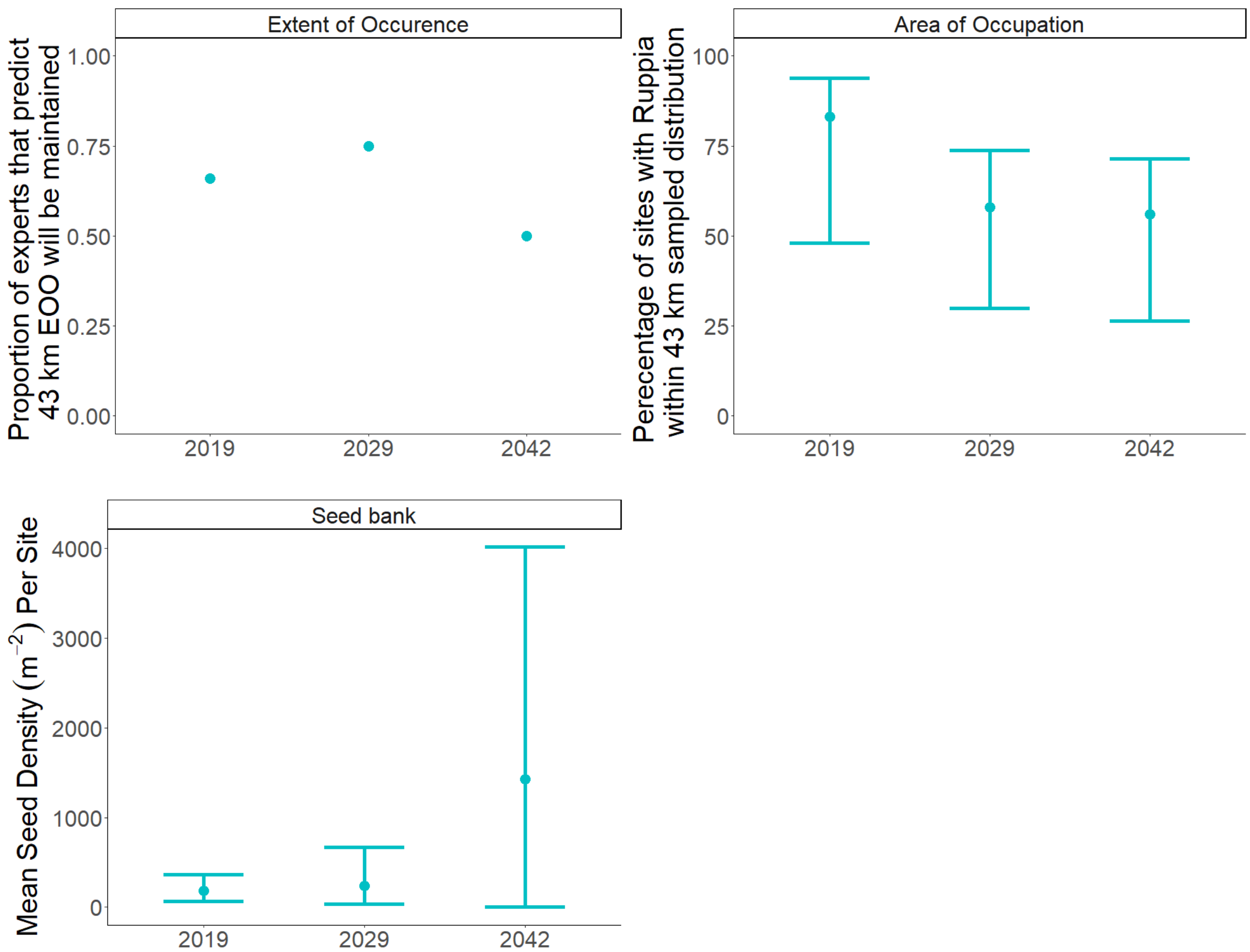

Figure 6-3. Expected environmental outcomes for *R. tuberosa* extent of occurrence (EOO), area of occupation (AOO) and long-term resilience (seed bank) across the 43 km sampling distribution in the Coorong in 2019, 2029 and 2042.

Over time, it was expected that the distribution of *R. tuberosa* (i.e. the 43 km EOO) will be maintained. Similarly, it is expected that the area of occupation of *R. tuberosa* for *R. tuberosa* within the 43 km sampling distribution will decline over time. Expert opinion differed on the long-term resilience expected environmental outcome, with expectations varying from an improvement in the seed bank of *R. tuberosa* to be reflective of a resilient population to the decline and subsequent loss of the seed bank. For all expected environmental outcomes, the confidence in estimates attenuated with time. However, there were no statistical differences in the predicted seed densities of *R. tuberosa* across 2019, 2029 and 2042.

6.3 Method

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

Summer monitoring

The distribution and abundance of shoots, seeds and turions were assessed annually in January at 8 sites, spaced ~5 km apart, on both the eastern and western shores of the South Lagoon. A further 4 sites, spaced ~5 km apart, on the eastern shore of the North Lagoon were also assessed. It should be noted that the 43 km historic extent of *R. tuberosa*, includes the most southern site in the North Lagoon, located 2 km from the junction of the North and South Lagoon. At each site, 25 core samples (75 mm diameter, 400 mm deep) were taken at 4 water depths: dry mud, waterline, 30 cm deep and 60 cm deep. The number of live shoots were recorded for each core. After which, the core was sieved through a 500 µm Endecott sieve and the number of seeds and turions remaining were counted.

Winter monitoring

The distribution and abundance of *R. tuberosa* shoots were assessed annually in July at 8 sites in the South Lagoon and 4 sites in the North Lagoon. It should be noted that the 43 km historic extent of *R. tuberosa*, includes the most southern site in the North Lagoon, located 2 km from the junction of the North and South Lagoon. The winter monitoring program is comprised of 2 sampling methodologies. The first method consists of sites with 5 permanent transects spread 25 m apart from each other that run perpendicular to the shore into the water. Along each transect, 2 core samples were collected at water depths of 20 cm, 40 cm, 60 cm, 80 cm and 90 cm, yielding a total of 10 samples per transect. Within each core, the number of live shoots were recorded. Following this, each core was sieved through 500 µm Endecott sieves, enabling seeds and turions to be counted.

The second method builds upon the first, with an additional 4 areas between adjacent transects sampled by taking 50 cores in water depths between 40 and 70 cm. Within each core, the number of live shoots were recorded. Cores were not subsequently sieved for seeds.

Monitoring data

The data collected during monitoring activities is made available in the Australian National Data repository (https://data.gov.au/data/dataset/ruppia-monitoring-southern-coorong). Assessments of trends, summary analyses and other summarised presentations of data are based on the data lodged in this repository.

6.3.1 Assessment of environmental outcomes

Expected environmental outcomes were assessed using data from 2012 to 2019 as there was large increase in sample effort in winter 2012 and summer 2013. Repeat visits to sites established in winter 2012 and summer 2013 as well as sites established earlier in the monitoring program has occurred up to winter 2019 (end of assessment period).

6.3.2 Trend assessment

The approach to assess trend using a Bayesian Generalised Linear Mixed Model is discussed in section 3.2.1. Trend was assessed for EOO, AOO and seed bank (as described below).

Distribution – Extent of occurence

Trend for *R. tuberosa* extent of occurrence was assessed based on changes in the frequency that *R. tuberosa* were detected over its 43 km historic distribution in the southern Coorong (inclusive of sites within the historic distribution of *R. tuberosa*, i.e. N02E to S41E/W) during January and July assessments from 2009 to 2019. Data used for the trend assessment commenced in 2009 as this was the first year that site N02E was assessed in winter. A binary dataset was used for the trend analysis, with assessments where *R. tuberosa* were detected over the 43 km historic distribution allocated a 1 and assessments where this did not occur were allocated a 0. Time step (years since the commencement of the assessment period) was included as a random effect within the model. A binomial family was fitted to the Bayesian Generalised Linear Mixed Model as binary data were used.

Area of occupation

Trend for *R. tuberosa* area of occupation was assessed based on the proportion of sites with shoots over the eastern and western shores of the southern Coorong (inclusive of sites within the historic distribution of *R. tuberosa*, i.e. N02E to S41E/W) in January and July from 2009–2019. Data used for the trend assessment commenced in 2009 as this was the first year that site N02E was assessed in winter. A binary dataset was used for the trend analysis, with sites where shoots were detected allocated a 1 and sites where no shoots were detected allocated a 0. Time step (years since the commencement of the assessment period) was included as a random effect and site was included as a fixed effect within the model to account for spatial differences. A binomial family was fitted to the Bayesian Generalised Linear Mixed Model as binary data were used.

Seed bank

Trend for the *R. tuberosa* seed bank was assessed based on the counts of seeds in each core sampled over sites on both the eastern and western shores of the southern Coorong (inclusive of sites within the historic distribution of *R. tuberosa*, i.e. N02E to S41E/W) from January 2007 to 2019. Time step (years since the commencement of the assessment period) was included as a random effect and site was included as a fixed effect within the model to account for spatial differences. A negative binomial family was fitted to the Bayesian Generalised Linear Mixed Model as count data were used.

6.3.3 Contextual analysis of shoot and seed bank data

The performance of *R. tuberosa* during the height of the Millennium Drought, from 2007 to 2010, and following the return to barrage flows, from 2011 to 2019, was assessed to provide an understanding of its post-drought recovery. The distribution and mean densities of *R. tuberosa* shoots in both winter and summer and the mean seed bank of *R. tuberosa* in summer were analysed at a site level using data from 2007 to 2019.

6.3.4 Condition assessment

The condition of *R. tuberosa* for 2019 was assessed based on seed bank densities at sites along the eastern and western shores of the southern Coorong (within 43 km sampled distribution) recorded in January 2019. The mean seed density recorded at each site was compared against Table 6-3 to determine a population condition rating, with the criteria read from very good to poor. If the criteria of a particular condition class was not satisfied, then the population was assessed against the next highest population condition rating until the criteria were met.

The thresholds for very good and good were based upon historic data from the southern Coorong and Lake Cantara. The condition assessment used seed densities ≥10,000.m^{-2} at 50% or more sites in the 43 km sampled distribution as reflective of an *R. tuberosa* population in 'very good condition' as a vigorous population of *R. tuberosa* exists at Lake Cantara where winter seed densities can exceed 10,000 seeds.m^{-2} (Paton et al. 2017b). Furthermore, historically seed densities in the southern Coorong were as high as 20,000 seeds.m^{-2} in the 1980s (Paton 1986), therefore, such a threshold for a population in 'very good' condition is reflective of maximum observed historic conditions when *R. tuberosa* was thriving and abundant throughout the southern Coorong (Paton 1996). The very limited evidence base for this upper value should be noted. Seed densities ≥2,000.m^{-2} at 50% or more sites in the 43 km sampled distribution were considered to be representative of an *R. tuberosa* population in 'good condition', as seed densities of 2,000.m^{-2} reflect a population with an initial level of resilience (Paton et al. 2017b). The criteria for 'fair' population was set using data from winter 1998 and 1999 (i.e. prior to the Millennium Drought) when ≥50% of sampled sites in the South Lagoon had seed densities above or near 1,000.m^{-2}.

Table 6-3. Assessment of *R. tuberosa* population condition in the southern Coorong based upon seed bank densities along the eastern and western shores of the southern Coorong (within the 43 km sampled distribution) in January 2019.

Condition class	Criteria
Very good	≥10,000 seeds.m^{-2} at ≥50% of sites within the 43 km sampled distribution.
Good	≥2,000 seed.m^{-2} at ≥50% of sites within the 43 km sampled distribution.
Fair	≥1,000 seed.m^{-2} at ≥50% of sites within the 43 km sampled distribution.
Poor	<1,000 seed.m^{-2} at ≥50% of sites within the 43 km sampled distribution.

6.3.5 Information reliability

The information reliability assessment for *R. tuberosa* was conducted as per section 3.2.2.

6.4 Results

6.4.1 Expected outcome assessment: Extent of Occurrence (EOO)

Sixty-six per cent (66%) of experts expected the extent of *R. tuberosa* would cover the 43 km sampling distribution in the southern Coorong in 2019. As the distribution in summer and winter of 2019 was ≥43 km, this expected environmental outcome was met. Progression towards the achievement of the LTWP target since the adoption of the Basin Plan has improved, with the target distribution of *R. tuberosa* in the Coorong achieved in all years of the assessment, from 2013 to 2019, with the exception of 2016 (Table 6-4; Figure 6-4). In 2016, the 43 km target extent was met in summer (43 km) but not in winter (41 km) (Table 6-4; Figure 6-4).

Table 6-4. The extent of occurrence (EOO) (km) of *R. tuberosa* along the Coorong, excluding outliers, during summer and winter monitoring periods from 2012 to 2019. The EOO of *R. tuberosa* were determined by its presence at all established sites sampled over the North and South Lagoon of the Coorong. Data source: Paton et al. (2015a, 2016b, 2017c, 2018b, 2019a, 2019b).

Season	2012	2013	2014	2015	2016	2017	2018	2019
Summer	1	43	43	43	43	43	43	43
Winter	8	45	60	43	41	43	43	56

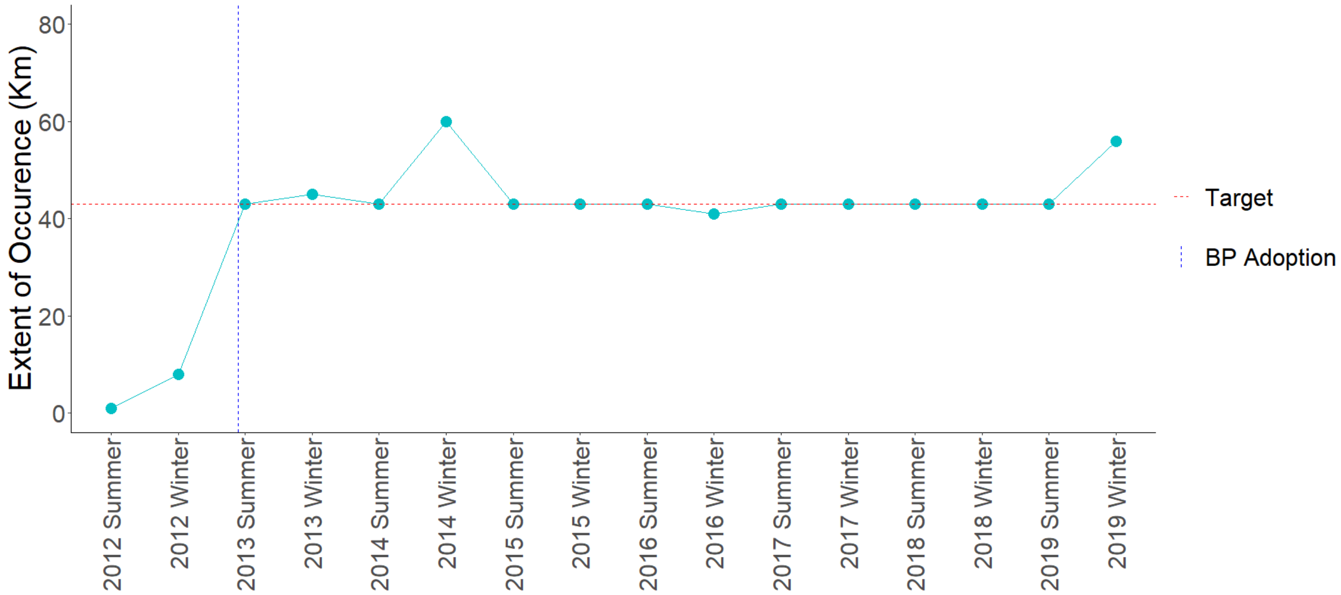

Figure 6-4. Distribution: the extent of occurrence (EOO) (km) of R. tuberosa along the Coorong, excluding outliers, during summer and winter monitoring periods from 2012–2019. The EOO of R. tuberosa were determined by its presence at all established sites sampled over the North and South Lagoon of the Coorong. The ecological target (Target) is shown by a horizontal dashed red line. Basin Plan (BP) Adoption (November 2012) is marked by a vertical dashed blue line. Data source: Paton et al. (2015a, 2016b, 2017c, 2018b, 2019a, 2019b).

6.4.2 Trend: Extent of Occurrence (EOO)

The frequency of *R. tuberosa* detection over its 43 km historic extent in the southern Coorong for a given assessment (i.e. winter and summer) from 2009 to 2019 was virtually certain (100% likelihood) to be **getting better**.

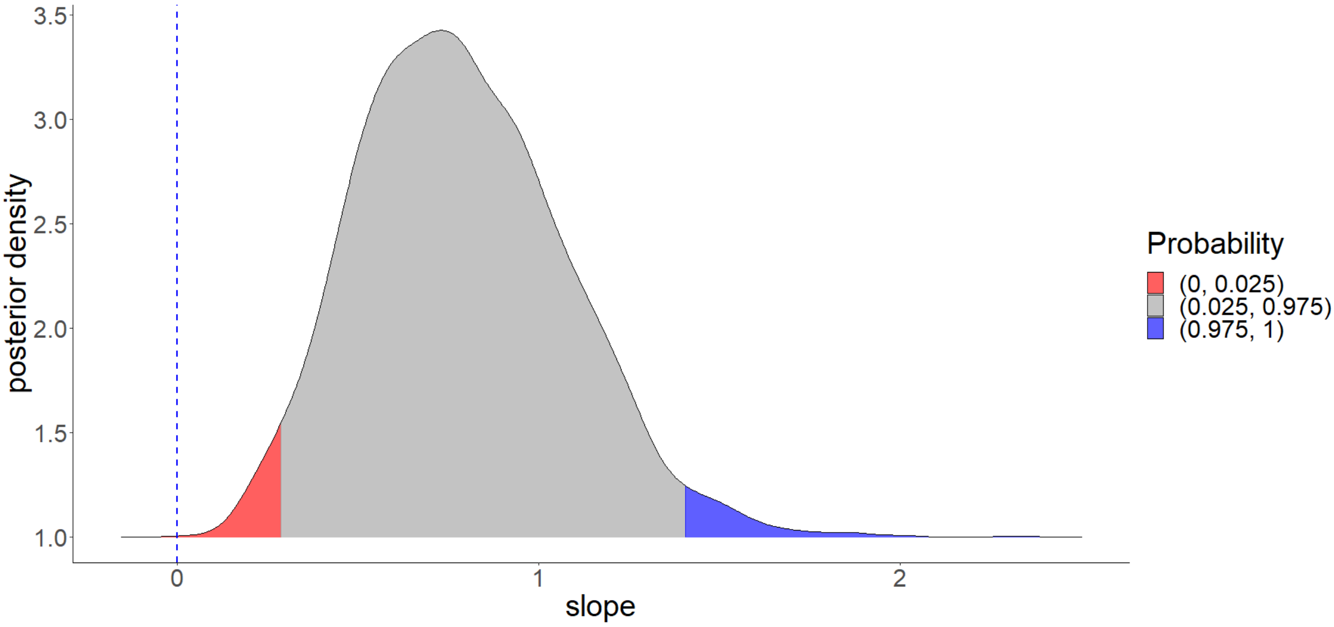

Figure 6-6. Estimated values for the slope generated from Bayesian modelling for the frequency of *R. tuberosa* occurring over its 43 km historic extent for a given assessment (i.e. winter and summer) from 2009 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

6.4.3 Expected outcome assessment: Area of Occupation (AOO)

The expected environmental outcome for *R. tuberosa* area of occupation (i.e. 83% of sites sampled) within the sampled distribution of the Coorong was not met in 2019. Summer monitoring identified *R. tuberosa* plants at 78% of sites, but winter monitoring identified *R. tuberosa* plants at 100% of sites. As a result, the expected environmental outcome of *R. tuberosa* being present at a minimum of 83% of sites in both summer and winter of 2019 was not met. Since the adoption of the Basin Plan, some progress towards the achievement of the LTWP has been made (but not across both seasons in each year) (Table 6-5; Figure 6-). The area of occupation (AOO) of *R. tuberosa* was met on 2 of 7 years of monitoring (2017 and 2018) since the adoption of the Basin Plan (Table 6-5; Figure 6-). The AOO of *R. tuberosa* increased between 2011 and 2014, and since 2014 has been relatively stable (78-100%), with the exception of summer 2016 (44%). Seasonal variations in AOO were also recorded, with *R. tuberosa* recorded at a greater percentage of sites in winter.

Table 6-5. The percentage (%) of sampled sites within the 43 km sampled distribution (i.e. all sampled sites in the South Lagoon and Magrath Flat in the North Lagoon) that had live *R. tuberosa* shoots during summer and winter monitoring periods from 2012 to 2019. Data source: Paton et al. (2015a, 2016b, 2017c, 2018b, 2019a, 2019b).

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

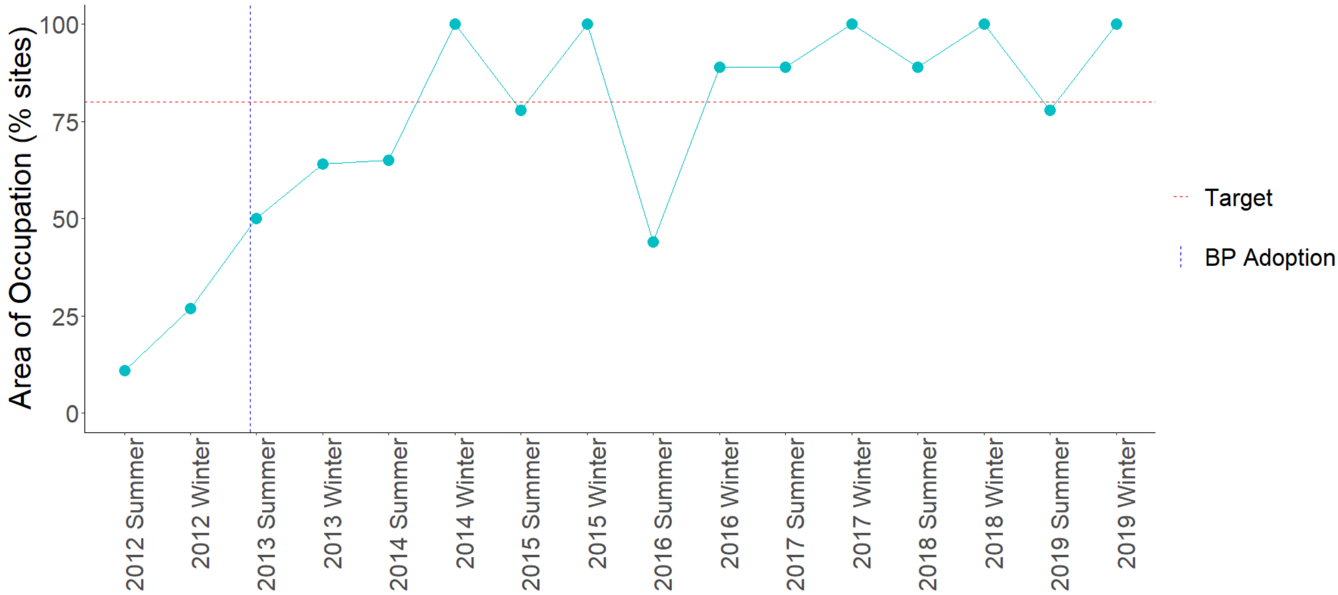

Figure 6-7. Area of occupation: the percentage (%) of sampled sites within the 43 km sampled distribution (i.e. all sampled sites in the South Lagoon and Magrath Flat in the North Lagoon) that had live *R. tuberosa* shoots during summer and winter monitoring periods from 2012 to 2019. The ecological target (Target) is shown by a horizontal dashed red line. The adoption of the Basin Plan (BP) (November 2012) is marked by a vertical dashed blue line. Data source: Paton et al. (2015a, 2016b, 2017c, 2018b, 2019a, 2019b).

6.4.4 Trend: Area of Occupation (AOO)

The proportion of sites with *R. tuberosa* shoots over the eastern and western shores of the southern Coorong in January and July from 2009 to 2019 was virtually certain (100% likelihood) to have increased (Figure 6-). Therefore, the area of occupation for *R. tuberosa* in the southern Coorong is considered to be **getting better** since the Millennium Drought.

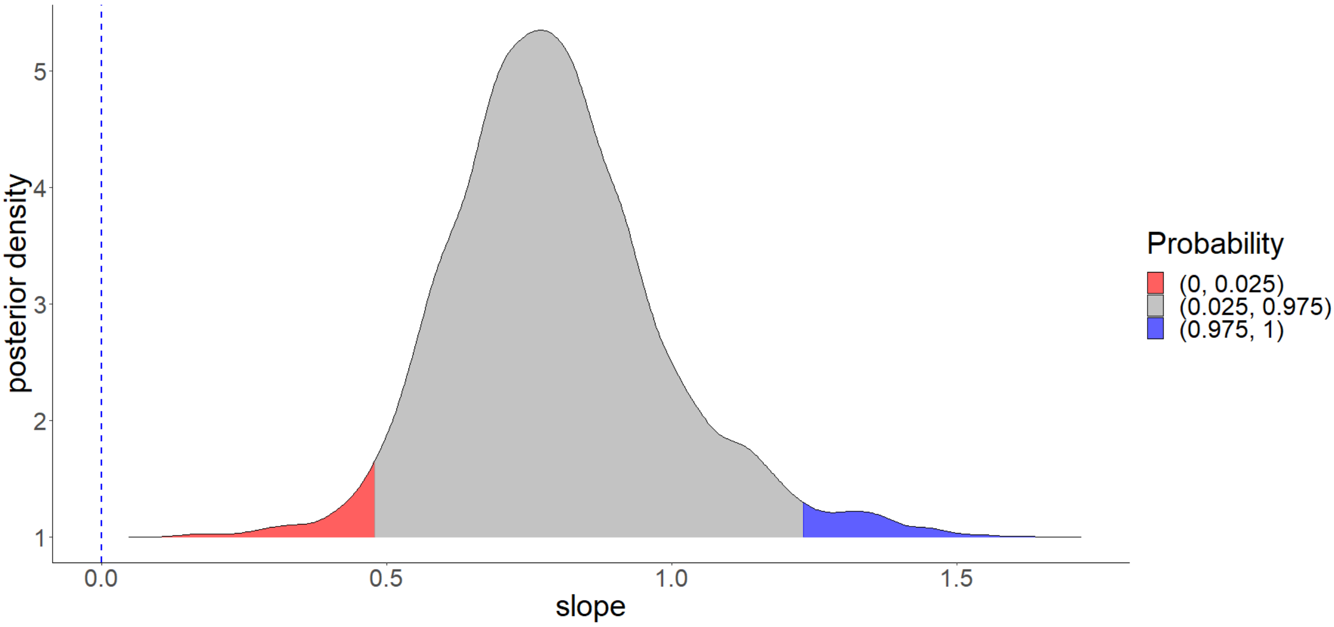

Figure 6-8. Estimated values for the slope generated from Bayesian modelling for the proportion of sites sampled on both the eastern and western shores of the southern Coorong (within the 43 km historic distribution) that had *R. tuberosa* shoots from 2009 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

6.4.5 Expected outcome assessment: long-term resilience (seed bank densities)

The expected environmental outcome for the *R. tuberosa* seed bank in 2019 was that mean densities would be 181 seeds.m^2 (80% confidence interval of 68-363 seeds.m^{-2}) (Table 6-2). Therefore, as the mean seed density in summer 2019 was 330 ± 90 seeds.m^{-2}, the expected environmental outcome for 2019 was exceeded (Table 6-6). Since the adoption of the Basin Plan progression towards the achievement of the LTWP has not been made, with the target seed densities of *R. tuberosa* not met in any year of summer monitoring nor at any site since 2012 and no sites recording seed densities >2000 seeds.m^{-2} (Table 6-6). The seed densities of *R. tuberosa* at sites across the eastern and western shores of the 43 km sampling distribution in the southern Coorong fluctuated between 2012 and 2019, with seed densities increasing to reach their peak of 347 ± 102 seeds.m^{-2} in summer 2016. Seed densities varied greatly between sites and years and ranged from 0-2788 seeds.m^{-2}.

Table 6-6. Mean and standard error (S.E.) of *R. tuberosa* seed densities at all sampled sites on the eastern shore of the 43 km sampled distribution (i.e. all sampled sites in the South Lagoon and Magrath Flat in the North Lagoon) along the southern Coorong in January from 2007 to 2019. Site names include the lagoon sampled (S for South Lagoon and N for North Lagoon) and its distance from the junction of the lagoons in kilometres. No sampled sites met the conditions of a resilient population (>2000 seeds.m2) from 2012-2019. Data source: *R. tuberosa* monitoring Southern Coorong (MDBA 2020) compiled by Assoc. Prof. David Paton, University of Adelaide.

Site	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
N02E	337	135	216	124	369	72	114	447	269	505	479	181	875
S06E	43	2788	2153	2933	926	301	160	274	420	1539	702	245	575
S06W							106	420	567	848	1571	1032	1110
S11E	4	0	4	0	291	27	61	45	72	88	27	262	5

Site	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
S11W							51	35	59	117	372	43	569
S16E	50	110	0	21	4	8	0	27	74	27	24	24	35
S16W							120	35	72	149	266	418	415
S21E	35	202	39	25	14	19	5	138	122	48	114	122	82
S21W							133	72	69	447	163	173	82
S26E	71	14	124	124	32	358	309	458	202	731	407	481	399
S26W							152	27	8	96	43	24	48
S31E	0	4	4	0	0	0	24	11	0	3	5	93	5
S31W							239	202	585	8	11	274	32
S33E							732	1053	475	915	766	741	1142
S36E	14	4	60	7	21	48	122	130	74	93	223	138	29
S36W							0	0	5	0	0	5	0
S41E	106	163	71	266	50	152	149	420	333	603	93	245	287
S41W							24	13	0	32	4	46	248
Mean	**73**	**380**	**297**	**389**	**190**	**109**	**139**	**211**	**189**	**347**	**293**	**253**	**330**
S.E.	**35**	**305**	**233**	**319**	**103**	**45**	**40**	**63**	**47**	**102**	**94**	**64**	**90**

6.4.6 Trend: seed bank densities

The seed bank densities of *R. tuberosa* at sites over the eastern and western shores of the southern Coorong in January from 2007 to 2019 was virtually certain (99% likelihood) to have increased and therefore the long-term resilience of *R. tuberosa* is considered to be **getting better** albeit marginally (**Figure 6-**). While there is very high likelihood of an increase in seed density, the magnitude of increase is relatively minor (Table 6-6) with the seed bank remaining well short of the seed bank target (2,000 seed.m^{-2} at 50% of sites within the 43 km sampled distribution) (Table 6-6) that is reflective of a resilient population. Therefore, overall seed bank recovery of *R. tuberosa* since the Millennium Drought has been limited.

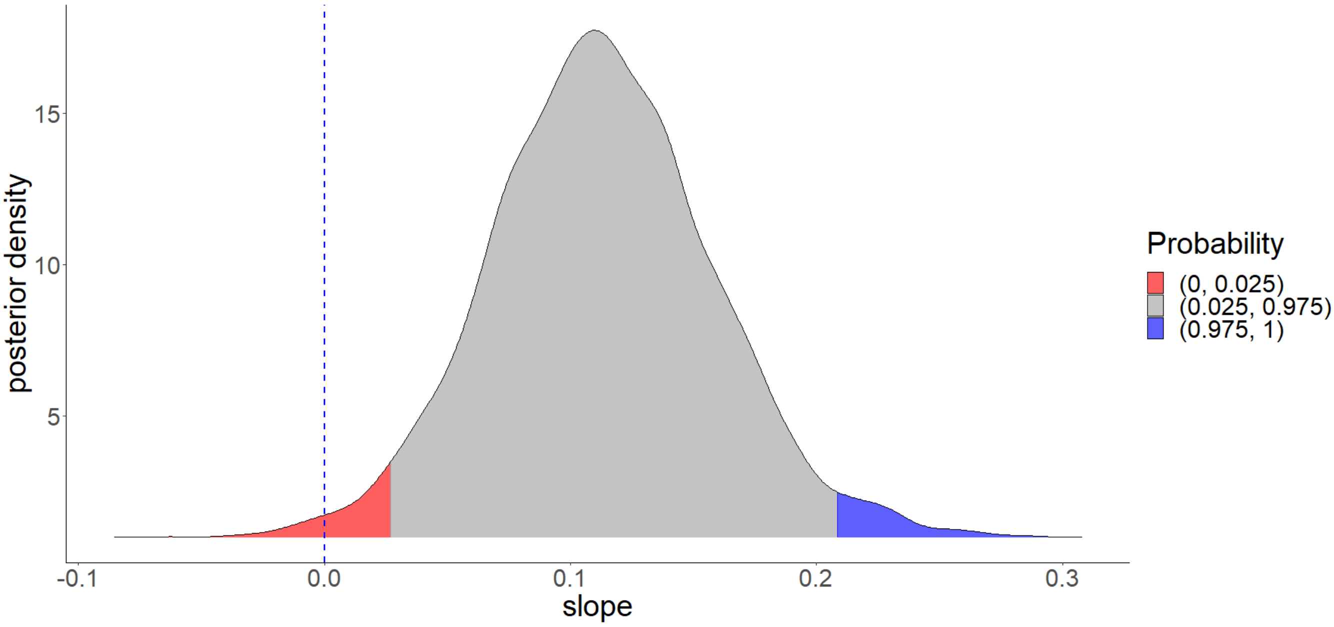

Figure 6-9. Estimated values for the slope generated from Bayesian modelling for the seed bank densities at sites on the eastern and western shores of the Coorong in January from 2007 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

6.4.7 Shoot distribution and densities

The distribution of *R. tuberosa* and densities of its shoots have varied greatly in both summer (Figure 6-) and winter (Figure 6-) from 2007 to 2019. In 2007, *R. tuberosa* shoots only remained at the northern end of the South Lagoon (i.e. S06E) in winter, however, by 2008, shoots of *R. tuberosa* were no longer present within the South Lagoon in winter and summer. *Ruppia tuberosa* started to colonise the central section of the North Lagoon (15–29 km from the junction of the lagoons) in 2008, however, densities >10 shoots.core^{-1} were not recorded at sites in the central section of North Lagoon until winter 2009 (i.e. N15E). Between winter 2009 and summer 2011, the extent of *R. tuberosa* beds increased over the central section of the North Lagoon. Following the high (unregulated) flow event in 2010/11, plants in the North Lagoon were largely lost by winter 2011 and had re-colonised the northern end of the South Lagoon (S06E). By 2013, *R. tuberosa* had returned to its historic 43 km distribution over the southern Coorong (S41E to N02E). From 2013 to 2019, *R. tuberosa* has maintained its 43 km historic distribution over the southern Coorong, except in winter 2016 when its EOO was 41 km (see section 6.4.1). However, since the recolonisation of *R. tuberosa* over the southern Coorong, shoot densities have varied greatly between since and years.

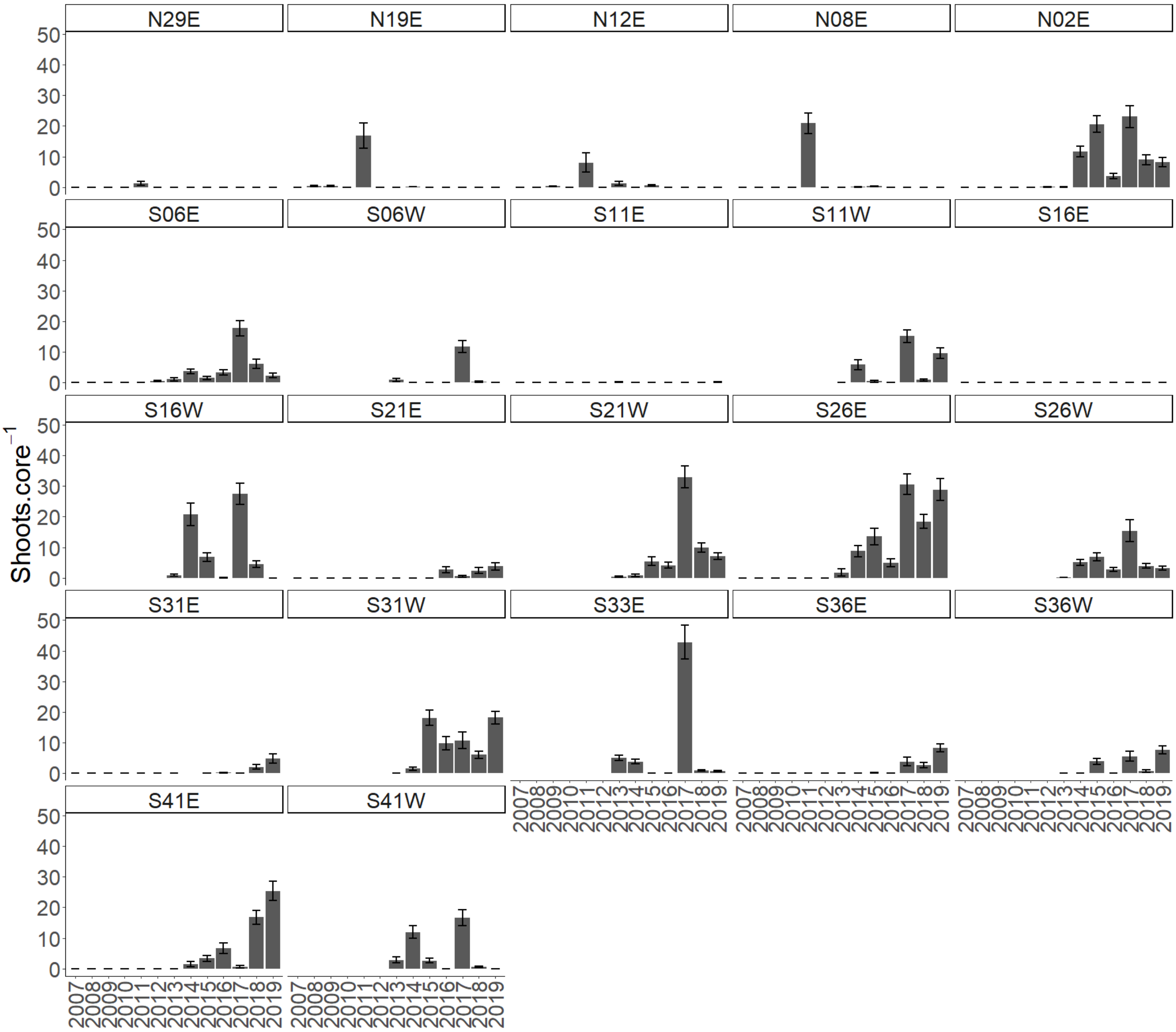

Figure 6-10. Mean (± standard error) number of *R. tuberosa* shoots per core (75 mm diameter × 4 cm deep) sampled at sites over the central section of the North Lagoon (N29E to N08E) and the southern Coorong (N02E to S41E/W) in January from 2007 to 2019. Note: some sites were established after 2007, and therefore, have no values in years where data collection did not occur. Data source: https://data.gov.au/ – Ruppia monitoring Southern Coorong, D.C. Paton, University of Adelaide for Murray Darling Basin Authority.

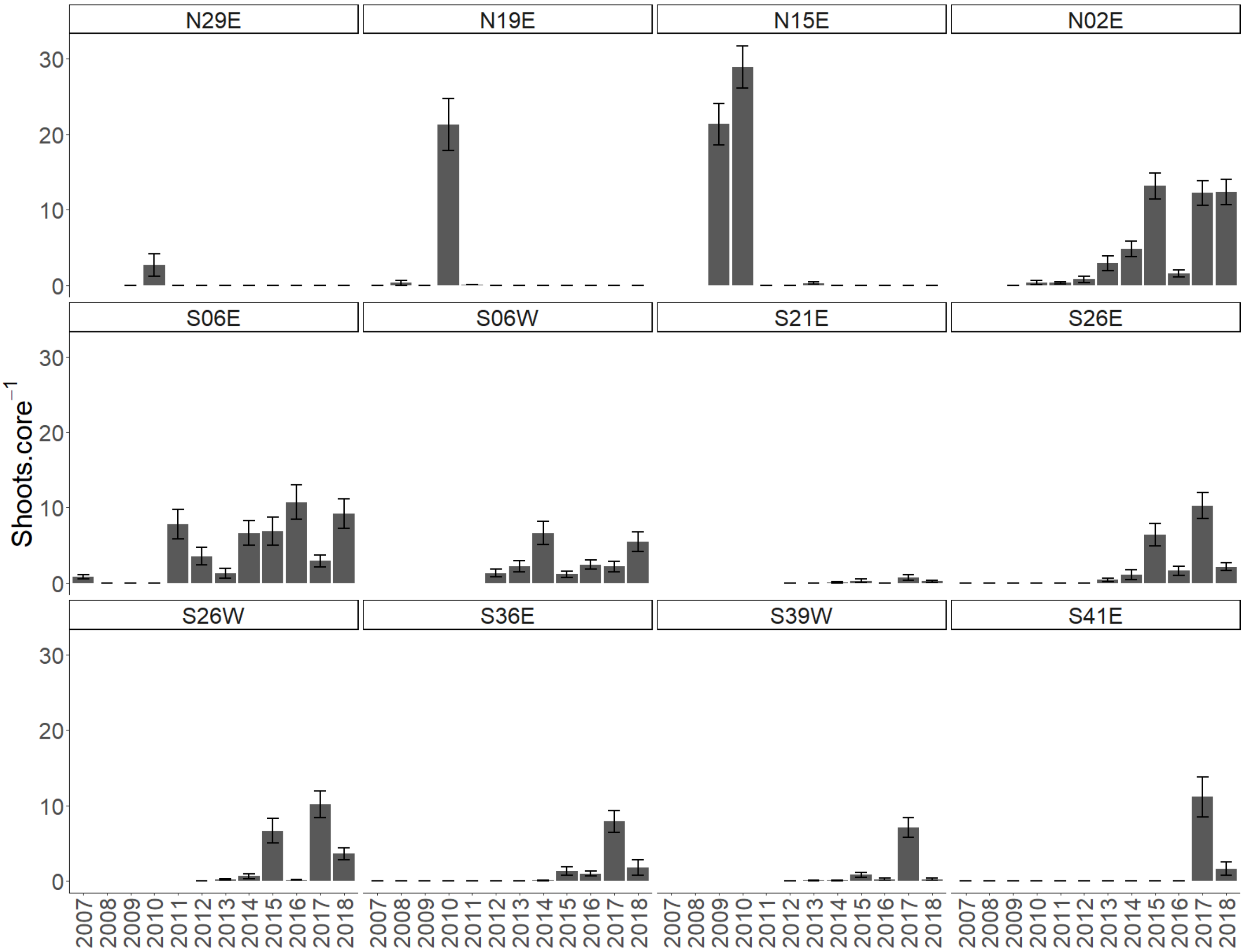

Figure 6-11. Mean (± standard error) number of *R. tuberosa* shoots per core (75 mm diameter × 4 cm deep) sampled at sites over the central section of the North Lagoon (N29E to N15E) and the southern Coorong (N02E to S41E) in July from 2007–2019. Note: some sites were established after 2007, and therefore, have no values in years where data collection did not occur. Data source: https://data.gov.au/ – Ruppia monitoring Southern Coorong, D.C. Paton, University of Adelaide for Murray Darling Basin Authority.

6.4.8 Seed bank distribution and densities

The seed bank of *R. tuberosa* sampled in January over the North and South Lagoons of the Coorong has varied greatly both within and between sites across years (Figure 6-). During the height of the Millennium Drought, from 2007 to 2010, mean seed densities ranged from 0–337 seeds.m^{-2} at all sites, except S06E, where mean seed densities ranged from 2788–2933 seeds.m^{-2} between 2008 and 2010. Beds of *R. tuberosa* that established in the central section of the North Lagoon during the Millennium Drought set very little to no seed (0–78 seeds.m^{-2}). Following the break of the Millennium Drought, the recovery of the *R. tuberosa* seed bank has been highly limited, with densities at all sites remaining well below densities (>2000 seeds.m^{-2}) reflective of a resilient population.

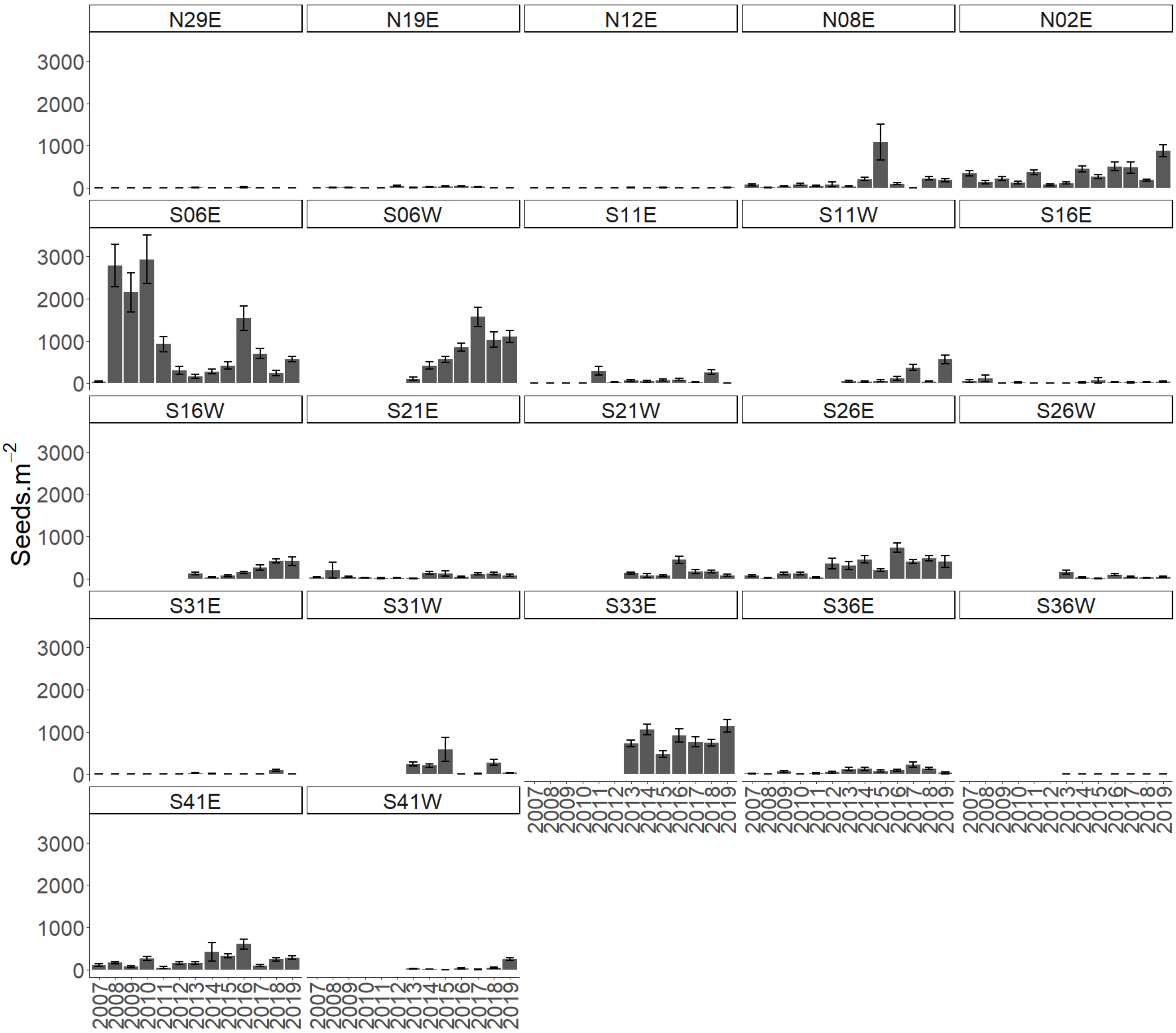

Figure 6-5. Mean (± standard error) number of *R. tuberosa* seeds.m-2 sampled at sites over the central section of the North Lagoon (N29E to N08E) and the southern Coorong (N02E to S41E/W) in January from 2007–2019. Note: some sites were established after 2007, and therefore, have no values in years where data collection did not occur. Data source: https://data.gov.au/ – Ruppia monitoring Southern Coorong, D.C. Paton, University of Adelaide for Murray Darling Basin Authority.

6.4.9 Condition assessment

The condition of *R. tuberosa* in the southern Coorong in January 2019 was considered to be **poor** (see Table 6-3) as seed densities were <1,000 seed.m^{-2} at ≥50% of sites within the 43 km sampled distribution (Table 6-6).

6.4.10 Information reliability

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

Table 6-7. Reliability of *R. tuberosa* data to assess the expected environmental outcomes for *R. tuberosa*. The methods used in data collection as well as the representativeness, repetition of sampling were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *Condition Monitoring Plan* (DEWNR 2017)	**2**
Standard methods	Has the same method been used over the sampling program?	**Yes.** The sampling method for *R. tuberosa* as presented in the *Condition Monitoring Plan* (DEWNR 2017) were used each year, at the same time of year.	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort?	**Yes.** A total of 12 winter, 8 spring and 20 summer sampling sites are evenly spread across the southern Coorong.	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** The assessment period for *R. tuberosa* spanned from 2012 to 2019 and therefore has included years of monitoring pre- and post-Basin Plan adoption years.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** All winter monitoring sites have been revisited annually over the assessment period (2012–2019). An additional 8 sites on the western side of the South Lagoon were added in 2013 to the 12 existing summer monitoring sites. All summer monitoring sites were revisited annually over the assessment period following establishment.	**2**
Time	Has the frequency of sampling been sufficient	**Yes.** Sampling has been conducted bi-annually over the assessment period	**2**

Methods	Question	Answer and justification	Score
	to represent change over the assessment period?	(2012–2019) and therefore has been conducted over a range of hydrological and seasonal conditions.	
Final score			**12**
Information reliability			**Excellent**

6.5 Evaluation

The resilience of *R. tuberosa* in the southern Coorong is principally influenced by the occurrence of adequate water levels in spring and into summer that enable annual plants to complete their reproductive cycle (Paton et al. 2019b). In addition, unsuitable salinities, the hyper-eutrophic conditions and the occurrence of excessive filamentous algal growth and phytoplankton loads also limit *R. tuberosa* growth, flowering and seed set (Collier et al. 2017). *R. tuberosa* was lost from the southern Coorong during the Millennium Drought due to falls in water level over spring leaving plants unable to complete their reproductive cycle and prone to desiccation (Paton 2010). Salinities during the height of the Millennium Drought were consistently above 100 $g.L^{-1}$ and may have also contributed to the loss of *R. tuberosa* in the southern Coorong, as the germination of seeds and growth of seedlings were impeded (Paton and Bailey 2012; Kim et al. 2013).

The high (unregulated) flow event in 2010/11 increased water levels and the Coorong and restored salinities to those more typical for the system (Paton and Bailey 2012). With the return of barrage outflows to the system, the extent of *R. tuberosa* recovered to its historic 43 km distribution, however, there was a slow and limited recovery in area of occupation of *R. tuberosa* that continued until 2014. Since 2014, there has not been notable improvement in area of occupation of *R. tuberosa* in the southern Coorong. Similarly, while it is highly likely that the seedbank of *R. tuberosa* improved from 2007 to 2019, this improvement has been limited. At present, the seedbank of *R. tuberosa* falls well below target densities reflective of a healthy resilient population, and therefore, recovery of *R. tuberosa* to a stable and resilient state following the Millennium Drought has yet to occur.

The failure of *R. tuberosa* to recover since the adoption of the Basin Plan has been predominantly due to inadequate water levels in spring and in to summer (see section 6.5.1). Moreover, salinities unfavourable to seed germination and seed set (see section 6.5.2), the hyper-eutrophic conditions and the excessive filamentous algal growth and phytoplankton (see section 6.5.3) have also contributed to the failure of *R. tuberosa* to recover following the adoption of the Basin Plan. Volumes of water for the environment delivered have been too low and delivered too early (i.e. peaking in winter) to provide adequate water levels to support *R. tuberosa* reproduction and growth in spring and in to summer. However, the delivery of water, including water for the environment and unregulated flows, has helped to limit the spatial and temporal extents of unsuitable salinities for germination of *R. tuberosa* in the southern Coorong (see section 6.5.2).

6.5.1 Water levels in spring

The maintenance of water levels above 0.3 m AHD in spring and into summer over the southern Coorong is vitally important to *R. tuberosa* reproduction and vigour (i.e. total plant material) (Collier et al. 2017; Paton et al. 2019b). A fall in water levels over spring exposes beds of *R. tuberosa* to desiccation before plants had set seed or produced turions and limits the growth of plants (Paton et al. 2019b).

Water levels >0.3 m AHD over spring and into summer were only recorded in 2016/17 following Basin Plan adoption (Paton et al. 2017a) (Figure 2-6). The flows of freshwater from the barrages to the southern Coorong were associated with a high (unregulated) flow event and from a water level perspective, led to the best conditions for *R. tuberosa* growth and reproduction in over 20 years (Paton et al. 2017a). Barrage outflows required to maintain adequate water levels in the southern Coorong to improve the resilience of *R. tuberosa* have rarely been delivered under the Basin Plan, and the contribution of water for the environment to the adequate water levels recorded in 2016/17 was low, highlighting the importance of unregulated flow events to achieving water levels that would improve *R. tuberosa* condition. However, the interaction of factors (e.g. salinity and nutrient conditions and algal growth) in addition to adequate water levels being provided, remains important in achieving environmental outcomes for *R. tuberosa* in the southern Coorong.

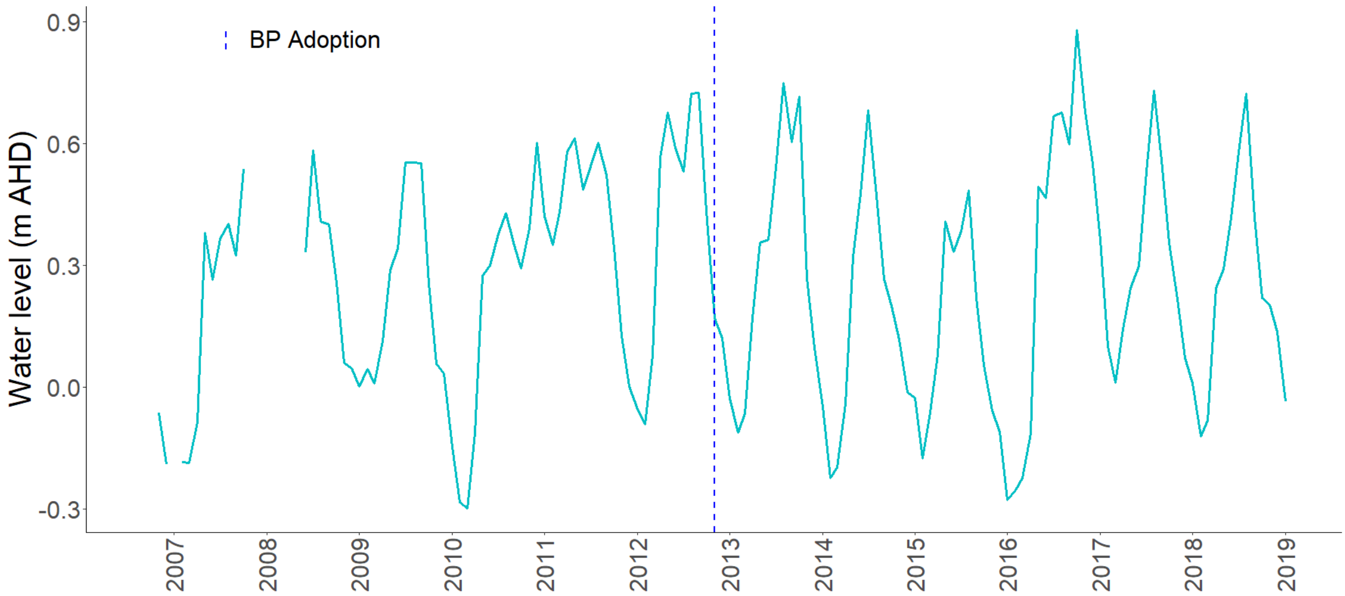

Figure 6-6. Mean monthly water level (m AHD) in the South Lagoon (A4260633, A4261209, A4261165) of the Coorong from 2006 to 2019. The adoption of the Basin Plan (BP) in November 2012 as shown by a dashed blue line. Data source: WaterConnect (2020).

6.5.2 Salinities in the southern Coorong

Salinity is second to the presence of adequate water levels as a deterministic factor in the decline and recovery of *R. tuberosa* in the southern Coorong (Collier et al. 2017). Salinities for *R. tuberosa* growth in the southern Coorong vary dramatically and appears to dictate the plant life cycle pathways followed each seasonal cycle: annual or perennial (Figure 6-1), sexual or asexual domination of the reproductive cycle (Figure 6-1). In addition, salinity influences the presence of and intensity of excessive filamentous algal growth. The life stages most affected by elevated salinities are flowering, turion formation, seed germination and turion sprouting. Salinities in the southern Coorong that were recorded over important periods for flowering (August–October), germination of seeds (April–June) and turion sprouting (April–June) were compared against salinities considered to be optimal, sub-optimal and unsuitable for each life stage and the salinity tolerance for filamentous algae. The evaluation of these results are detailed below.

R. tuberosa flowers between August and December each year. Salinities exceeding 100 $g.L^{-1}$ are considered to be unsuitable for flowering (Collier et al. 2017), however, salinities below 80 $g.L^{-1}$ in late spring and early summer (Collier et al. 2017; Auricht et al. 2019) are also unfavourable as excessive filamentous algal growth can occur, which limits seed set (Collier et al. 2017; Paton et al. 2019b) (see section 6.5.3 for further detail). Since adoption of the Basin Plan (2013 onwards), salinities within the range of favourable *R. tuberosa* reproductive performance (80–100 $g.L^{-1}$) were only recorded in the South Lagoon (80 km and 93 km from the Murray Mouth) for more than a month in 2014 and

2015 flowering seasons (Figure 6-7), while the southern extent of the North Lagoon (63 km from the Murray Mouth) also had more favourable salinities in the 2015, 2017 and 2018 flowering seasons (Note: limited salinity data was available for the 2014 flowering season). The more favoured salinities (80–100 $g.L^{-1}$) encountered in the flowering season of 2015 may have played a role in the improved seed bank densities recorded in January 2016 (Table 6-6). As salinities were largely below 80 $g.L^{-1}$ in the southern Coorong during the 2016, 2017 and 2018 flowering seasons, conditions were suitable for excess filamentous algal growth (Collier et al. 2017), which may have contributed to limited seed production in these years (Paton et al. 2017a; Paton et al. 2018a; Paton et al. 2019b). It must also be recognised that annual *R. tuberosa* plants produce turions from August–December, and that salinities below 70 $g.L^{-1}$ are unsuitable for turion production (Kim et al. 2015). Therefore, salinities below 80 $g.L^{-1}$ between August and December are likely to be unfavourable to both sexual and asexual reproduction for annual *R. tuberosa* plants. The temperature of the water during this period will have a tertiary effect and this cannot be accounted for at this time.

Seed germination and turion sprouting occurs from April to July (Collier et al. 2017). Laboratory studies have determined that salinities >85 $g.L^{-1}$ are unsuitable for seed germination and salinities >130 $g.L^{-1}$ are unsuitable for turions to sprout (Kim et al. 2013; Collier et al. 2017). Since Basin Plan adoption, salinities in southern extent of the North Lagoon were largely suitable for seed germination (<85 $g.L^{-1}$) (Figure 6-), however, salinities in the South Lagoon were mostly unsuitable for seed germination (>85 $g.L^{-1}$) until July if at all. Field observations (e.g. Paton et al. 2019b) suggest that when salinities are high (i.e. >85 $g.L^{-1}$) few *R. tuberosa* seed germinate. The failure of seeds to germinate may be beneficial if salinities are such that the growth and establishment of seedlings are compromised, as un-germinated seeds will remain in the sediment, providing *R. tuberosa* with a safety net and some resilience (Paton et al. 2019a). However, as the viability of *R. tuberosa* seed are considered to decline with time since seed production (Paton and Bailey 2013b), the limited spatial and temporal scales where salinities were suitable for germination in South Lagoon since adoption of the Basin Plan (Figure 6-) may be detrimental to the long-term condition of *R. tuberosa*. Although, seed germination may have been limited in the South Lagoon, salinities over the southern Coorong were suitable for turion sprouting (>130 $g.L^{-1}$) in all years since the adoption of the Basin Plan.

Discharge of fresh to brackish water from Salt Creek, predominantly between late-winter and spring, has freshened the southern most sectors of the South Lagoon. This has contributed to salinities in the southern South Lagoon in April–June being similar to or greater than those in mid-summer. This may disrupt seed germination and turion sprouting (Paton et al. 2019a), as a reduction in salinity may be required to trigger germination or sprouting (Kim et al. 2013). Furthermore, freshening of the southern South Lagoon below 80 $g.L^{-1}$, may have promoted filamentous algal growth when *R. tuberosa* were in flower or setting seed (Collier et al. 2017) (see section 6.5.3).

Water for the environment supports barrage outflow with its contribution proportionally greater in years of low flow (Stewardson and Guarino 2018, 2019). Water for the environment had the greatest impact on salinities in the Coorong during low flow years, such as 2017/18, when Commonwealth Environmental Water (CEW) comprised 89% of annual barrage outflow (Stewardson and Guarino 2019). This water helped to limit the extent of the Coorong with salinities unsuitable for the germination of seeds (>85 $g.L^{-1}$; Kim et al. 2013) between April and July. In its absence approximately a third of the Coorong would have had salinities above 85 $g.L^{-1}$ from April to July in 2018 (Stewardson and Guarino 2019). However, with the delivery of CEW, salinities above 85 $g.L^{-1}$ were only recorded over approximately a quarter of the Coorong in April and by mid-May the entire system had freshened below 85 $g.L^{-1}$ (Stewardson and Guarino 2019). The delivery of CEW helped increased the spatial and temporal availability of more suitable, albeit suboptimal conditions, for seed germination of *R. tuberosa* in the Coorong (example in Collier et al. 2017). Furthermore, without CEW, it was modelled that an additional 20 million tonnes of salt would have been transported to the Coorong from July 2014 to June 2019 (Ye et al. 2020). If such volumes of salt had entered the Coorong, salinities would have been comparable to those recorded at the end of the Millennium Drought (Ye et al. 2020), when salinities in the South Lagoon were largely unsuitable for *R. tuberosa* to flower, germinate from seed and sprout from turions (Collier et al. 2017).

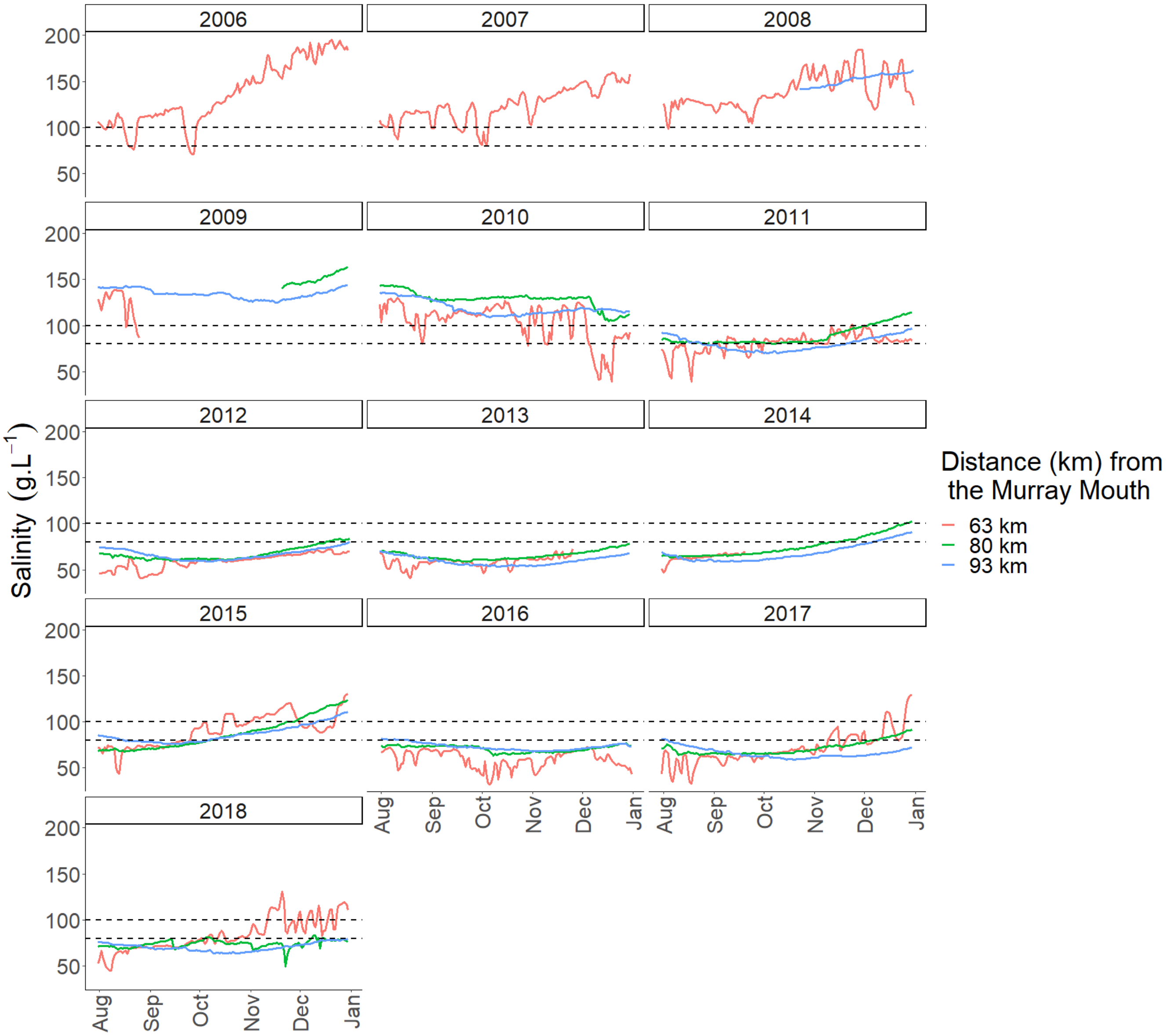

Figure 6-7. Salinities (g.L^{-1}) recorded during the *R. tuberosa* flowering season (August–December) at water stations located 63km (A4260633), 80 km (A4261209) and 93 km (A4261165) from the Murray Mouth in the southern Coorong from 2006 to 2018. The lower threshold (80 g.L^{-1}) reflects the upper salinity tolerance of filamentous green algae (Collier

et al. 2017). The upper threshold (100 g.L^{-1}) reflects the threshold at which salinities become unsuitable for flowering (Collier et al. 2017). Data source: WaterConnect (2020).

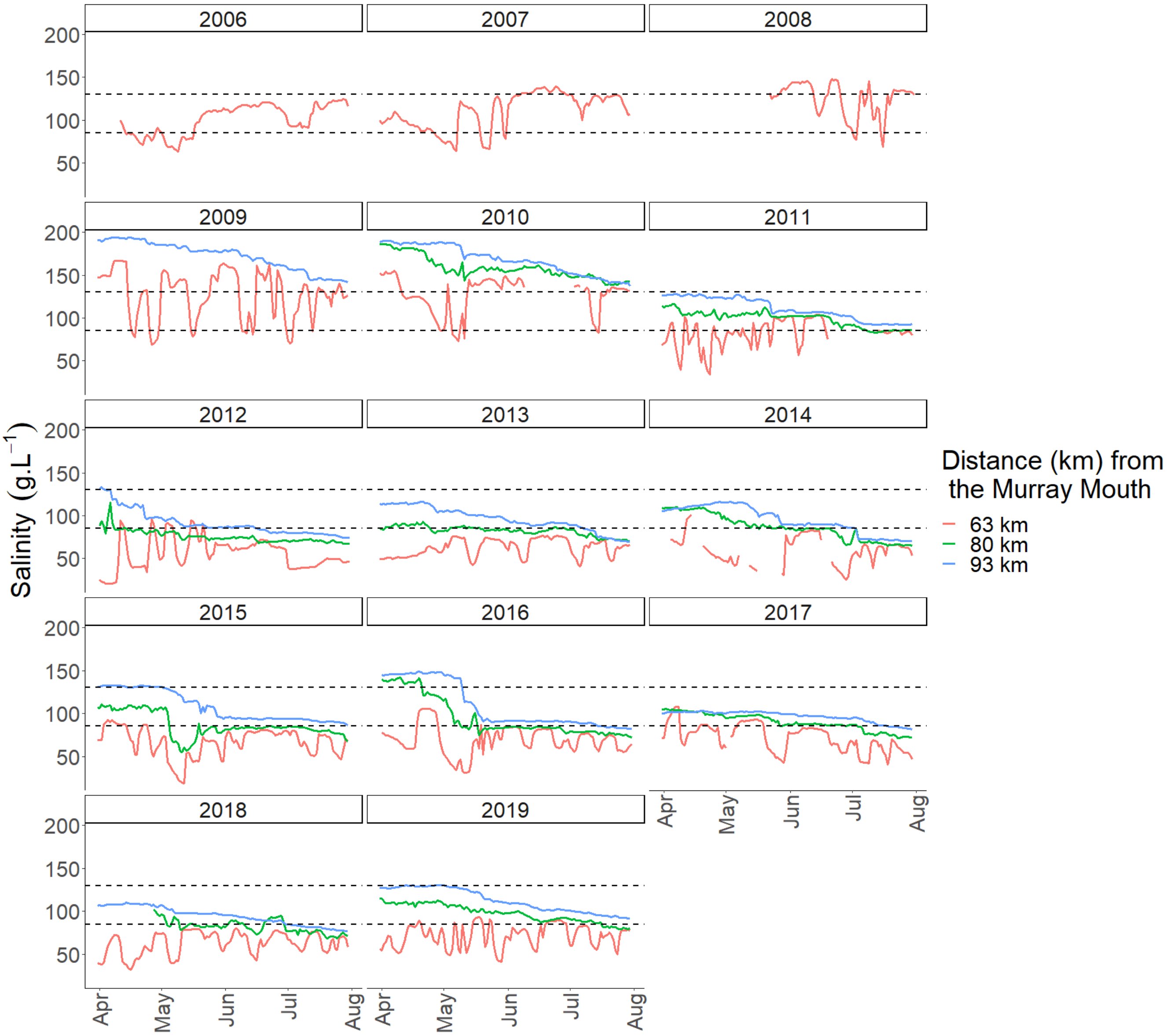

Figure 6-8. Salinities (g.L^{-1}) recorded during the peak R. tuberosa sprouting (from turions) and germinating (from seeds) season (April–June) at water stations 63km (A4260633) 80 km (A4261209) and 93 km (A4261165) from the Murray Mouth in the southern Coorong from 2006 to 2018. The lower threshold (85 g.L^{-1}) reflects the threshold at which salinities become unsuitable for seed germination (85 g.L^{-1}) (Collier et al. 2017). The upper threshold (130 g.L^{-1}) reflects the threshold at which salinities become unsuitable for turion sprouting (Collier et al. 2017). Data source: WaterConnect (2020).

6.5.3 Nutrients and filmentous algae

The southern Coorong is currently undesirably enriched with nutrients and algae, and therefore, is considered to be in a hyper-eutrophic state (Mosley and Hipsey 2019). The primary driver of the hyper-eutrophic state is likely to be a lack of freshwater flows that flush the system (Mosley and Hipsey 2019). Recent research (Mosley 2020; Waycott 2020) has been investigating whether the loss of *R. tuberosa* during the Millennium Drought contributed to or exacerbated the hyper-eutrophic state of the southern Coorong where slow-growing *R. tuberosa* that retain nutrients for relatively long periods (weeks to months) were replaced by fast-growing phytoplankton and filamentous algae that retain nutrients for short periods (days to weeks).

Phytoplankton loads (using chlorophyll-a concentrations as a proxy) likely increased in the Coorong from 1998 to 2019 (Mosley and Hipsey 2019). Extremely hypersaline conditions in the 2007–2010 Millennium Drought period likely caused phytoplankton loads to decline, however, phytoplankton loads likely increased in the period of data collection post-drought, from 2013 to 2019 (Mosley and Hipsey 2019). Excessive filamentous algal growth were detected in the North lagoon in 2011 when water levels returned to the Coorong following the Millennium Drought (Paton et al. 2011), however, were not recorded in the South Lagoon until 2014 (Frahn and Gehrig 2015).

Excessive phytoplankton and filamentous algal growth may have led to nitrogen limitation in *R. tuberosa* through competition for nutrients (Collier et al. 2017). Reduced benthic light availability attributed to shading from excess phytoplankton and filamentous algal growth may also impact *R. tuberosa*. Mesocosm experiments have found *R. tuberosa* to be relatively shade tolerant, with total biomass only significantly lower in treatments of 5% of full sunlight for 8 or more weeks (Collier et al. 2017). However, *R. tuberosa* may utilise their carbohydrate storage reserves in poor light conditions (Collier et al. 2017).

Filamentous algae proliferate over the southern Coorong in late spring and early summer (Auricht et al. 2019) when water temperatures are warmer and salinities fall below their tolerance threshold of 80 $g.L^{-1}$ (Collier et al. 2017). Filamentous algae are co-associated with *R. tuberosa* beds (Waycott et al. 2020), and their overlap has been significant in recent years with filamentous algae present at all spring (flowering) and summer monitoring sites in 2015/16 (Paton et al. 2016a), 2016/17 (Paton et al. 2017a) and 2017/18 (Paton et al. 2018a), while the majority of both spring (75%) and summer (78%) monitoring sites recorded filamentous algae in 2018/19 (Paton et al. 2019b). Filamentous algae has likely severely limited seed production of *R. tuberosa* by preventing flower-heads from reaching the water surface where pollen is shed and breaking stalks with flower-heads and in some cases developing fruit (Collier et al. 2017; Paton et al. 2019b). Furthermore, filamentous algae are thought to have impacted the vigour of *R. tuberosa* by causing light limitation and senescence attributed to sulphide intrusion from sediments turned anoxic during the decay of the algae (Collier et al. 2017). Repeated formation of excessive algal growth leads to long-term impacts on sediment quality (Dittmann et al. 2019). Filamentous algae has undoubtedly had a severe impact on the recovery of *R. tuberosa*, however, the plant has maintained its current distribution (extent of occurrence), area of occupation and low seed bank status for the past 5 years despite the prominent yet patchy distribution of excessive filamentous algae growth.

6.6 Actions to achieve environmental outcomes

To improve the health and resilience of Ruppia in the Coorong, the following are required:

- Maintenance of favourable water levels, with monthly barrage flows of at least approximately 1000 GL between September and January
- Maintenance of water levels in the Coorong South Lagoon above 0.3 m AHD in spring and into summer
- Avoiding a fall in water levels over spring to avoid the drying out of plants before they have been able to set seed
- Ensuring salinity conditions remain within the ranges required to support Ruppia reproduction, including maintenance of salinities above 80 $g.L^{-1}$ in spring and into summer to limit excessive growth of filamentous algae (Collier et al. 2017; Paton et al. 2019b)
- Strategic delivery of water at the tail end of high flow events, to prolong more favourable conditions in the southern Coorong to support *R. tuberosa* growth and reproduction.

Although outside of current management influence, periodic high (unregulated) flow events are important and are needed more frequently to support improvement in the health of *R. tuberosa* in the southern Coorong. Full implementation of the Basin Plan, including addressing current water delivery constraints, is required to deliver sufficient volumes of water at a frequency needed to achieve desired water level conditions.

6.6.1 **Future investigations**

Future management of the Coorong will be reviewed as part of the Healthy Coorong Healthy Basin (HCHB) Program (DEW 2020). The HCHB Trials and Investigations Project will inform broader HCHB investigations into long-term management solutions (including infrastructure options) to support the health of the Coorong (DEW 2020). Investigations relating to *R. tuberosa* population condition and resilience include nutrient cycles, drivers and management of excessive filamentous algae growth and restoration of a functional foodweb (including *R. tuberosa*), one that is able to produce and supply energy to key biota (DEW 2020). Findings from these investigations will fill key knowledge gaps and inform management actions required to reduce the nutrient loads and algal abundance in the Coorong, switch the Coorong South Lagoon back to an aquatic plant dominated system rather than an algal dominated system. This also includes informing the management of how freshwater flows from the barrages and Salt Creek, as well as the dredging regime of the Murray Mouth, can best be managed; and developing the engineering solutions required to promote long-term environmental outcomes in the Coorong, including successful restoration of *R. tuberosa* populations in the southern Coorong (DEW 2020).

Additionally, the On-Ground Works Project, as part of the HCHB Program, is seeking to implement no-regrets on-ground actions that address the immediate threats to the Coorong. Actions include the restoration of priority aquatic plants (such as *R. tuberosa*) and options for the physical removal of filamentous algae. These works seek to not only provide direct benefits to *R. tuberosa* in the Coorong, but also aim to improve the availability and quality of habitat for key biota (e.g. waterbirds) while the longer-term rehabilitation of the Coorong is undertaken.

6.7 Conclusion

The distribution of *R. tuberosa* has recovered with the return of barrage outflows to the system and improvements in salinity conditions in the Coorong following the end of the Millennium Drought. There has been, however, slow and limited recovery in the area of occupation and seed densities. This has been influenced by:

- unsuitable water levels in spring and into summer that have limited the ability of *R. tuberosa* to complete its lifecycle
- lack of freshwater flows to flush the system, which has created undesirable high nutrient and algae conditions in the southern Coorong
- salinity conditions, which have not been suitable to support key life cycle stages, including seed production, despite supporting improvements in *R. tuberosa* distribution.

Key messages:

- The extent of *R. tuberosa* has recovered to its historic 43 km distribution following the Millennium Drought, and this has been maintained since the adoption of the Basin Plan.
- There has been a slow and limited recovery in area of occupation that continued until 2014. Since 2014, there has been no notable improvement in area of occupation of *R. tuberosa* in the Coorong.

- Seed bank densities of *R. tuberosa* have only marginally improved since the Millennium Drought and remain well below densities (>2000 seeds.m^{-2}), reflective of a resilient population. It is expected that densities of seed (>2000 seeds.m^{-2}) required for a resilient population will not be met in future years unless falling water levels in spring and into summer and disruption caused by filamentous algae are addressed.
- Adequate water levels for *R. tuberosa* to complete reproductive cycle occurred in 2016/17, however, this was not supported in any other year since the adoption of the Basin Plan. A high (unregulated) flow event was associated with the adequate water levels in 2016/17, along with water for the environment delivered at the tail-end of the unregulated flow event to prolong more favourable water levels.
- Implementation of the Basin Plan has prevented salinities in the Coorong becoming reminiscent of the Millennium Drought, and therefore, the Basin Plan has helped prevent salinities exceeding the respective thresholds for different life stages, with the exception of seed germination in low flow years.
- Excessive filamentous algae growth and phytoplankton has directly and severely impacted the reproductive output of *R. tuberosa*. In addition, reduced light levels as a result of water column phytoplankton blooms will be further reducing seed production.

7 Black bream and greenback flounder

7.1 Introduction

7.1.1 Black Bream

Black bream (*Acanthopagrus butcheri*) are a large-bodied fish (typically <1.5 kg) (Bice 2010) that inhabits estuarine and coastal waters over southern Australia (ALA 2020). In the Murray–Darling Basin, black bream are restricted to the Murray estuary and the North Lagoon of the Coorong (Bice 2010), where it is an important recreational and commercial fisheries species, and forms part of the Lakes and Coorong Fishery (Norris et al. 2002). Due to its importance within the Lakes and Coorong Fishery and the current 'overfished' status in this region (Earl et al. 2016), management of black bream is required to promote successful recruitment and rebuild the population abundance and resilience in the Coorong to ensure that this species can support a sustainable fishery (Ye et al. 2019a, b).

Black bream are capable of withstanding wide ranges of temperatures, salinity and dissolved oxygen concentrations (Ye et al. 2020a). The salinity environments inhabited by black bream in the CLLMM are broad, with the species recorded in the Lakes (Bice 2010) and in the hypersaline Coorong lagoons at salinities up to approximately 70 $g.L^{-1}$ (Ye et al. 2020a). Although, their LC_{50} in aquaria was determined to be 88 $g.L^{-1}$ at 23°C (McNeil et al. 2013). Despite their tolerance to hypersaline conditions, black bream are most abundant in areas where salinities range from 15–25 $g.L^{-1}$, particularly during the spawning period (Hindell et al. 2008). Studies in aquaria have determined the survival of black bream eggs to be optimal at salinities from 15–35 $g.L^{-1}$ and that physical abnormalities in larvae were lowest from eggs that were incubated at salinities from 15–35 $g.L^{-1}$ (Haddy and Pankhurst 2000). In addition, juvenile black bream in aquaria were observed to be able to survive and grow in aquaria in salinities that ranged from 0–48 $g.L^{-1}$ with osmotic stress observed at 60 $g.L^{-1}$ (Partridge and Jenkins 2002).

Black bream can complete their lifecycle within their natal estuary (Chaplin et al. 1997; Elsdon and Gillanders 2006). The life history of black bream is characterised by slow-growth (k=0.04 for females and 0.08 for males), high longevity (29–32 years), intermediate age of maturity (>2 years) and high fecundity (estimated up to 3 million eggs for a large female) (Morison et al. 1998; Ye et al. 2020a). Spawning occurs over spring and summer in the upper reaches of the estuary at the fresh-saltwater interface (Haddy and Pankhurst 1998; Williams 2013; Ye et al. 2019a).

Low to moderate inflows to estuaries generate salinity stratification of the water column at the freshwater and marine interface, known as salt-wedge habitat, which provides favourable spawning and nursey habitat for black bream (Jenkins et al. 2010; Williams et al. 2013; Ye et al. 2019a, 2019b). Salt-wedge habitats are important as they provide cues for adults to locate spawning grounds and spawn, and suitable nursery habitat for larvae and juveniles to develop and grow (Newton 1996; Ye et al. 2019b). Importantly, salt-wedge habitats hold greater food resources (Newton 1996; Williams 2013) and may reduce predation risk (Islam et al. 2006), culminating in increased black bream recruitment (Jenkins et al. 2010).

7.1.2 Greenback flounder

Greenback flounder are a medium-bodied flatfish (typically <355 mm total length, TL) that inhabit bare substrates in estuarine and protected coastal waters (Bice 2010; Earl 2014; Earl and Ye 2016). The species are considered to be 'marine-estuarine opportunists' as they primarily occur in marine waters, however, also regularly enter estuaries, especially as juveniles (Earl et al. 2017). Greenback flounder have been recorded in the Coorong up to 50 km from the Murray Mouth during the Millennium Drought and 70 km during high flow periods (e.g. 2010/11), when salinities were approximately 74 and 80 $g.L^{-1}$ (Ye et al. 2020a). While greenback flounder can occur within hypersaline areas of the Coorong lagoons, in aquaria juveniles have an LC_{50} of 79–88 $g.L^{-1}$ (McNeil et al. 2013), and they primarily occur within estuarine waters free from osmotic stress (Earl et al. 2017).

In southern Australia, the greenback flounder is an important commercial and recreational fishery species. In the Lakes and Coorong Fishery, all commercial catches of greenback flounder are from the Coorong lagoons (Ferguson 2006). Catches in the Coorong have been suggested to be influenced by freshwater flow from the River Murray (Earl 2014; Ye et al. 2020a). Strong recruitment from flow events often translate to increased fishery production after a 1- to 2-year lag (Earl 2014).

The life history of the greenback flounder is characterised by its fast growth, moderate longevity (~10 years), early maturity (one year) and high fecundity (up to 2 million eggs) (Ferguson 2006; Sutton et al. 2010; Earl 2014). Spawning in the Coorong occurs between March and October, with a peak period between April and July (Earl 2014). Juveniles often use estuarine waters as a nursery, however, also use marine waters (Earl et al. 2017). Sexual maturity is reached when individuals are approximately 210 mm Total Length (TL) (Earl 2014). Adults may grow to 500 mm TL (Sutton et al. 2010), though average less than 300 mm TL (Earl 2014).

7.2 Ecological objective, target and environmental outcomes

The ecological objective for fish and the ecological targets for black bream and greenback flounder as described in the SA River Murray LTWP (DEWNR 2015) are presented in Table 7-1. The ecological target formed the basis of the expected environmental outcomes for black bream and greenback flounder in the CLLMM PEA. Additional ecological indices (referred to as ecological targets in the LLCMM Condition Monitoring Plan) that quantified population condition scores are those detailed in the 'Black bream and greenback flounder chapter' (Ye et al. 2017) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) are also presented in Table 7-1.

Table 7-1. Ecological objective, target and indices for black bream and greenback flounder.

Characteristic	Description
Ecological objective	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lakes and Coorong.
Ecological target	Maintain or improve abundances, distribution and recruitment of black bream and greenback flounder with population condition score ≥3 (max 4).
Ecological indices for black bream	1. Relative abundance (based on commercial fishery catch, t/year) – Annual catch ≥ 8 t or positive trend over previous 4 years (linear regression)
	2. Distribution – >50% of the catch from southern part of the Coorong (south of Mark Point)
	3. Age structures – Need to meet at least 2 of the following 3 targets: >20% fish above 10 years; at least one strong cohort over the last 5 years; ≥2 strong cohorts in the population. Note: strong cohort is defined as a cohort representing ≥ 15% of the population.
	4. Recruitment – Catch per unit effort (CPUE) of young-of-the-year (YOY) >0.77 fish.net $night^{-1}$ by fyke net
Ecological indices for greenback flounder	1. Relative abundance (based on commercial fishery catch, t/year) – Annual catch ≥24 t or positive trend over previous 4 years (linear regression)

Characteristic	Description
	2. Distribution – >70% of the catch from southern part of the Coorong (south of Mark Point)
	3. Age structure – Presence of a very strong cohort (>60%) or at least a strong cohort (>40%) in year 0–2 and >20% of fish >2 years
	4. Recruitment – CPUE of YOY >1.04 fish.seine net^{-1} – YOY distribution in the Coorong: >50% sites with YOY present

The expected environmental outcomes for black bream (Table 7-2) and greenback flounder (Table 7-3) population condition scores in 2019, 2029 and 2042 were determined by elicitation with key experts. It is expected that the population condition scores for both species will improve, however, the confidence in future predictions attenuates with time.

Table 7-2. Expected environmental outcomes for black bream in the Murray estuary and Coorong.

Year	Expected environmental outcomes
2019	Population condition score will be 2.25 (80% confidence interval 0.88-3.35)
2029	Population condition score will be 2.75 (80% confidence interval 1.00-3.66)
2042	Population condition score will be 3.25 (80% confidence interval 1.25-4.13)

Table 7-3. Expected environmental outcomes for greenback flounder in the Murray estuary and Coorong.

Year	Expected environmental outcomes
2019	Population condition score will be 2.75 (80% confidence interval 1.86-3.40)
2029	Population condition score will be 3.00 (80% confidence interval 1.65-3.92)
2042	Population condition score will be 3.25 (80% confidence interval 0.89-3.81)

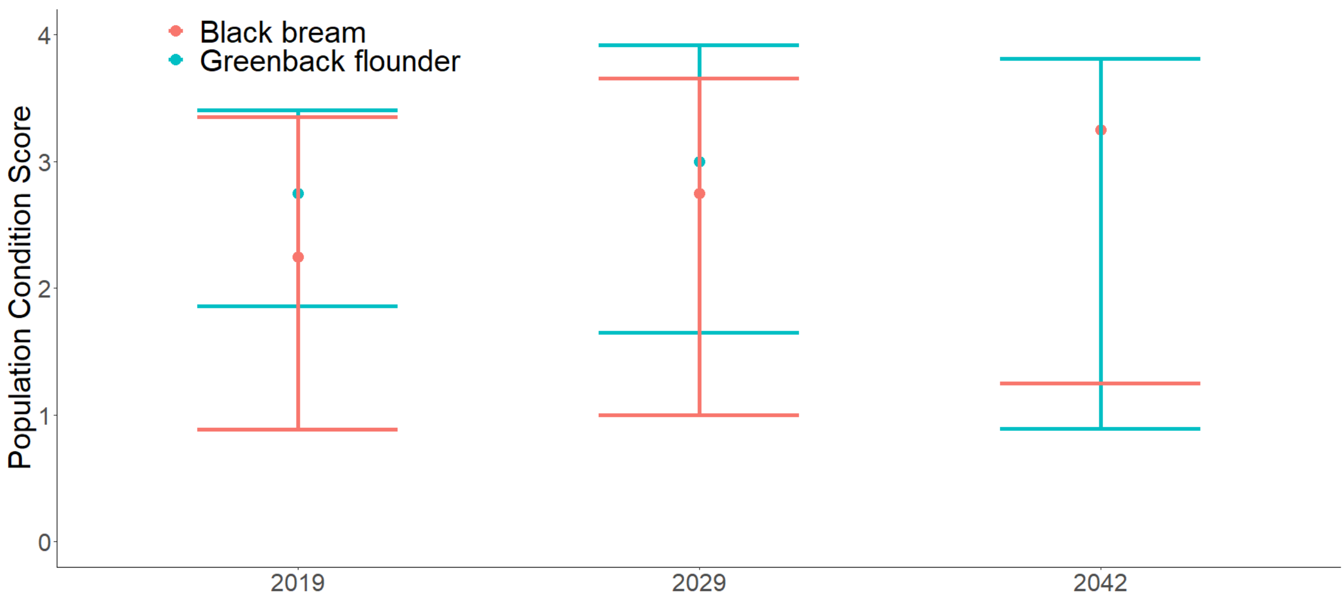

Figure 7-1. Expected population condition scores (±80% confidence interval) for black bream and greenback flounder in 2019, 2029 and 2042.

7.3 Method

The methodology used to monitor black bream and greenback flounder is described in the black bream and greenback flounder chapter (Ye et al. 2017) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and summarised below.

The relative abundance (catch), adult fish distribution and age structure of black bream and greenback flounder was determine based on data/sample collected from the Lakes and Coorong Fishery (LCF). Data from the LCF included annual catch (kg) and spatial reporting from fishing blocks 4 to 14 located over the Murray estuary and North Lagoon. Commercial catches from the Murray estuary and North Lagoon of the Coorong were obtained to determine the age structure of black bream and greenback flounder. Otoliths were extracted and analysed to assess age structure of the population and determine the presence of strong year classes.

Sampling independent of fishery catches were conducted between spring and early autumn to quantify the abundance of juvenile black bream and greenback flounder to assess annual recruitment of YOY. Black bream were sampled at a minimum 4 regular sites in the Murray estuary using single-winged fyke nets, with 4 replicates (nets) at each site. Greenback flounder were sampled at 7 to 9 sites evenly distributed along the Coorong using a 61 m long seine net that swept an area of approximately 592 m^2. Sweeps were replicated 3 times at each site (i.e. 3 replicates). The number of juvenile black bream and greenback flounder from each net were counted and a random subsample of up to 50 individuals per species per net measured for Total Length (mm).

7.3.1 Trend assessment

Trend analysis was undertaken using the approach detailed in section 3.2.1. Models aimed to determine the likelihood of trend (either positive or negative) in the population condition for black bream and greenback flounder were assessed based upon the success or failure of ecological indices for each given year over the assessment period (Table 7-1). A binomial family was fitted to the model, to assess the proportion of ecological indices that were successful in being met for a given year. The model included time step (the number of years since the inaugural year of monitoring) as a fixed effect.

7.3.2 Condition assessment

The population condition score of black bream and greenback flounder was assessed using the metrics regarding their relative abundance, recruitment and distribution as per Ye et al. 2020a. The matrix in Table 7-4 was used to align the categories used to describe the population condition of each species with that used for River Murray Trend and Condition Report Cards to ensure a consistent approach. There was no Very Good population condition rating for black bream and greenback to align with that of the Report Cards.

Table 7-4. Alignment of population condition categories (as per Ye et al. 2020a) with condition classes used for the River Murray Trend and Condition Report Cards.

Population condition	Condition (Report Cards)
Extremely poor	Poor
Very poor	Poor
Poor	Poor
Moderate	Fair
Good	Good

Population condition	Condition (Report Cards)
N/A	Very Good

7.3.3 Information reliability

The information reliability assessments for black bream and greenback flounder were conducted as per section 3.2.2.

7.4 Results

7.4.1 Expected outcome assessment: black bream population condition

The expected environmental outcome for 2019 was not met. In 2019, it was expected that the population condition score for black bream would be 2.25 (Table 7-2), however, a population condition score of 1 (very poor) was recorded in the 2018/19 assessment (Figure 7-; Table 7-6). Progression towards the LTWP target has been limited, with the target population condition met once (2017/18) over the duration of the assessment period (Figure 7-; Table 7-6). Overall, the population condition scores were generally highest in the year after a high flow year (>6,000 GL.year^{-1}).

The population condition score for black bream was 1 (Very Poor) during the Millennium Drought in 2008/09 and 2009/10 (Figure 7-; Table 7-6). Flood in 2010/11 coincided with a further decline in population condition score to 0 (Extremely Poor). In subsequent years of high flow (2011/12 and 2012/13), the population condition score increased to 2 (Poor). Low flows from 2013/14 to 2015/16 coincided with a decline in population condition to 0 (Extremely Poor). The population condition score increased to 2 (Poor) in 2016/17 with high flows and improved further to 3 (Moderate) in 2017/18, a year of low flow. Low flows were again recorded in 2018/19 and the population condition score decline to 1 (Very Poor).

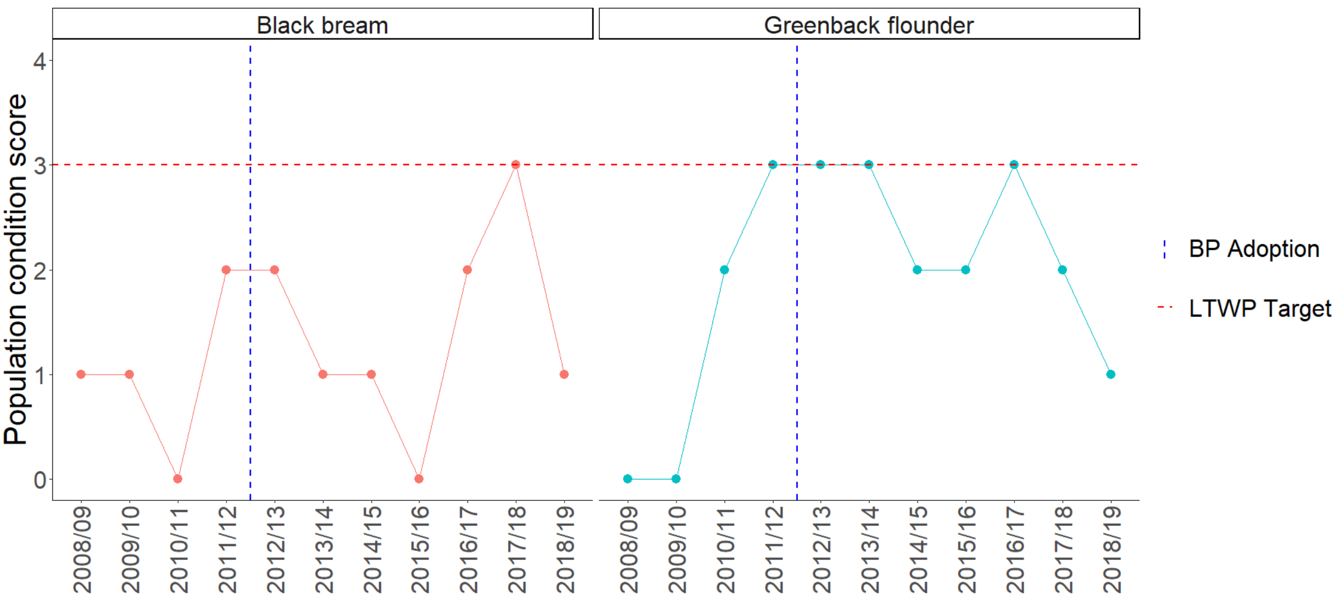

Figure 7-2. Population condition scores for black bream and greenback flounder from 2008/09 to 2018/19 in the Coorong (Ye et al. 2020a). The adoption of the Basin Plan is marked by a vertical dashed blue line and the LTWP population condition target is marked by the horizontal dashed red line.

7.4.2 Expected outcome assessment: greenback flounder population condition

The expected environmental outcome for 2019 was not met. In 2019, it was expected that the population condition score for greenback flounder would be 2.75 (Table 7-3), however, a population condition score of 1 was recorded in the 2018/19 assessment (Figure 7-; Table 7-7). Some progress towards the achievement of the LTWP has been made, with the target population condition met in met in 4 of 11 years (Figure 7-; Table 7-7). Since the adoption of the Basin Plan, the LTWP target population condition has been met on 3 of 7 years. Overall, the population condition scores increased and were greatest during flood and high flow years and declined or were very low during low flow and drought years.

The population condition score for greenback flounder was 0 (Extremely Poor) during the peak of the Millennium Drought in 2008/09 and 2009/10 (Figure 7-; Table 7-7). Increased flows from 2010/11 to 2013/14 were associated with improved condition scores that ranged from 2 (Poor) in 2010/11 to 3 (Moderate) between 2011/12 and 2013/14. With low flows in 2014/15 and 2015/16, condition scored reduced to 2 (Poor) in both years. The condition score increased to 3 (Moderate), with high flow in 2016/17. Low flows in 2017/18 and 2018/19 were associated with a decline in condition score to 2 (Poor) and 1 (Very Poor), respectively.

7.4.3 Trend in population condition scores of black bream and greenback flounder

Population condition scores of black bream and greenback flounder from 2008/09 to 2018/19 were likely to be **getting better** (Figure 7-). There was an 81% and 75% likelihood that black bream and greenback flounder population condition scores had improved over the assessment period, respectively.

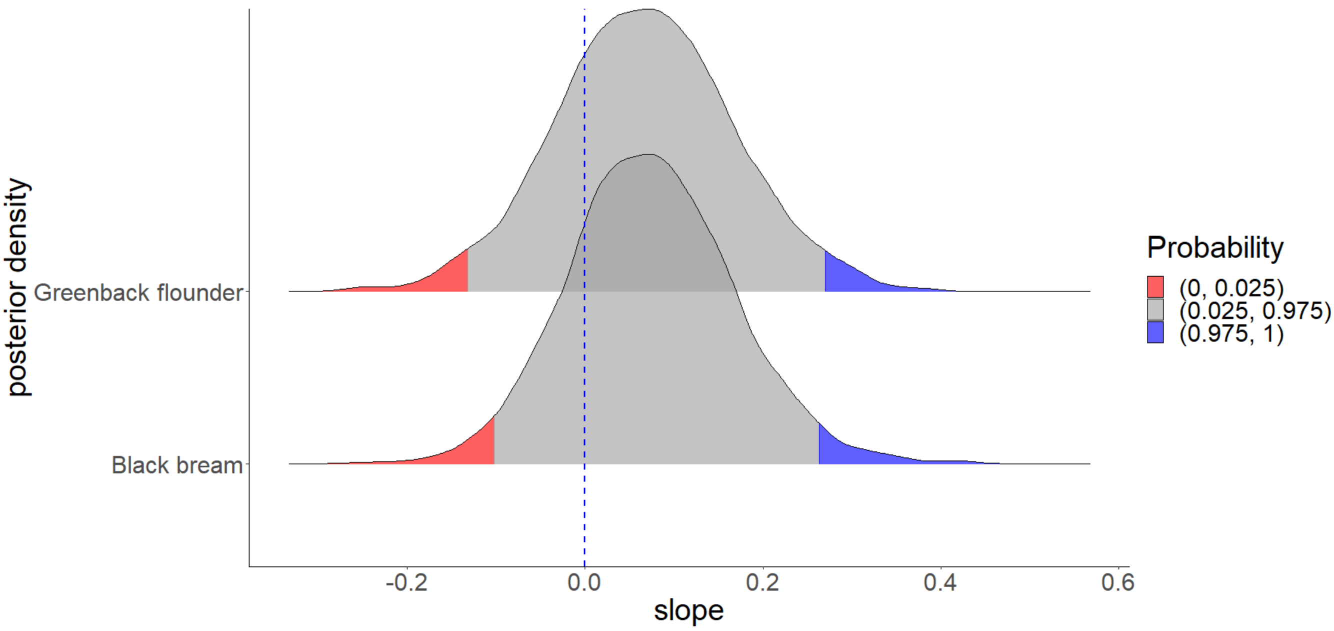

Figure 7-3. Estimated values for the slope generated from Bayesian modelling for the population condition scores of black bream and greenback flounder from 2008/09 to 2018/19. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

7.4.4 Condition

The population condition of both black bream (Table 7-6) and greenback flounder (Table 7-7) as per Ye et al. (2020a) were both very poor. Therefore, the condition assessment rating for black bream and greenback flounder in the Report Cards for 2019 was **poor**.

7.4.5 Information reliability

The data reliability rating for black bream and greenback flounder evaluation was **very good** (final score of 11). Justification for the scoring of black bream and greenback flounder data reliability is provided in Table 7-5.

Table 7-5. Reliability of black bream and greenback flounder data to assess the expected environmental outcomes for each fish species. The methods used in data collection as well as the representativeness and repetition of sampling were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *Condition Monitoring Plan* (DEWNR 2017)	**2**
Standard methods	Has the same method been used over the assessment period?	**Yes.** The respective methods for black bream and greenback flounder as presented in the *Condition Monitoring Plan* (DEWNR 2017) were used each year.	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort?	**Yes.** Commercial fishery data (annual catch) and sampling sites established by SARDI are well distributed throughout the Coorong estuary and North Lagoon for black bream and additionally the South Lagoon for greenback flounder.	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Sampling has been conducted from 2008/09 to 2018/19, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and range of hydrological conditions.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** Commercial fishery data were collected between fishing blocks 4 to 14 in the LCF. Sampling of YOY were conducted at 4 and 9 regular sites for black bream and greenback flounder, respectively. However, YOY black bream were also sampled from up to 25 additional sites.	**2**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Yes.** Daily catch and effort data from fishery statistics on an annual basis. For age structure assessment, adult black bream are sampled each year particularly in spring/summer, and greenback flounder over the entire year. YOY black bream are sampled annually over summer/autumn. YOY greenback	**1**

Methods	Question	Answer and justification	Score
		flounder are generally sampled in late spring/summer, however in some years, we used summer/autumn sampling data because there was a lack of later spring/summer sampling due to funding constraint.	
Final score			**11**
Information reliability			**Very good**

Table 7-6. Condition assessment for black bream population in the Coorong from 2008/09 to 2018/19. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of these indices meets the ecological target; (2) Distribution – meets the ecological target; (3) Age structure – a minimum of 2 indices must meet their ecological targets and (4) Recruitment – both indices must meet their ecological targets. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2020a).

Population indicator	Indices	Condition assessment											Ecological targets (Reference point)
		2008/09 Drought	2009/10 Drought	2010/11 Flood	2011/12 High flow	2012/13 Moderate flow	2013/14 Low flow	2014/15 Low flow	2015/16 Low flow	2016/17 High flow	2017/18 Low flow	2018/19 Low flow	
Relative abundance	Catch (t/year)	No	No	No	No	No	No	No	No	No	No	No	≥8 t
	4-year trend	No	No	No	Yes	Yes	No	No	No	No	No	No	Positive (slope)
	Score	**0**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	
Distribution	Proportional catch	No	No	No	No	Yes	No	No	No	Yes	Yes	No	>50% from southern part
	Score	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**1**	**0**	
Age structure	% fish >10 years	Yes	Yes	No	Yes	No	No	No	No	No	No	No	>20% of fish >10 years
	Number of strong cohorts in first 5 years	Yes	No	No	Yes	No	Yes	Yes	No	Yes	Yes	Yes	At least one strong cohort (≥ 15%)
	Number of strong cohorts in population	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	≥2 strong cohorts
	Score	**1**	**1**	**0**	**1**	**0**	**1**	**1**	**0**	**1**	**1**	**1**	
Recruitment	YOY CPUE	Yes	No	No	No	Yes	No	No	No	No	Yes	No	>0.77 YOY.net night^{-1}
	YOY distribution	*	No	No	No	No	No	No	No	No	Yes	No	>50% sites (detected)
	Score	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	
Icon site total score		**1**	**1**	**0**	**2**	**2**	**1**	**1**	**0**	**2**	**3**	**1**	
Black bream condition		**Very poor**	**Very poor**	**Extremely poor**	**Poor**	**Poor**	**Very poor**	**Very poor**	**Extremely poor**	**Poor**	**Moderate**	**Very Poor**	

*Although YOY were present at >50% sites, this vale should be treated with caution as most of the sampling sites in 2008/09 were in the Murray estuary.

Table 7-7. Condition assessment for greenback flounder population in the Coorong from 2008/09 to 2018/19. Note: Age composition was based on calendar year. Population indicators score 1 point if indices meet the following ecological targets: (1) Relative abundance – one of the indices meets their ecological target; (2) Distribution – meet the ecological target; (3) Age structure – one of the indices meets the ecological target and (4) Recruitment – both indices meet their ecological target. Icon site scores convert to the following fish population conditions: 4 – Good; 3 – Moderate; 2 – Poor; 1 – Very Poor and 0 – Extremely Poor. Source: Ye et al. (2020a).

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

7.5 Evaluation

7.5.1 Black bream

The population condition score of black bream in the Murray estuary and Coorong was determined to have likely improved over the duration of the assessment period, from 2008/09 to 2018/19. The likely improvement was attributed to the increased spatial distribution of black bream in the Coorong, with years that recorded more than half of the commercial catch in the North Lagoon and South Lagoon becoming more frequent (Ye et al. 2020a). Furthermore, strong recruitment of YOY black bream were recorded for the first time over the assessment period in 2017/18. Despite these improvements, the population abundance is low and age structure of black bream features relatively few fish over 10 years old and is characteristic of a depleted population with low resilience (Ye et al. 2020a).

Likely improvement in population condition of black bream since 2008/09 were associated with improved barrage outflow, which are dependent on the timing and volumes of flow contributing to either more favourable salinities throughout the Murray estuary and Coorong or conditions (i.e. salt-wedge formation) conducive to recruitment. The maintenance of an open Murray Mouth (primarily through dredging) has also contributed to supporting improved system connectivity and productivity that has supported more favourable habitat and nursery grounds for black bream. However, commercial and recreational catches of larger, older black bream reduce the number of fish that are capable of reproducing, which limits the resilience of the population. Actions to improve the future achievement of environmental outcomes for black bream include management of barrage outflow to increase salt-wedge habitat, management of lake levels to enhance productivity and subsequent food resource support to the Murray estuary, continued maintenance of an open Murray Mouth and sustainable fishery management including on-going fishery closures during the spawning season near the barrages (see section 7.6).

Barrage outflow

The timing and volumes of barrage outflow influence the distribution and recruitment of black bream, with high flows increasing the distribution of black bream throughout the Coorong and low (<1000 GL/year) to moderate (4000-6000 GL/year) flows during the spawning season associated with the generation of salt-wedge habitats in the Murray estuary that facilitate recruitment. Water for the environment helps to maintain the distribution of black bream particularly during low flow years by contributing to greater extents of estuarine salinity conditions that support adult black bream and its managed outflow from the barrages can generate salt-wedge habitats for recruitment.

High (unregulated) flow events

High (unregulated) flows from 2010/11 to 2012/13 and in 2016/17 helped to significantly reduce salinities over the Murray estuary and Coorong (Ye et al. 2020a) and increased the extent of suitable (<50 $g.L^{-1}$) and tolerable (~80 $g.L^{-1}$) salinities for black bream (see section 2.2.2). High flow to the Murray estuary can temporally reduce salinities below preferred concentrations for black bream (<15 $g.L^{-1}$), however, the extent of preferred salinities (15–35 $g.L^{-1}$) would have increased within a few months of the end of a high (unregulated) flow event (Stewardson and Guarino 2018). The distribution of black bream increased in association with the greater extents of preferred, suitable and tolerable salinities along the Murray estuary and Coorong, indicated by greater proportional commercial fishery catches in the southern part of the Coorong lagoons following high flows (Ye et al. 2020a). After high (unregulated) flow events, estuarine conditions are maintained in the Murray estuary and into the Coorong for 2 to 3 years under succeeding low flows (<1,400 $GL.year^{-1}$). These events enhance the productivity in the system which in turn supports increases in the numbers and distribution of black bream, including new recruits.

Low-moderate flows during spawning period

Recruitment of black bream in the Murray estuary were associated with the timing and volume of low (<1000 GL/year) to moderate (4000-6000 GL/year) outflow from the barrages, with YOY detected in 2008/09, 2012/13 and 2017/18 (Ye et al. 2020a). In the Murray estuary, targeted monitoring to identify and describe salt-wedge habitats was conducted in 2014/15 (Ye et al. 2015), 2017/18 (Ye et al. 2019a) and 2018/19 (Ye et al. 2019b), which determined that salt-wedge habitats (i.e. an area where freshwater sits above saltwater) were generated during the black bream spawning period in 2014/15 and 2017/18 (Ye et al. 2015; Ye et al. 2019a). These conditions during black bream spawning periods help keep the eggs and larvae buoyant and provide food for newly hatched fish to develop and grow.

A strong cohort of YOY black bream was detected in 2017/18, with the successful spawning period (late December to early February) having commenced 1 to 2 weeks after a ~10,000−12,000 $ML.day^{-1}$ flow pulse and corresponded with barrage outflow of 600−5,000 $ML.day^{-1}$ and water temperatures of 18−25°C (Ye et al. 2019a). Although monitoring of salt-wedge habitats did not occur over the successful spawning period, data collected in the weeks prior under similar barrage outflows suggested that favourable salinities (15−30 $g.L^{-1}$) and haloclines (>10 $g.L^{-1}$) were likely to be present (Ye et al. 2019a). Despite the generation of salt-wedge habitats in 2014/15, there were no YOY detected in sampling for that year, suggesting that recruitment of black bream is more complex than simply the generation of salt-wedge habitats (Ye et al. 2015; Ye et al. 2019a).

Contribution of water for the environment

Water for the environment has helped to maintain the extent of salinities below 35 $g.L^{-1}$, 55 $g.L^{-1}$ and 85 $g.L^{-1}$ over the Murray estuary and Coorong (Stewardson and Guarino 2019), and therefore increased the extent of preferred (10–35 $g.L^{-1}$), suitable (<50 $g.L^{-1}$) and tolerable (~80 $g.L^{-1}$) salinities for black bream. Furthermore, water for the environment has supported the establishment of salt-wedge habitats that facilitate recruitment (Ye et al. 2019b). The influence of water for the environment on the salinity conditions were greatest in years of low flow, when barrage outflow were largely or solely comprised of water for the environment (Stewardson and Guarino 2018, 2019). For example, in 2017/18, a year characterised by low flow, salinities below 35 $g.L^{-1}$ were typically available at over 25% of the Murray estuary and Coorong, whereas such conditions would have largely been absent without water for the environment (namely Commonwealth environmental water) (Stewardson and Guarino 2019). Therefore, water for the envionment increased the extent of salinities within the required range for black bream spawning and recruitment (10−35 $g.L^{-1}$). Furthermore, in 2017/18, more than half of the Murray estuary and Coorong had salinities below 55 $g.L^{-1}$, however, if water for the environment was not delivered, such conditions would have been available at less than a quarter of the Murray estuary and Coorong (Stewardson and Guarino 2019). As such, water for the environment increased the extent of suitable salinities for black bream (<50 $g.L^{-1}$) over the Murray estuary and Coorong.

The establishment of salt-wedge habitats in 2014/15 and 2017/18 were largely attributed to the delivery of water for the environment. The management of barrage outflow in 2014/15 and 2017/18 demonstrated that water for the environment can be delivered to generate salt-wedge habitats, which in 2017/18 led to the recruitment of a strong cohort of black bream (Ye et al. 2019a). Without water for the environment, the conditions required for black bream to recruit would not have occurred (Ye et al. 2019a).

Fishery catches

The population abundance of black bream did not increase over the assessment period, from 2008/09 to 2018/19, despite periodic recruitment (Ye et al. 2020a). Fishery catches of black bream have likely contributed to a depleted population of black bream with reduced spawning biomass and a truncated age structure (reduced resilience) by removing older and larger individuals from the population (Earl et al. 2016). As black bream typically complete their lifecycle within estuaries (Chaplin et al. 1997, Elsdon and Gillanders 2006), it is unlikely that the spawning biomass of black bream in the Murray estuary and Coorong is supported by immigration of fish from other estuaries (Ye et al. 2020a). Therefore, fishery management should continue to seek to protect the remnant spawning biomass and maximise the survival of new recruits in this region. (Ye et al. 2020a).

Year-round fishery closures within 150 m of the barrages were established prior to the assessment period, however, were extended to within 300 m of the barrages during the peak spawning period for black bream (September to November) in 2018 (K Rowling Pers. Comm. 2020). The fishery closures will help protect the remnant spawning population and increase the survival of YOY to reproductively mature fish (e.g. minimising fishing mortality of undersized black bream), which help to enhance the spawning biomass of black bream (Ye et al. 2019a,b). Increased recruitment and survival will help re-build the population abundance and resilience of black bream in the Murray estuary and Coorong (Ye et al. 2019a, 2019b).

7.5.2 Greenback flounder

The population condition score of greenback flounder in the Murray estuary and Coorong was determined to have likely improved over the duration of the assessment period, from 2008/09 to 2018/19. Improvement in the population of condition were most notable following the Millennium Drought, with age structure and the distribution of commercial catch and YOY targets met in nearly all years following the drought. In years of moderate and high flow after the high (unregulated) flow event in 2010/11, a positive trend in the commercial catches over the last 4 years were recorded. Counterintuitively, the YOY CPUE targets were only met during drought and low flow conditions as suitable conditions (e.g. salinities) for spawning and recruitment became concentrated at few sites in the Murray estuary (Ye et al. 2020a). Despite the likely general improvements in the population condition score of greenback flounder, the population condition in 2018/19 is considered to be very poor with a low relative abundance, contracting distribution and truncated population age structure with approximately only 9% of fish aged 3+ years old (Ye et al. 2020a).

Likely improvement in the population condition of greenback flounder in the Murray estuary and Coorong between 2008/09 and 2018/19 were attributed to improved barrage outflow, which are dependent on the timing and volume of flow contributing to either more favourable salinities throughout the Murray estuary and Coorong. The maintenance of an open Murray Mouth (primarily through dredging) has also contributed to supporting improved system connectivity and productivity that has supported more favourable habitat and nursery grounds for greenback flounder, and increased the amount of salt exported out of the system therefore reducing the amount of salt entering the Coorong. Irrespective of flow conditions, commercial and recreational catches may have compromised the population condition of greenback flounder by reducing their population abundance and spawning biomass. Actions to improve the achievement of environmental outcomes for greenback flounder include the maintenance/improvement of estuarine conditions through the delivery of water for the environment, maintenance of an open Murray Mouth and fishery management (see section 7.6).

Barrage outflow

Barrage outflow is critical to the population condition of greenback flounder in the Murray estuary and Coorong. Freshwater inflow to the Murray estuary and Coorong via barrage discharge influences (1) the salinity regime, (2) system connectivity and (3) productivity. The timing and volumes of barrage outflow influence the distribution and recruitment of greenback flounder, with high flows increasing the distribution of greenback flounder throughout the Coorong and low (<1000 GL/year) to moderate (4000-6000 GL/year) flows providing conditions to support greenback flounder recruitment. Water for the environment helps to maintain the distribution of greenback flounder, particularly during low flow years, by contributing to greater extents of estuarine salinity conditions that support adult greenback flounder.

High (unregulated) flow events

High (unregulated) flow events are associated with an increase in the extent of brackish to near-marine salinities (<40 $g.L^{-1}$) and productivity that often results in increases in the distribution of new recruits and adults of greenback flounder in the Coorong lagoons and increased annual fishery catches after 1–2 years following the event (Ye et al. 2020a).

High (unregulated) flow events and high flows from 2010/11 to 2012/13 and in 2016/17 contributed to an increase in the extent of salinities <40 $g.L^{-1}$ (Ye et al. 2020a) within which adult and juvenile greenback flounder primarily reside (Earl et al. 2017; Ye et al. 2020a). Therefore, high flows that restore or maintain salinities <40 $g.L^{-1}$ in the Murray estuary and Coorong enable adults and new recruits to increase their distribution southward from the estuary to the lagoons. Such increases in the distributions of catch (adult fish) and new recruits were recorded during the high flows from 2010/11 to 2012/13 and in 2016/17 (Ye et al. 2020a).

The pelagic productivity in the Murray estuary and Coorong is also enhanced by high flows, which entrain microinvertebrates and nutrients in flow from the River Murray and Lakes (Shiel and Tan 2013; Furst et al. 2014; Ye et al. 2020b). Outflow from the barrages releases water enriched with microinvertebrates and nutrients to the Murray estuary and Coorong, where it may directly increase the availability of food resources for greenback flounder or stimulate primary production and subsequently indirectly increase food resources (Ye et al. 2020a).

Contribution of water for the environment

Water for the environment has helped to increase the extent of brackish to near-marine salinities (<40 $g.L^{-1}$) and subsequently the distributions of adult and juvenile greenback flounder in the Murray estuary and Coorong. The influence of water for the environment on the salinity conditions along the Murray estuary and Coorong were greatest in years of low flow, when barrage outflow were largely or solely comprised of water for the environment (Stewardson and Guarino 2018, 2019). For example, in 2017/18, water for the environment (namely Commonwealth environmental water) helped maintain conditions below marine salinities (<35 $g.L^{-1}$) across ~25% of the Murray estuary and Coorong from September to March, that otherwise would have largely been absent in the system without this water delivered for the environment (Stewardson and Guarino 2019). The delivery of water for the environment in 2017/18 may have enhanced recruitment though the increased extent of preferred salinities for greenback flounder larvae and YOY.

Productivity in the Coorong is enhanced by water for the environment (Ye et al. 2020b). The delivery of water for the environment facilitates barrage outflow that otherwise would have been negligible in its absence (Stewardson and Guarino 2019; Ye et al. 2020b), which in turn, facilitates connectivity and matter exchange between the Lakes and Coorong. Modelling of matter transport through the lower River Murray, Lakes and Coorong by Ye et al. (2020b) determined that environment flows over 4 of the past 5 years (2014/15, 2015/16, 2017/18 and 2018/19) were a key driver in the enhancement of estuarine productivity. The combined effects of greater extents of estuarine conditions and enhanced productivity would provide more favourable habitat and nursery grounds in the Coorong to facilitate the recruitment of greenback flounder (Ye Pers. Comm. 2020).

Open Murray Mouth

An open Murray Mouth is critical to greenback flounder as it provides system connectivity that allows fish to move between estuarine and marine habitats (Earl et al. 2017) and helps to regulate salinities in the Murray estuary and Coorong by providing an avenue for salt export (Webster 2005; Brookes et al. 2009; Kingsford et al. 2009; Higham 2012), which in turn, provides more favourable salinities for greenback flounder. As a marine estuarine opportunistic species, system connectivity is needed to support the passage of larval and juvenile greenback flounder from the marine environments to the nursery habitats of the Murray estuary (Bice et al. 2018). The dispersal and movements of greenback flounder also rely on system connectivity, with fish in their second or third year of life departing the Coorong for the sea. With most individuals not returning, others had return migrations between the estuary and sea (Earl et al. 2017). The maintenance of an open Murray Mouth was primarily achieved through dredging, with dredging conducted following the adoption of the Basin Plan during prolonged low flow conditions (see section 4.3.1). These periods included January 2015 to October 2016 and August 2017 to June 2019 (end date for assessment period; noting dredges continue to operate) to maintain an open and functional Murray Mouth.

Fishery catches

The population age structure of greenback flounder in the Murray estuary and Coorong is highly truncated, with approximately only 9% of fish aged ≥3 years old (Ye et al. 2020a) despite being able to live for more than 10 years (Sutton et al. 2010). The lack of fish ≥3 years old may be related to the removal of larger older fish through commercial and recreational fishing (Earl and Ye 2016), however, the movement of fish from the Murray estuary and Coorong to sea when 2 to 3 years old may also contribute to lack of older fish (Earl et al. 2017). As the spawning biomass of greenback flounder in marine environments remains a knowledge gap (Earl et al. 2017; Ye et al. 2020a), it is unknown whether fishery catches have reduced the sustainability and resilience of the greenback flounder population.

7.6 Actions to achieve environmental outcomes

Ongoing actions to improve the future achievement of environmental outcomes for black bream and greenback flounder include the maintenance of estuarine conditions and conditions to support recruitment through the management of barrage outflows and the maintenance of an open Murray Mouth (see section 7.6.1) and on-going fishery management (see section 7.6.2) . Although outside of current management influence, periodic high (unregulated) flow events are important and are needed more frequently to enable the maintenance of suitable habitat conditions in the Murray estuary and Coorong, particularly following low flow years. High (unregulated) flow events also enhance the productivity in the system, which in turn supports increases in the abundances, distribution and recruitment of both black bream and greenback flounder, including new recruits.

7.6.1 Maintenance of estuarine salinity conditions

Key to future management of black bream and greenback flounder is the maintenance of estuarine conditions in the Murray estuary and Coorong to provide suitable salinity conditions to facilitate recruitment (Ye et al. 2020a). The continued support of water for the environment to barrage outflow and maintenance of an open and functional Murray Mouth (primarily through dredging) has been and will continue to be important for achieving these environmental outcomes, especially in low flow years (Ye Pers. Comm. 2020). Furthermore, maintenance of an open Murray Mouth is essential system connectivity which supports the immigration and emigration of greenback flounder at various life stages (Earl et al. 2017; Bice et al. 2018).

Optimisation of lake level regimes should be considered to enhance productivity of freshwater derived biota, as well as improving connection between Lakes and Coorong to subsidise productivity in the Murray estuary (Ye et al. 2019b). Lake levels may be surcharged throughout winter and spring, before discharge in early summer to transport nutrients, phytoplankton and zooplankton to the Murray estuary and Coorong (Ye et al. 2019b). This may increase food resources in barrage outflow to the Coorong for estuarine fish (Ye et al. 2019b), including black bream and greenback flounder.

Outflow from the barrages can be managed to increase salt-wedge habitat and potentially enhance recruitment of black bream (Ye et al. 2019a, 2019b). Where feasible, it is recommended that flow regimes similar to those that facilitated strong black bream recruitment in 2017/18 be delivered in future years (Ye et al. 2019a, 2019b).

7.6.2 Fishery management

Fishery management is key to the sustainability and resilience of black bream and greenback flounder populations in the Murray estuary and Coorong through the restrictions on licenses, commercial net type, mesh size, net depth and net length (Earl et al. 2016; Earl and Ye 2016). Specifically, fishery closures from 150m of the barrages for the protection of black bream during the spawning period are critical. This management action is required to continue in order to protect the remnant spawning biomass. Fishery management should also seek to maximise the survival of new recruits to help improve the abundance and resilience of the black bream population in the Murray estuary and Coorong (Ye et al. 2019b).

7.6.3 Future investigations

Future management of the Coorong will be reviewed as part of the Healthy Coorong Healthy Basin (HCHB) Program (DEW 2020). The HCHB Trials and Investigations Project will inform broader HCHB investigations into long-term management solutions (including infrastructure options) to support the health of the Coorong (DEW 2020). The investigations into restoring a functioning Coorong food web (as part of the Trials and Investigations Project) will determine how barrage inflows, flows from Salt Creek and dredging of the Murray Mouth should be managed in order to restore a functioning South Lagoon food web (DEW 2020), of which black bream and greenback flounder are important secondary consumers in the Murray estuary and Coorong North Lagoon (Giatas and Ye 2016).

Further monitoring of salt-wedge habitats over the black bream spawning period is also recommended, as this will be critical to our understanding of the processes that drive black bream recruitment, which will underpin future delivery of water for the environment for black bream outcomes (Ye et al. 2019b).

7.7 Conclusion

The implementation of the Basin Plan, including the delivery of water for the environment, has contributed to some actions which have led to some improvements in the population condition of black bream and greenback flounder in the Murray estuary and Coorong. The delivery of water, including water for the environment as part of Basin Plan implementation, has helped to restore and maintain estuarine conditions that support the residence and recruitment of black bream and greenback flounder. Despite this, the population condition of both species currently remains very poor. In future years, it is expected that with effective fisheries management, continued maintenance of estuarine conditions, and continued implementation of the Basin Plan, the population condition of both bream and flounder in the Murray estuary and Coorong will continue to improve.

Key messages:

- Overall improvements in the population condition of black bream and greenback flounder in the Murray estuary and Coorong have been recorded, but with recent low flow conditions population condition has declined.

- Delivery of water for the environment in low flow years helps to maintain estuarine salinity conditions and enhance productivity and food resources in the Murray estuary and Coorong, which would increase the extent and quality of nursery habitats for black bream and greenback flounder.
- Strategic management of barrage outflow supported by water for the environment is required to generate salt-wedge conditions in the Murray estuary that may enhance productivity and recruitment of black bream.
- Dredging has helped to maintain an open Murray Mouth since the adoption of the Basin Plan. An open Murray Mouth is critical to the maintenance of estuarine conditions and connectivity between the estuary and the sea, which greenback flounder are reliant upon for immigration and emigration at various life stages.
- High (unregulated) flow events are important for maintaining estuarine salinity conditions and likely increasing the extent of such conditions in the Murray estuary and Coorong.

8 Diadromous Fish

8.1 Introduction

Diadromous fish are those that migrate between freshwater and seawater environments to complete their lifecycle (McDowall 1997). Worldwide, populations of many diadromous fishes are threatened due to impaired connectivity (Hammer et al. 2009), habitat loss, overfishing, invasive species, pollution and climate change (Lin et al. 2017). These anthropogenic impacts, and dependency on migration between disparate habitats, result in diadromous species being among the most threatened fishes globally (McDowall 1992; Miles et al. 2014).

The CLLMM is unique within the Murray–Darling Basin, comprising the sole interface between freshwater, estuarine and marine environments, and therefore, critical migratory pathways and habitats for diadromous fishes (Lintermans 2007). System connectivity, among the River Murray, Lakes Alexandrina and Albert, Murray estuary, Coorong and Southern Ocean is critically important to the population dynamics of diadromous fish in the Basin.

Freshwater flows through open barrage gates and fishways are critical to enable the bi-directional movement of diadromous fish past the Murray barrages. The fishways on the barrages are designed to facilitate upstream migration, but are likely poor at facilitating downstream migration. These movements are likely best facilitated through barrage gates and the timing of upstream and downstream migration may differ among species. The importance of system connectivity was demonstrated during the Millennium Drought, with the closure of barrages and fishways from 2007 to 2010 causing diadromous fish populations to decline significantly (Bice et al. 2018b; Bice et al. 2019).

The most abundant diadromous fish species in the CLLMM are the congolli (*Pseudaphritis urvillii*) and common galaxias (*Galaxias maculatus*) (Bice et al. 2019). The life histories of congolli differ between sexes, as adult females are fully catadromous, meaning they migrate from freshwater habitats to marine habitats to spawn (Bice et al. 2019) (Figure 8-1). During winter, adult females move downstream from the River Murray and Lower Lakes, and through the Coorong, to spawn in the Southern Ocean in winter/spring (Bice et al. 2018b). Adult males display a slightly different life history characterised by predominantly estuarine residence (e.g. within the Coorong; Hortle 1978 in Crook et al. 2010; Cheshire et al. 2013) and presumed migration into the Southern Ocean for spawning. Females become sexually mature at 3 to 4 years of age (Hortle 1978 in Bice et al. 2019), however males may mature faster than females (Cheshire et al. 2013). Spawning, and larval and juvenile development occur in the Southern Ocean (Bice et al. 2019). Juveniles then migrate upstream to freshwater habitats in spring/summer (Bice et al. 2019). It is possible that there is environmental sex determination in congolli, with juveniles that enter freshwater developing as females and those that stay in marine environments developing as males (Crook et al. 2010).

Common galaxias are semi-catadromous, meaning they migrate from freshwater to estuarine habitats to spawn (Bice et al. 2019) (Figure 8-2). Adults sexually mature at one year of age (Pollard 1971) and migrate downstream from the River Murray and Lakes to spawn in the Coorong estuary in winter/spring (Bice et al. 2019). Larvae commonly are dispersed to sea, where they develop, and subsequently migrate upstream as juveniles in spring/summer to the Lakes and tributaries of the eastern Mount Lofty Ranges (Bice et al. 2018a), where adults reside (Bice et al. 2019).

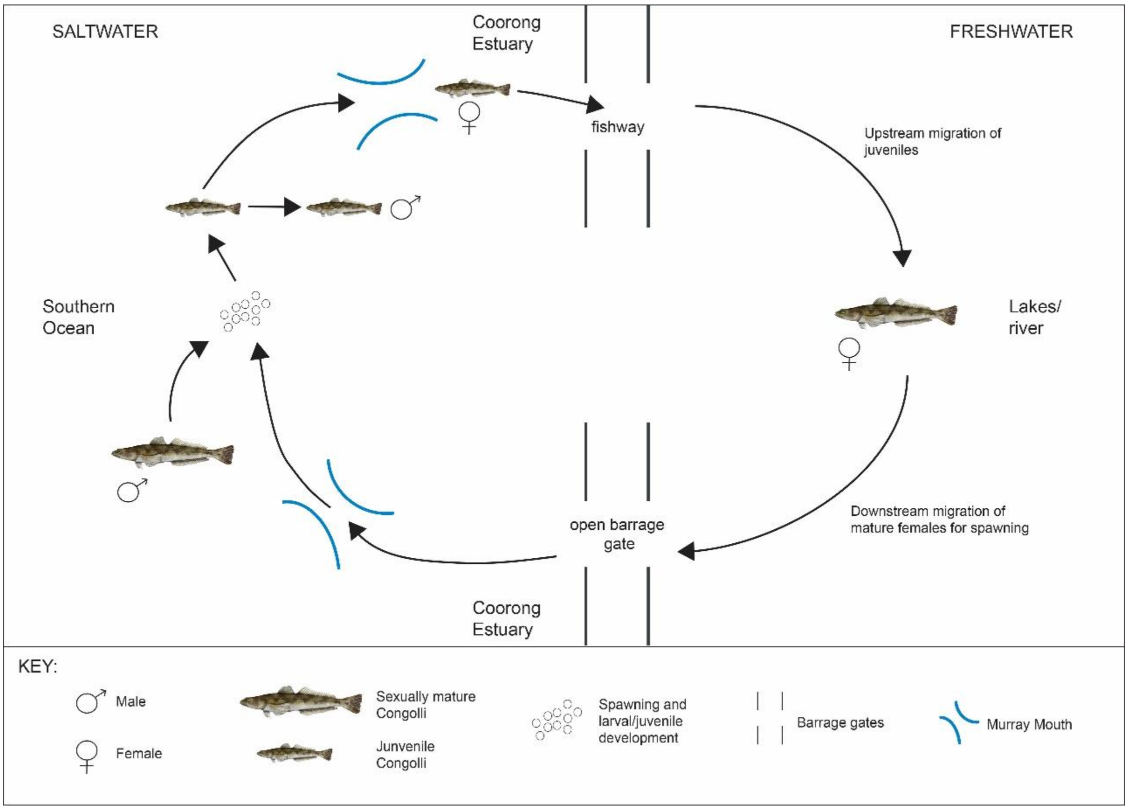

Figure 8-1. Life history of congolli in the CLLMM.

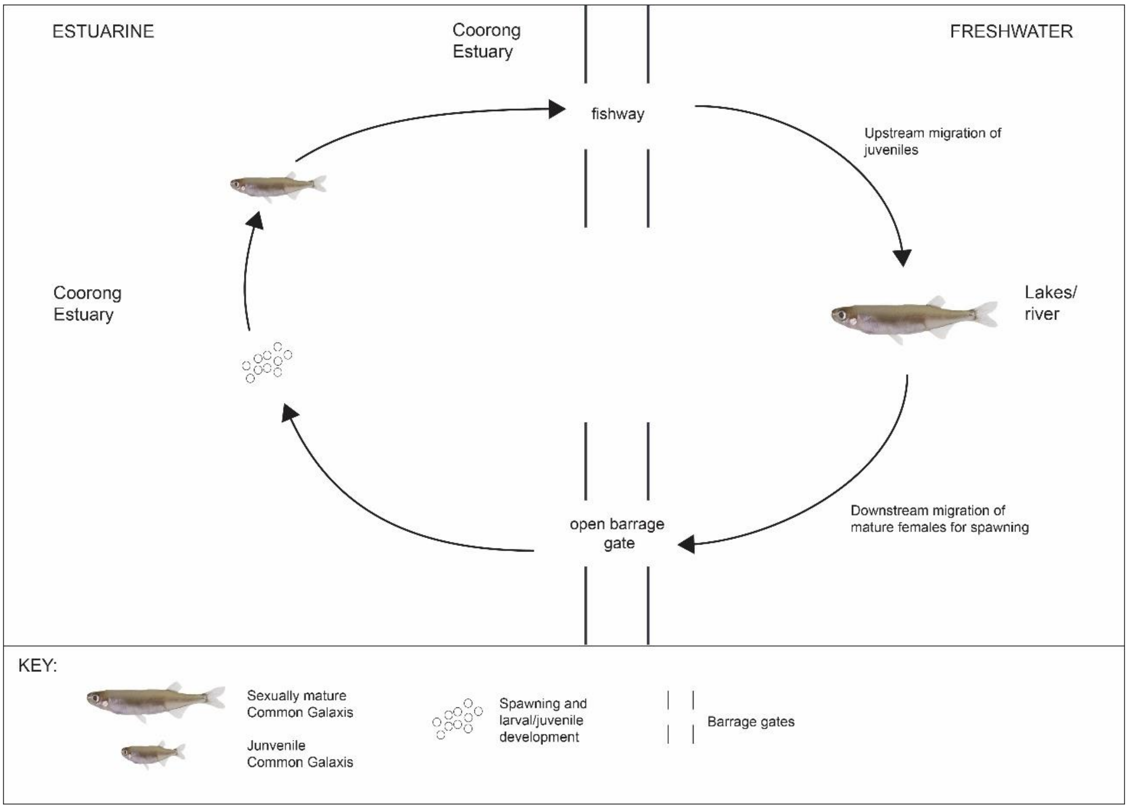

Figure 8-2. Life history of common galaxias in the CLLMM.

8.2 Ecological objective, target and environmental outcomes

The ecological objective for fish and the ecological targets for congolli and common galaxias as described in the SA River Murray LTWP (DEWNR 2015) are presented in Table 8-1. The ecological targets for diadromous fish in the CLLMM are from the 'Diadromous fish' chapter (Bice and Zampatti 2017b) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and are also presented in Table 8-1. The ecological target formed the basis of the expected environmental outcomes for congolli and common galaxias in the CLLMM PEA.

Table 8-1. Ecological objective and targets for diadromous fish species: congolli and common galaxias.

Characteristic	Description
Ecological objective	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the Lakes and Coorong.
Ecological target	1. Annual detection of upstream migrating YOY congolli is ≥ that of defined 'Recruitment Index' value (44.5 $YOY.hr^{-1}$)
	2. Annual detection of upstream migrating YOY common galaxias is ≥ that of defined 'Recruitment Index' value (6.1 $YOY.hr^{-1}$)

The expected environmental outcomes for congolli and common galaxias annual recruitment index (RI) scores in 2019, 2029 and 2042 were determined by elicitation with key experts. Over time, it is expected that the percentage of years that congolli (Table 8-2) and common galaxias (Table 8-3) meet their respective recruitment index values will remain relatively stable (Figure 8-3).

Table 8-2. Expected environmental outcomes for annual congolli recruitment index values.

Year	Expected outcome
2019	The LTWP target is met on 6.5* of 7 (93%) years of monitoring since Basin Plan implementation.
2029	The LTWP target is met on 15 of 17 (88%) years of monitoring since Basin Plan implementation.
2042	The LWTP target is met on 23 of 30 (77%) years of monitoring since Basin Plan implementation.

*Note: absence of whole numbers is due to averaged results from 3 experts

Table 8-3. Expected environmental outcomes for annual common galaxias recruitment index values.

Year	Expected outcome
2019	The LTWP target is met on 5.5* of 7 (79%) years of monitoring since Basin Plan implementation.
2029	The LTWP target is met on 14 of 17 (85%) years of monitoring since Basin Plan implementation.
2042	The LWTP target is met on 23 of 30 (77%) years of monitoring since Basin Plan implementation.

*Note: absence of whole numbers is due to averaged results from 3 experts

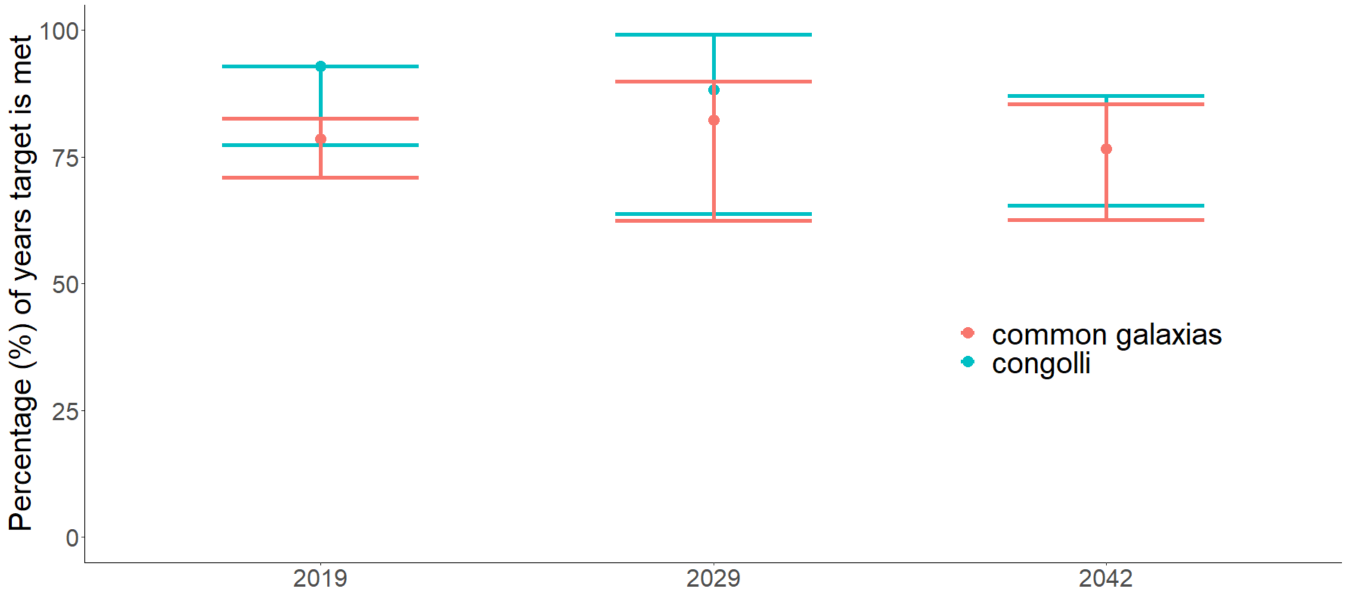

Figure 8-3. Percentage (%) of years (±80% confidence interval) since the adoption of the Basin Plan that recruitment target values for congolli and common galaxias were expected to be met in 2019, 2029 and 2042.

8.3 Method

The methodology for diadromous fish monitoring follows the 'Diadromous fish' chapter (Bice and Zampatti 2017b) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017). The methodology used to monitor diadromous fish is summarised below.

Fish are sampled at up to 6 sites across the Murray barrages, including fishways on the Tauwitchere and Goolwa barrages, sites adjacent to these barrages, and at Hunters Creek causeway fishway. The entrances to the vertical slot fishways are sampled using cage traps designed to fit in to the first cell of each fishway, while the site adjacent the Tauwitchere rock ramp and adjacent Goolwa Barrage are sampled with a large double-winged fyke net.

A week of fish sampling (4 in total) is conducted for each month between October and January. Vertical slot fishways are sampled overnight typically 3 times per sampling week and the sites adjacent the Tauwitchere rock ramp and adjacent Goolwa Barrage are sampled once overnight per sampling week. All trapped congolli and common galaxias trapped are identified, counted and during each trapping event a random subsample of up to 50 individuals are measured to the nearest millimeter (total length, TL) to represent the size structure of the population.

8.3.1 Recruitment index (RI) calculation

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

An annual recruitment index is determined for congolli and common galaxias by calculating the overall site abundance of upstream migrating YOY (i.e. fish.hr^{-1}) during the sampling period (Table 8-4) and comparing that against a predetermined reference value. Reference values were calculated by using monitoring data from the years 2006/07, 2010/11, 2011/12 and 2013/14, which comprise years of variable barrage outflow.

Table 8-4. Sampling period and year-of-young size thresholds for congolli and common galaxias.

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

Annual recruitment was calculated for congolli using Equation 1 and for common galaxias using Equation 2.

Equation 1 $RI = (S_1(mean((r*A_{Nov}))+(r*A_{Dec})+(r*A_{Jan})) + S_2(mean((r*A_{Nov})+(r*A_{Dec})+(r*A_{Jan}))\ldots..S_n)$

where S = site, A = abundance (fish hour^{-1}) and r = the percentage of the sampled population comprised of YOY (i.e. <60 mm TL).

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

RI_{final}= mean ($RI_{2006/07}$+ $RI_{2010/11}$+$RI_{2012/13}$+$RI_{2013/14}$) ± half confidence interval.

RI_{final}= 44.26 ± 21.78 YOY.hr^{-1}.

Equation 2 $RI = (S_1(mean((r*A_{Oct}))+(r*A_{Nov})+(r*A_{Dec})) + S_2(mean((r*A_{Oct})+(r*A_{Nov})+(r*A_{Dec}))\ldots..S_n)$

where S = site, A = abundance (fish hour^{-1}) and r = the percentage of the sampled population comprised of YOY (i.e. <40 mm TL).

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

RI_{final}= mean ($RI_{2006/07}$+ $RI_{2010/11}$+$RI_{2012/13}$+$RI_{2013/14}$) ± half confidence interval.

RI_{final}= 6.12 ± 3.00 YOY.hr^{-1}.

8.3.2 Trend assessment

Trend analysis was undertaken in R Studio (R version 3.5.0, R Core Team 2018) using a Bayesian generalised linear model (using the stan-glm function in the rstanarm package, Goodrich et al. [2020], 4000 runs) with a gamma family. Models aimed to determine the likelihood of trend (either positive or negative) in the rate of upstream migrating YOY (i.e. fish.hr^{-1}) of diadromous fish through the Murray barrages. The model included an interaction effect between time step (years since commencement of monitoring program) and species, to allow species to have different slopes as well as intercepts. As such, the likelihood of trend could be determined for both congolli and common galaxias recruitment index.

8.3.3 Condition assessment

The condition of the congolli and common galaxias population in the CLLMM were assessed based on the RI values of each species in the last year of the assessment period (2018/19). The matrix used in the conversion of an RI value to a condition rating is provided in Table 8-5. The condition of the fish species in poorest condition was used to represent condition of diadromous fish for the Report Cards.

Table 8-5. Criteria used to define recruitment index value ranges that align with condition classes used for the Trend and Condition Report Cards.

Criteria	RI value range		Condition rating
	congolli	common galaxias	
>100% greater than the RI reference value	≥88.53	≥12.25	Very good

Criteria	RI value range		Condition rating
	congolli	common galaxias	
>RI reference value + half confidence interval to 100% greater than RI reference value	66.05-88.52	9.13-12.24	Good
RI reference value ± half confidence interval	22.48-66.04	3.12-9.12	Fair
< RI reference value – half confidence interval	≤22.47	<3.11	Poor

8.3.4 Information reliability

The information reliability assessment for diadromous fish recruitment in the CLLMM was conducted as per section 3.2.2.

8.4 Results

8.4.1 Environmental outcome assesssment

In 2019, it was expected that the recruitment index values would be exceeded in all monitoring years for congolli and 6 out of 7 years of monitoring for common galaxias. As a result, the expected environmental outcomes for both species in 2019 was met (Figure 8-4). Progression towards the achievement of the LTWP since the adoption of the Basin Plan has increased compared to years prior to the adoption of the Basin Plan. Prior to the adoption of the Basin Plan, congolli had not met the recruitment index value from 2006/07 to 2011/12, and common galaxias only met the recruitment index value only in 2006/07. Since the adoption of the Basin Plan both species have exceeded the recruitment index values in all years (with the exception of common galaxias in 2016/17), but this result should be treated with caution as discussed in section 8.5.

The annual RI value for congolli was very low in 2006/07, with 18.2 YOY migrating upstream per hour (Figure 8-4). There was almost no attempted upstream migration of YOY between 2007/08 and 2009/10, with RI values varying from 0.07-0.14. Annual RI values increased in 2010/11 and 2011/12 to 7.6 and 16.3, respectively. No monitoring was conducted in 2012/13, when the Basin Plan was adopted. Since the adoption of the Basin Plan, RI values have been greater although variable, with fluctuations between 74.4 and 395.4.

The annual RI value for common galaxias was moderate in 2006/07, with 11.7 YOY migrating upstream per hour (Figure 8-4). There was no attempted upstream migration of YOY in 2007/08 and 2008/09, with RI values below 0.1. Annual RI values remained low from 2009/10 to 2011/12, however, increased over this period from 3.5 to 6.6. No monitoring was conducted in 2012/13, when Basin Plan was adopted. Following the adoption of the Basin Plan, annual RI values were relatively high from 2013/14 to 2015/16, ranging from 11.6 to 29.4. In 2016/17, there was a great reduction in the RI value to 2.2, however, this result should be treated with caution as discussed in section 8.4. Moderate RI values were recorded in 2017/18 and 2018/19, with annual RI values of 7.5 and 8.6, respectively.

Overall, the recruitment index of both species showed similar patterns in variability, and were typically low from 2006/07 to 2011/12 and were moderate to high from 2013/14 to 2018/19 (Figure 8-4).

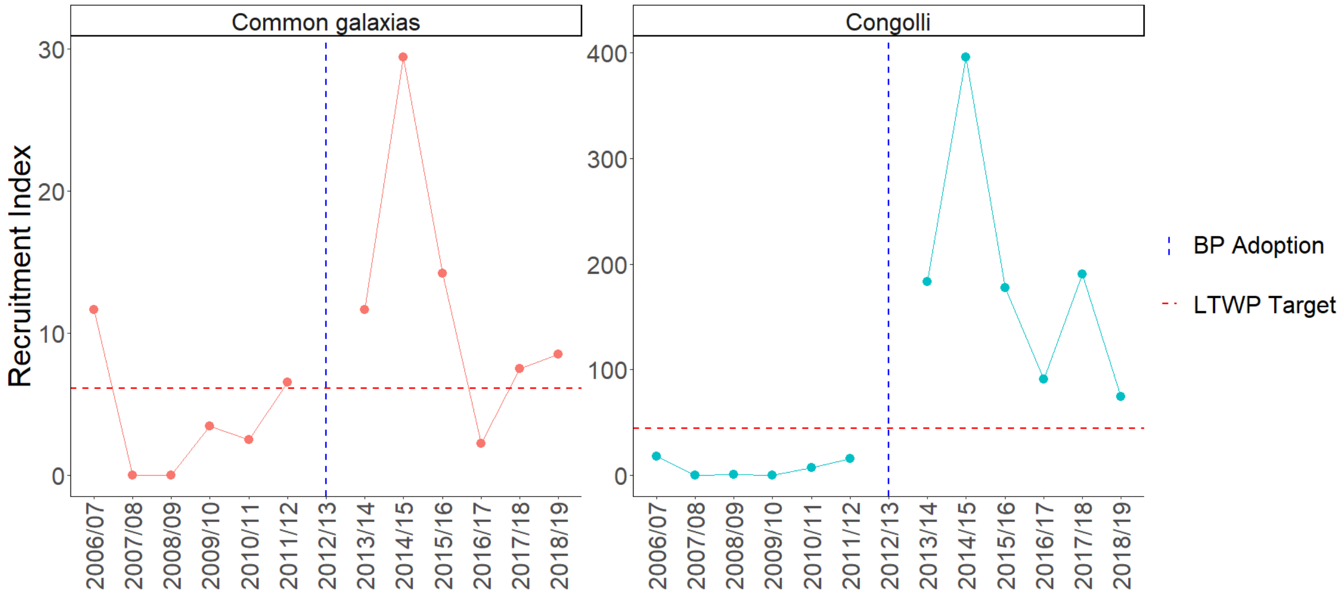

Figure 8-4. Annual recruitment index (RI, number of upstream migrating YOY.hour-1) for congolli and common galaxias from 2006/07 to 2018/19 (no monitoring was conducted in 2012/13). Basin Plan adoption is shown as a vertical dashed blue line and the Long Term Watering Plan Target is shown as a horizontal dashed red line.

8.4.2 Trend assessment

Recruitment index values of congolli and common galaxias from 2006/07 to 2018/19 were virtually certain (99%) and likely (80%) to be **getting better,** respectively.

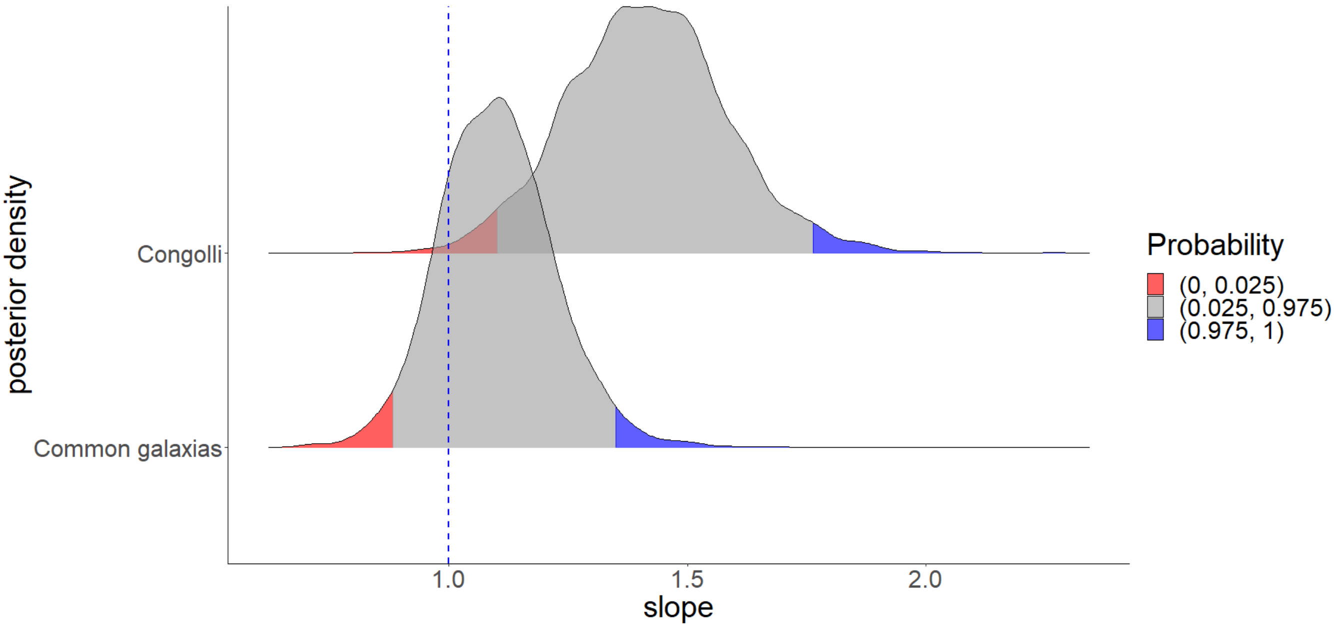

Figure 8-5. Estimated values for the slope generated from Bayesian modelling for recruitment index values for congolli and common galaxias from 2006/07 to 2018/19. Posterior slope values >1 infer a positive trend (getting better) and values <1 infer a negative trend (getting worse).

8.4.3 Condition

The recruitment index values of congolli and common galaxias in 2018/19 were 74.37 and 8.55 YOY migrating upstream per hour, respectively. Therefore, the population condition of congolli was considered to be good, while the population condition of common galaxias was fair for this assessment. As the condition of the fish species in poorest condition is used to represent condition of diadromous fish for the Trend and Condition Report Cards, the condition of diadromous fish in the CLLMM for that reporting is also considered to be **fair.**

8.4.4 Information reliability

The information reliability rating for diadromous fish was **good** (final score of 10). Justification for the scoring of diadromous fish data reliability is provided in Table 8-6.

Table 8-6. Reliability of diadromous fish recruitment index data to assess the expected environmental outcomes for congolli and common galaxias. The methods used in data collection as well as the representativeness, repetition and sample independence of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data collected were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *Condition Monitoring Plan* (DEWNR 2017).	**2**
Standard methods	Has the same method been used over the sampling program?	**Somewhat.** The same method has been used at individual sampling sites over the monitoring program, however, there are differences in method between sites due to differences in the size and type of barrage fishways.	**1**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	**Yes.** Sampling sites are well spread across the Murray barrages.	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Sampling has been conducted from 2006/07 to 2018/19, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and range of hydrological conditions.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Somewhat.** There has been an increase in the geographical spread of sites over the monitoring program associated with the construction of new fishways.	**1**
Time	Has the frequency of sampling been sufficient to represent	**Yes.** Sampling was conducted on an annual basis (except for the absence of sampling in 2012/13) and over a time period (October –	**2**

Methods	Question	Answer and justification	Score
	change over the assessment period?	January) that the majority of congolli and common galaxias YOY migrate upstream.	
Final score			**10**
Information reliability			**Good**

8.5 Evaluation

The recruitment of congolli and common galaxias over the duration of the assessment period (2006/07 – 2018/19) were virtually certain and likely to have improved, respectively. These diadromous fish species both exceeded their respective recruitment index values every year since the adoption of the Basin Plan, with the exception of common galaxias in 2016/17. Upstream migration for common galaxias in 2016/17 peaked in January rather than between October and December, which is more typical for the species (Bice et al. 2017a). As the annual RI value for common galaxias is calculated for the period of October – December (typical peak migration period), the RI value for 2016/17 missed the peak period of upstream migration. This resulted in a deflated RI value for common galaxias that failed to meet the recruitment index value. However, if the January migration of common galaxias had been included within the RI calculation for 2016/17, the recruitment index value would have been met (Bice et al. 2017a). Therefore, since the adoption of the Basin Plan, the annual recruitment of congolli and common galaxias are considered to have surpassed their recruitment index values in each year of this assessment.

The delivery of water for the environment recovered through the Basin Plan has contributed to improved connectivity by maintaining open barrage gates in winter, and increased volumes of water reaching the Lakes in spring and summer supported by the operation of fishways and provided flow cues for upstream movement (see section 8.5.1). Additionally, in years when high (unregulated) flows did not occur during winter months (i.e. 2015, 2017, 2018 and 2019), the coordinated delivery of water for the environment with upstream catchments (particularly the Goulburn) contributed to winter flow pulses in the South Australian River Murray, which supported diadromous fish movement and recruitment. The low abundance of reproductively mature adults in the populations was also a primary factor that influenced diadromous fish recruitment over the assessment period (2006/07 – 2018/19) (Bice et al. 2019) (see section 8.5.2).

8.5.1 System connectivity

The delivery of water, including water for the environment has contributed to the improved recruitment of diadromous fish by maintaining system connectivity. In years when high (unregulated) flow events did not occur during winter months (i.e. 2015, 2017, 2018 and 2019), water for the environment was used for environmental objectives in upstream catchments (particularly the Goulburn) that contributed to a winter flow pulse in the South Australian River Murray (Bice and Zampatti 2017a). Winter flow pulses increased the volume of water in the Lakes when lake levels were low and subsequently enabled water to be discharged through open barrage gates, maintaining connectivity (Bice and Zampatti 2017a). Open barrage gates allow diadromous fish to complete their downstream migration from freshwater to estuarine and/or marine habitats. Likewise, the increased volume of water for the environment reaching the Lakes in spring and summer supported the operation of fishways and contributed to ‘attractant flow’ that was provided through open barrage gates adjacent to fishways. Attractant flow is delivered to guide migrating fish to fishways, enhancing their performance (Bice and Zampatti 2017a).

The lack of freshwater inflows and loss of connectivity due to closure of the barrages (Figure 8-6) and fishways during the Millennium Drought, resulted in negligible recruitment of diadromous fish and a depletion of the population of reproductively mature adults (Bice et al. 2019). Since the end of the Millennium Drought in 2010/11 system connectivity has been restored, including the opening of barrage gates and fishways (Bice et al. 2019) (Figure 8-6; Figure 8-7) which has supported improved movement and recruitment in diadromous fish species, including congolli and common galaxias.

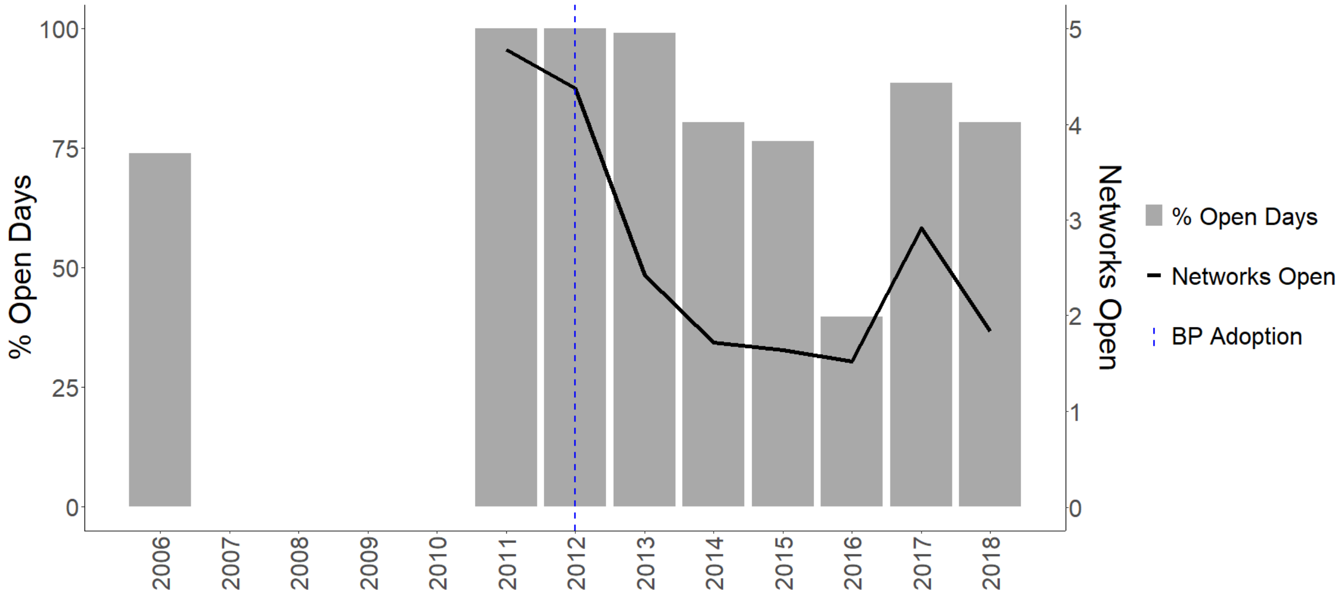

Figure 8-6. The percentage (%) of open days (i.e. when one or more barrage gates were open) from 2006 to 2018 and the mean number of barrage networks open (barrages with one or more gates open) per day from 2011 to 2018 during the downstream migration period (May-August) for diadromous fish in the CLLMM. Timing of the adoption of the Basin Plan is shown by the vertical dashed blue line.

Fishways

From 2003 to 2009, 5 fishways were constructed along the barrages to facilitate the movement of fish between the Coorong and Lower Lakes (Bice et al. 2017b). From 2015 to 2018, a further 6 fishways were constructed; fishways are now present on every barrage within the network (Bice et al. 2017b). The additional 6 fishways increased the geographical spread of migration pathways and allow the movement of a higher biomass of fish under a range of flow conditions (Bice et al. 2017b).

During the height of the Millennium Drought, all barrages and the existing 5 fishways were closed to prevent saltwater incursion (Bice et al. 2018b), prompting emergency measures to facilitate downstream spawning migrations of congolli through the Goolwa Barrage navigation lock in July 2010 (Zampatti et al. 2012). Since the break of the Millennium Drought in September 2010, a minimum of 4 fishways have remained open at all times (Figure 8-7).

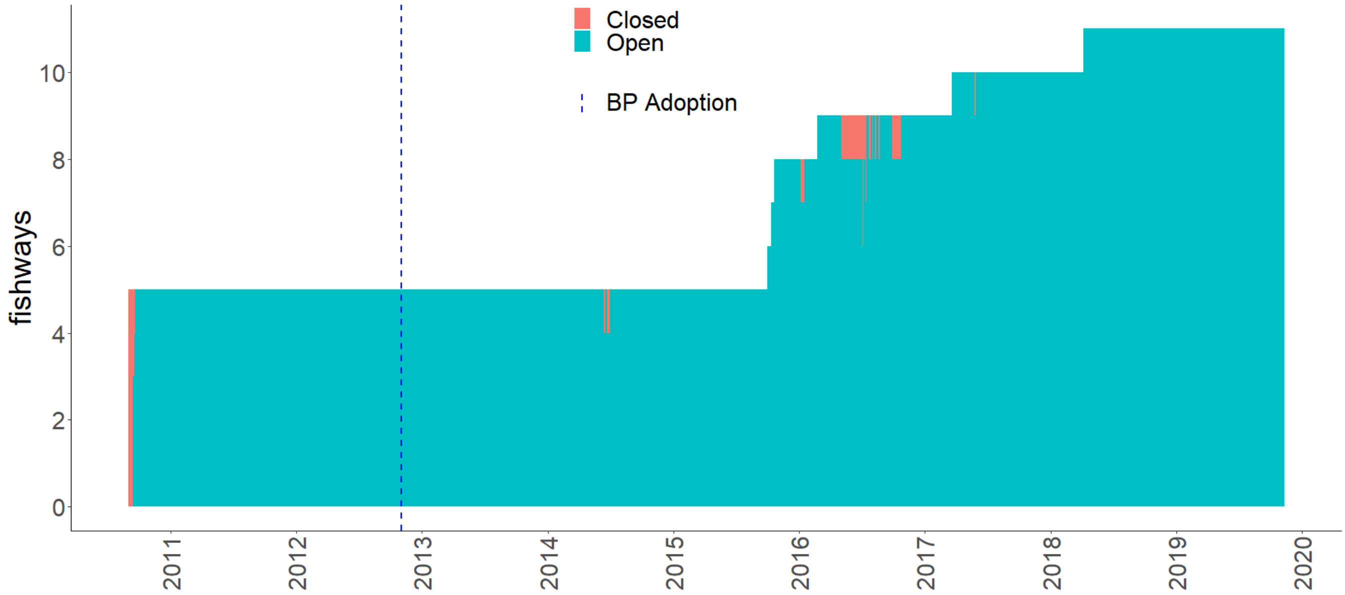

Figure 8-7. Number of open and closed fishways along the Murray barrages each day from 2010 to 2019 with respect to the adoption of the Basin Plan shown by the dashed vertical blue line. Please note that all fishways were closed from 2007 to 2010 to prevent seawater ingression due to very low lake levels.

Open Murray Mouth

A permanently open Murray Mouth is critical to the recruitment of congolli and common galaxias (Bice et al. 2018a, 2018b). Adult congolli complete their downstream migration by passing through the Murray Mouth, before ultimately spawning, while juveniles must also pass through the Murray Mouth on their upstream migration (Bice and Zampatti 2017a). While common galaxias spawn in the Coorong, larvae are typically flushed to the ocean and undertake a marine larval phase (although some intra-estuarine development likely occurs in the Coorong), before migrating upstream (Bice et al. 2018a). The Murray Mouth was permanently open over the entire assessment period, from 2006/07 to 2018/19, due to dredging during periods of low flows and constriction. Despite contributing to improvements in system connectivity, it is not considered a primary factor influencing the recruitment of congolli and common galaxias in the CLLMM.

8.5.2 Low abundance of reproductively mature adults

Restored system connectivity in 2010/11 improved recruitment for congolli and common galaxias, however, the abundance of juveniles until 2014/15 were likely limited by the low population of reproductively mature adults (Bice et al. 2019). The abundance of reproductively mature adults may have limited recruitment for congolli and common galaxias until 2014/15. After 2014/15, however, the recruitment index values for both species may have been a function of the degree to which adults could migrate downstream past the barrages during the spawning seasons. For the congolli recruitment index, there was a correlation with the percentage of days when one or more barrage gates were open ('Open Days') over the downstream migration period between May and August (Figure 8-6) (Bice et al. 2019). The geographic spread of open barrage gates (networks) may also be important, however, their impact on subsequent recruitment is difficult to discern due to correlations with the percentage of open gate days across all barrage networks (Figure 8-6).

8.6 Actions to achieve environmental outcomes

To ensure successful recruitment of congolli and common galaxias in future years, it is imperative that bi-directional migration can occur (Bice and Zampatti 2017a; Bice et al. 2019). In order to support downstream migration of congolli and common galaxias, winter flow pulses supported by water for the environment can be delivered to ensure water is available for discharge through open barrage gates (Bice and Zampatti 2017a). Upstream migration of congolli and common galaxias can be supported by the delivery of water, including water for the environment, in spring and summer to enable operation of fishways and contribute to 'attractant flow' through open barrage gates adjacent to fishways to guide migration and maximise their performance (Bice and Zampatti 2017a; Bice et al. 2019). Moreover, there is potential to further promote upstream passage of congolli and common galaxias by opening barrage gates when water levels in Lake Alexandrina and the Murray estuary are very similar and the risk of saltwater ingression to Lake Alexandrina is low (i.e. under high flow conditions) (Bice, personal communication, 26 August 2020; Rumbelow, personal communication, 27 August 2020).

8.7 Conclusion

The recruitment of congolli and common galaxias were virtually certain and likely to have improved over the duration of the assessment period, from 2006/07 to 2018/19. The delivery of water for the environment, recovered through the Basin Plan, has contributed to improved system connectivity that has supported bi-directional migration and facilitated the recruitment of diadromous fish. The recruitment of congolli and common galaxias is expected to be maintained as Basin Plan implementation progresses, through the continued delivery of water to support connectivity through open barrage gates and fishways.

Key messages:

- The recruitment of congolli and common galaxias has improved over the duration of the assessment period, from 2006/07 to 2018/19.
- The delivery of water for the environment, recovered through the Basin Plan, has improved system connectivity, with its delivery helping to maintain open barrage gates in winter and operation of fishways in spring and summer, the key periods for migration for congolli and common galaxias.
- The degree of opportunity for passage of adults between freshwater and estuarine/marine environments during critical winter spawning migrations contributes to strong recruitment of catadromous fish.

- Construction of fishways and dredging of the Murray Mouth have been integral to the enhanced recruitment of diadromous fish in the CLLMM.

9 Small-mouthed hardyhead

9.1 Introduction

Small-mouthed hardyhead are critical to the Coorong foodweb, as an important secondary consumer, particularly in the South Lagoon (Giatas and Ye 2016). They are highly abundant and provide a major food resource for piscivorous fish and waterbirds (Giatas and Ye 2016; Paton et al. 2019a). Due to this importance, the maintenance or improvement of small-mouthed hardyhead abundance and distribution is an essential part of managing the health of the Coorong (Ye et al. 2020a).

Small-mouthed hardyhead are a small-bodied (<100 mm) fish that are distributed in south-eastern Australia (Lintermans 2007). Throughout their range, small-mouthed hardyhead inhabit the lower end of freshwater rivers, brackish lakes and wetlands, estuaries and hypersaline lagoons (Lintermans 2007). Small-mouthed hardyhead are euryhaline and therefore are able to tolerate a wide range of salinities, with a LD_{50} of 3.3 $g.L^{-1}$ to 108 $g.L^{-1}$ in aquaria (Lui 1969), although were recorded in salinities up to 130 $g.L^{-1}$ during the Millennium Drought, from 2001 to 2010, in the Coorong (Noell et al. 2009). Reproduction for small-mouthed hardyhead can be completed within the Coorong estuary and lagoons (Bice et al. 2018), where the species spawns from September to December (Molsher et al. 1994). Small-mouthed hardyhead die following spawning and complete their life span in one year (Molsher et al. 1994).

The high salt tolerance of small-mouthed hardyhead likely provides a competitive advantage in hypersaline waters, as salinities in such environments exceed the osmoregulatory limit of most predatory and competing species (Giatas and Ye 2016; Ye et al. 2018). Although small-mouthed hardyhead were recorded in the Coorong South Lagoon at salinities of up to 130 $g.L^{-1}$, they prefer salinities of 35–100 $g.L^{-1}$ (Noell et al. 2009). Salinities <100 $g.L^{-1}$ help to mitigate impacts to recruitment and maintaining the distribution of small-mouthed hardyhead in the Coorong (Ye et al. 2018). During the peak of the Millennium Drought, salinities in much of the Coorong exceeded the osmoregulatory limit of small-mouthed hardyhead and led to the >50% reduction in its distribution (Wedderburn et al. 2016), which was confined to the North Lagoon and fresher waters within and near Salt Creek (Ye et al. 2020a). The North Lagoon and Salt Creek are therefore important refugia for small-mouthed hardyhead during times of low freshwater inflows.

The abundance of small-mouthed hardyhead in the Coorong is driven by increased flows from the River Murray to the Coorong via barrage outflow. Freshwater flows help to maintain salinity within the preferred salinity range (<100 $g.L^{-1}$) for the small-mouth hardyhead (Noell et al. 2009; Ye et al. 2011; Ye et al. 2015) and enhance productivity and food resource availability (Ye et al. 2020a), with microinvertebrates and nutrients entrained in flow from the River Murray and Lower Lakes transported to the Coorong (Shiel and Tan 2013; Furst et al. 2014). Furthermore, freshwater inflows are critical in establishing salinities and water depths required for *Ruppia tuberosa* to reproduce and be protected from desiccation (Paton et al. 2019b). *R. tuberosa* is an aquatic macrophyte that provides habitat and an egg adhesion substrate for small-mouthed hardyhead. Adhesion of eggs to *R. tuberosa* may enhance egg survival and subsequent recruitment of small-mouthed hardyhead (Molsher et al. 1994).

Predator-prey relationships also influence the abundance of small-mouthed hardyhead in the Coorong. For example, higher than expected abundances recorded after about 2 consecutive low flow years (<1,400 $GL.year^{-1}$) are thought to be associated with an increased in salinities that approach or surpass the osmoregulatory threshold of piscivorous fish, and thereby, limit predation of small-mouthed hardyhead (Ye et al. 2020a).

9.2 Ecological objective, targets and environmental outcomes

The ecological objectives for fish and the ecological targets for small-mouthed hardyhead in the CLLMM as described in the SA River Murray LTWP is presented in Table 9-1 (DEWNR 2015). The additional LTWP target of 'Maintain an average Catch-Per-Unit-Effort (CPUE) of small-mouthed hardyhead sampled in spring/early summer of > 120 for adults, and >800 for juveniles' was not assessed as part of this reporting.

Table 9-1. Ecological objective and target for small-mouthed hardyhead.

Characteristic	Description
Ecological objective	Maintain a spatio-temporally diverse fish community and resilient populations of key native fish species in the lower lakes and Coorong
Ecological target	Maintain the proportional abundance of small-mouthed hardyhead juveniles at >60% in 75% of defined monitoring sites within the CLLMM

The expected environmental outcomes for the extent of small-mouthed hardyhead recruitment in 2019, 2029 and 2042 were determined by elicitation with key experts (Table 9-1). These form the basis of the assessment of small-mouthed hardyhead environmental outcomes in the SA River Murray CLLMM PEA.

Table 9-2. Expected environmental outcomes for extent of small-mouthed hardyhead recruitment in the Coorong in 2019, 2029 and 2042.

Year	Expected environmental outcomes
2019	63% of defined monitoring site in the Coorong will have a proportional abundance of juvenile small-mouthed hardyhead >60% (80% confidence interval of 34–93% sites)
2029	74% of defined monitoring site in the Coorong will have a proportional abundance of juvenile small-mouthed hardyhead >60% (80% confidence interval of 48–92% sites)
2042	63% of defined monitoring site in the Coorong will have a proportional abundance of juvenile small-mouthed hardyhead >60% (80% confidence interval of 38–88% sites)

Over time, it is expected that the extent of recruitment will be maintained between 2019 and 2042 (Table 9-2; Figure 9-1. In 2019, it was expected that 63% of monitoring sites would have a proportional abundance of juvenile small-mouthed hardyhead of >60%.

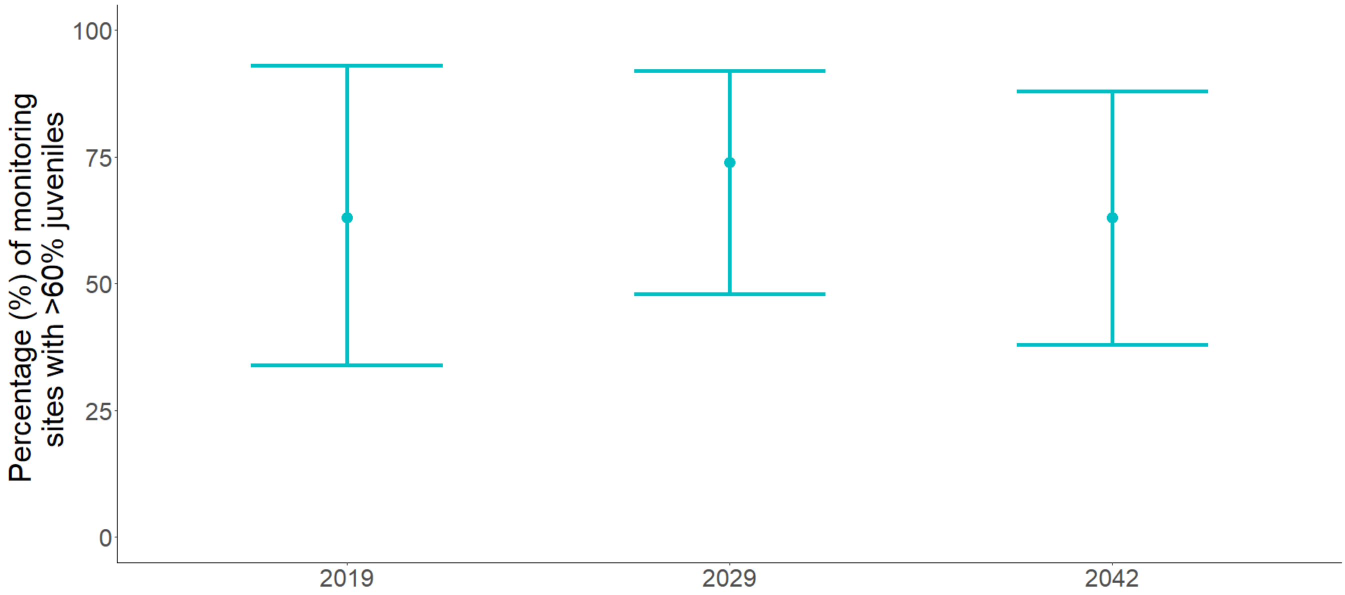

Figure 9-1. Percentage (%) of monitoring sites with >60% juveniles (± 80% confidence limits) in 2019, 2029 and 2042.

9.3 Method

The methodology for small-moutedh hardyhead monitoring followed the 'small-mouthed hardyhead' chapter (Ye et al. 2017) of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and is summarised below.

Sampling independent of fishery catches was conducted between spring and early autumn to quantify the abundance and distribution of small-mouthed hardyhead to assess annual recruitment of juveniles. Small-mouthed hardyhead were sampled at 8 regular sites along the Coorong using a standardised seine net methodology (combined large seine net and small seine net). Large (61 m long) seine nets swept an area of approximately 592 m^2 and small seine nets (8 m long) swept an area of approximately 100 m^2. Large and small seine net sweeps were replicated 3 times (shots) at each site. The number of small-mouthed hardyhead from each net were counted and a random subsample of up to 50 individuals per net measured for Total Length (TL) (mm). Fish ≥40 mm TL sampled in spring/early summer were classified as adults; whereas fish <40 mm TL sampled in late summer/early autumn were classified as juveniles (new recruits). The proportional abundance of juvenile small-mouthed hardyhead was calculated as the number of juveniles divided by the total number of juveniles and adults.

9.3.1 Trend assessment

Trend analysis was undertaken in R Studio (R version 3.5.0, R Core Team 2018) using Bayesian generalised linear mixed models (using the stan-glmer function in the rstanarm package, Goodrich et al. [2020], 4000 runs). Models aimed to determine the likelihood of trend (either positive or negative) in the proportion of defined monitoring sites that had a proportional abundance of juvenile small-mouthed hardyhead >60% over the monitoring program, from 2008/09 to 2018/19. A binomial family was fitted to the model, to assess the proportion of defined monitoring sites that were successful in meeting the conditions of the LTWP target for a given year. The model included time step (the number of years since the inaugural year of monitoring) as a fixed effect and site as a random effect to account for the difference in spatial location of defined monitoring sites.

9.3.2 Condition assessment

The population condition score of small-mouthed hardyhead was assessed using the metrics regarding their relative abundance, recruitment and distribution as per Ye et al. (2020a). The matrix in Table 9-3 was used to align the categories used to describe the population condition of small-mouthed hardyhead for the Trend and Condition report cards.

Table 9-3. Alignment of population condition categories (as per Ye et al. 2020a) with condition classes used for reporting.

Population condition	Condition
Extremely poor	Poor
Very poor	Poor
Poor	Poor
Moderate	Fair
Good	Good
Very Good	Very Good

9.3.3 Information reliability

The information reliability assessments for small-mouthed hardyhead were conducted as per section 3.2.2.

9.4 Limitations of assessment

Caution needs to be taken when interpreting long-term trends using data from 2014/15, 2015/16 and 2018/19 due to discrepancies in sampling methodology and timing. Sampling in 2014/15 only used large seine nets, which may have underestimated the relative proportions of juveniles, since they are caught more effectively by small seine nets (Ye et al. 2018). The extent of recruitment may also have been underestimated in 2015/16 and 2018/19 as adult fish data from late summer/autumn sampling were used rather than from late spring/early summer, which occurred in other years of monitoring (Ye et al. 2020a). As small-mouthed hardyhead spawn in spring/early summer (Molsher et al. 1994), there may have been a tendency to capture fish >40 mm during sampling conducted in late summer/autumn (Ye et al. 2020a).

As part of this assessment and evaluation, it was also assumed that piscivorous fish and waterbirds do not show size selectivity in the predation of small-mouthed hardyhead, i.e. the probability of prey choice was equal for fish total length of <40 mm and ≥40 mm.

9.5 Results

9.5.1 Environmental outcome assesssment

The 2019 expected environmental outcome for small-mouthed hardyhead was met. In 2019, it was expected that 63% of sites would have strong recruitment (Figure 9-1), however, 75% of sites had strong recruitment in 2018/19 (Figure 9-2). Toward the end of the Millennium Drought in 2008/09 and 2009/10, only 20% of sites showed significant recruitment (i.e. >60% of fish were new recruits) (Table 9-4; Figure 9-2). Increased flows from 2010/11 to 2013/14 were associated with significant recruitment at 88–100% of sites. Low flows were recorded in 2014/15 and 2015/16 and were associated with a reduction in recruitment to 63% of sites. With a return to high flows in 2016/17, all sites (100%) recorded significant recruitment. In 2017/18, significant recruitment was maintained at all sites (100%) despite reduced flows. However, in 2018/19 with low flows, the percentage of sites that showed significant recruitment reduced to 75%. As a result, progression towards the achievement of the LTWP has been varied, having been met in 4 (i.e. 2010/11−2013/14 and 2016/17−2017/18) out of the 7 years since the adoption of the Basin Plan.

Results of 2014/15, 2015/16 and 2018/19 should be interpreted with caution due to differences in timing and sampling techniques with respect to other years of sampling (see section 9.4).

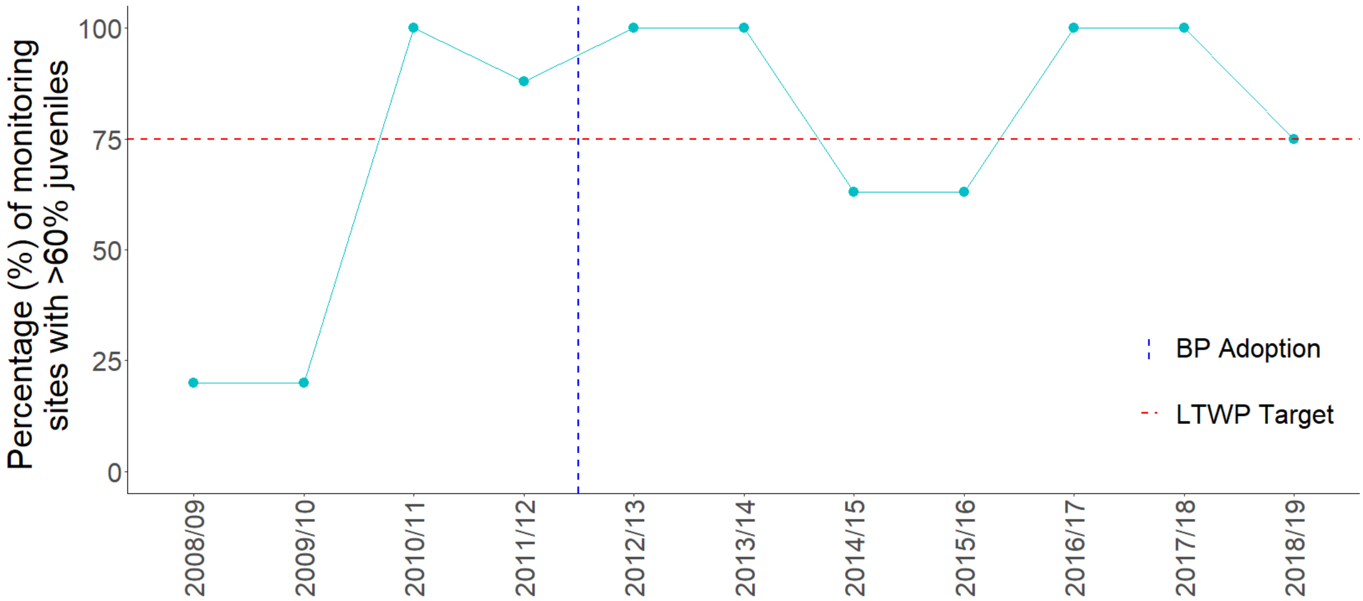

Figure 9-2. Percentage (%) of monitoring sites where the proportional abundance of juvenile small-mouthed hardyhead was >60% from 2008/09 to 2018/19. The LTWP target value is marked by a horizontal dashed red line. The adoption of the Basin Plan is marked by a vertical dashed blue line.

9.5.2 Trend assessment

The proportion of sites with significant recruitment of small-mouthed hardyhead from 2008/09 to 2018/19 was likely (71% likelihood) to be **getting better** (Figure 9-3).

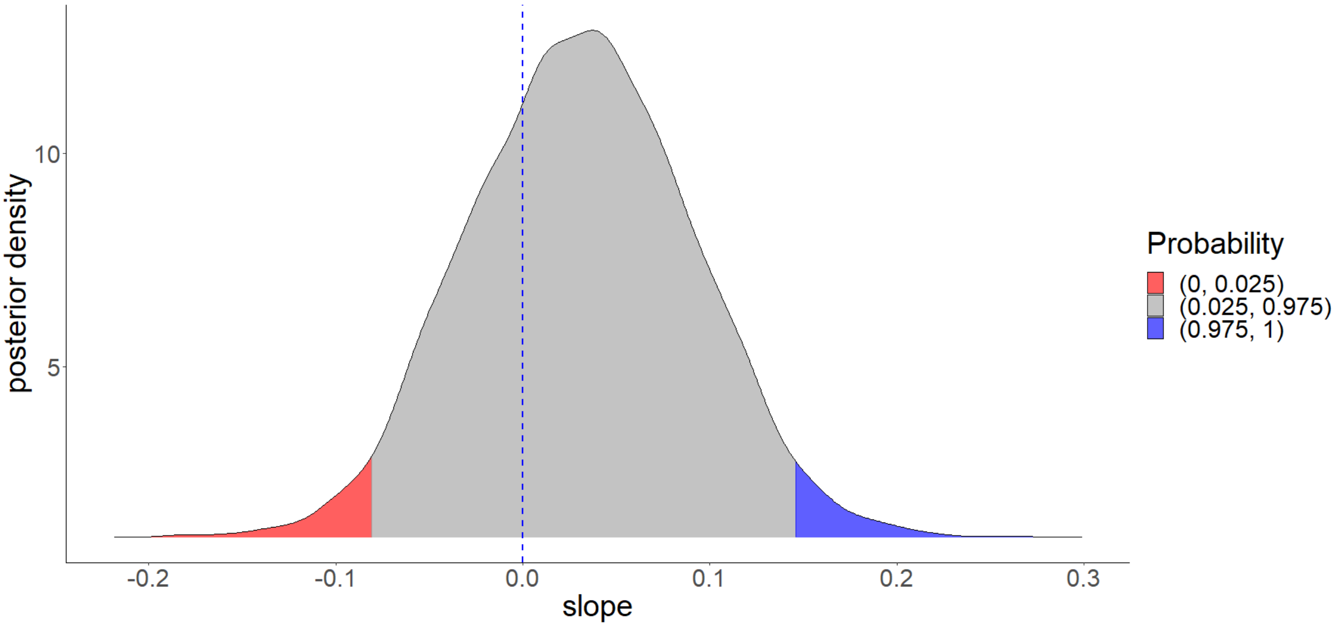

Figure 9-3. Estimated values for the slope generated from Bayesian modelling for the proportion of sites with significant recruitment of small-mouthed hardyhead (i.e. >60% of fish were juveniles) from 2008/09 to 2018/19. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

9.5.3 Condition assessment

The population condition of small-mouthed hardyhead as per Ye et al. (2020a) was moderate in 2018/19 (Table 9-5). Based on the alignment between the condition category as per Ye et al. (2020a) and the condition classes used for this reporting (see section 9.3.2), the condition rating for small-mouthed hardyhead in 2018/19 was **fair**.

Table 9-4. Percentage (%) of juvenile small-mouthed hardyhead in relation to the total abundance across 8 sites in the North and South lagoons of the Coorong from 2008/09 to 2018/19. Note: 2014/15 values are based on large seine net data only; 2015/16 and 2018/19 sampling was conducted in February and March (Ye et al. 2020a).

Year/Site	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19
Mark Point (N1)	100	51	88	50	99	97	88	69	69	81	43
Long Point (N2)			96	67	92	94	19	52	52	86	78
Noonameena (N3)	38	55	91	84	98	74	31	59	59	87	72
Mt Anderson (N4)			100	89	86	90	15	58	58	98	57
Hells Gate (S1)	0	0	97	76	86	94	83	61	61	90	80
Villa de Yumpa (S2)			100	96	79	91	86	94	94	75	90
Jack Point (S3)	-	0	94	94	97	90	63	94	94	97	73
Salt Creek (S4)	0	85	89	89	91	95	79	84	84	100	94
% of sites with significant recruitment	**20**	**20**	**100**	**88**	**100**	**100**	**63**	**63**	**100**	**100**	**75**

Table 9-5. Condition assessment for small-mouthed hardyhead populations in the Coorong from 2008/09 to 2018/19. Scoring system: each index receives 1 point if it is 'yes'. Icon site score: 0 = Extremely Poor, 1 = Very Poor, 2 = Poor, 3 = Moderate, 4= Good and 5 = Very Good (Ye et al. 2020a).

Population indicator	Indices	Condition assessment											Ecological targets (Reference point)
		2008/09 Drought	2009/10 Drought	2010/11 Flood	2011/12 High flow	2012/13 Moderate flow	2013/14 Low flow	2014/15 Low flow	2015/16 Low flow	2016/17 High flow	2017/18 Low flow	2018/19 Low flow	
Relative abundance	CPUE of adults	No	No	No	Yes	No	No	No	*	Yes	No	*	CPUE >120 fish.UE^{-1}
Recruitment	CPUE of juveniles	No	No	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	CPUE >800 fish.UE^{-1}
	Extent of recruitment	No	No	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	>75% of sites with >60% juveniles
Distribution	Adult	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	>87% of sites (i.e. 7 out of 8 sites)
	Juveniles	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	
Icon site score		**0**	**0**	**3**	**5**	**4**	**3**	**2**	**3**	**5**	**3**	**3**	
Small-mouthed hardyhead condition		**Extremely poor**	**Extremely poor**	**Moderate**	**Very good**	**Good**	**Moderate**	**Poor**	**Moderate**	**Very good**	**Moderate**	**Moderate**	

*CPUE of adults data were not comparable to other years of assessment as sampling was conducted in late summer/early autumn rather than spring-early summer.

9.5.4 Information reliability

The information reliability rating for small-mouthed hardyhead sampling was **good** (final score of 10). Justification for the scoring of small-mouthed hardyhead data reliability is provided in Table 9-6.

Table 9-6. Reliability of small-mouthed hardyhead data to assess the expected environmental outcome for small-mouthed hardyhead. The methods used in data collection as well as the representativeness and repetition of sampling were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *Condition Monitoring Plan* (DEWNR 2017)	2
Standard methods	Has the same method been used over the sampling program?	**Somewhat.** The sampling method for small-mouthed hardyhead as presented in the *Condition Monitoring Plan* (DEWNR 2017) were used each year. Sampling in 2014/15 only used large seine nets, which may have underestimated the relative proportions of juveniles, since they are caught more effectively by small seine nets.	1
Representativeness			
Space	Has sampling been conducted across the spatial extent of the studied process or biota within the PEA with equal effort?	**Yes.** Eight sampling sites are evenly spread across the North and South lagoons.	2
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Sampling has been conducted from 2008/09 to 2018/19, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years.	2
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** The same sampling sites have been revisited each year of the monitoring program. It should be noted that 5 sampling sites were established in 2008/09 and a further 3 sites were established in 2010/11.	2
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Somewhat.** Sampling has been conducted annually from 2008/09 to 2018/19 and therefore sampling has	1

Methods	Question	Answer and justification	Score
		been conducted over a range of hydrological conditions. The extent of recruitment may also have been underestimated in 2015/16 and 2018/19 as adult fish data from late summer/autumn sampling were used rather than from late spring/early summer, which occurred in other years of monitoring.	
Final score			**10**
Information reliability			**Good**

9.6 Evaluation

The population condition of small-mouthed hardyhead in the Coorong is primarily driven by freshwater flows and its induced effects on salinity, productivity and habitat availability (Ye et al. 2020a). The absence of barrage outflow from 2007 to 2010 led to salinities during the Millennium Drought exceeding the osmoregulatory threshold of small-mouthed hardyhead throughout much of the South Lagoon of the Coorong (Wedderburn et al. 2016). This subsequently limited the distribution and recruitment of small-mouthed hardyhead to the North Lagoon and fresher waters of Salt Creek and its outlet in the South Lagoon (Ye et al. 2011).

The return of flows following the end of the Millennium Drought and the delivery of water for the environment restored water levels, reduced salinity and enhanced productivity in the Coorong (Ye et al. 2011; Furst et al. 2014). Dredging has helped to maintain an open Murray Mouth which has enabled salt export and also helped to maintain water levels in the Coorong, supporting greater habitat availability for small-mouthed hardyhead. *R. tuberosa* beds started to re-colonise the South Lagoon following extirpation during the Millennium Drought (Paton and Bailey 2012). Such changes to the abiotic and biotic conditions of the Coorong following the high flow events led to significant improvement in the population condition of small-mouthed hardyhead with increased relative abundance, recruitment and a more widespread distribution (Ye et al. 2011; Wedderburn et al. 2016). The population condition of small-mouthed hardyhead has been maintained since the adoption of the Basin Plan in 2012/13, although has fluctuated in response to variability in barrage outflows, declining under low flow and improving following high flow (>5,000 GL.year^{-1}) conditions.

The extent of small-mouthedhardyhead recruitment has fluctuated with freshwater flow similarly to population condition, however, declines were only recorded when low flows persisted for more than one year. Years when the extent of recruitment were low (at or below the LTWP target value) since the adoption of the Basin Plan were associated with changes in the timing and technique for sampling small-mouthed hardyhead that may have under-estimated the proportions of juvenile fish (Ye et al. 2020a). Despite the potential under-estimates of the proportions of juvenile fish in 2014/15, 2015/16 and 2018/19, the proportion of sites with significant recruitment were found to have likely increased over the duration of the assessment period, from 2008/09 to 2018/19. The likely increase in the extent of recruitment for small-mouthed hardyhead over the assessment period were associated with improved barrage outflow (see section 9.6.1) attributed to high (unregulated) flow events and delivery of water for the environment, and were supported by the maintenance of an open Murray Mouth (see 9.6.2) and discharge from Salt Creek (see 9.6.3). Barrage outflow, an open Murray Mouth and discharge from Salt Creek influence salinities, productivity and extent of *R. tuberosa* beds in the Coorong, which in turn, impact the extent of small-mouthed hardyhead recruitment (Q, Ye. Pers. Comm. 2020).

9.6.1 Barrage outflow

High (unregulated) flow events

High (unregulated) flow events increase water levels and decrease salinities in the Coorong and also enhance pelagic productivity (Giatas et al. 2018). These events produced conditions that subsequently benefited small-mouthed hardyhead through the restoration of more favourable salinities (<100 $g.L^{-1}$), improved coverage of habitat (*R. tuberosa* cover) and greater availability of food resources. All of these conditions in turn, increased the distribution and recruitment of small-mouthed hardyhead in the Coorong (Ye et al. 2020a).

High (unregulated) flow events that occurred in 2010/11–2011/12 and 2016/17 freshened the South Lagoon to below 100 $g.L^{-1}$. During the Millennium Drought, extreme hyper-salinity caused the distribution of small-mouthed hardyhead to be restricted to the North Lagoon and fresher waters within and near Salt Creek in the South Lagoon (Ye et al. 2020a). High (unregulated) flow events in 2010/11 restored favourable salinities (<100 $g.L^{-1}$) to the South Lagoon, and subsequently increased the distribution of small-mouthed hardyhead to span both the North and South Lagoons (Ye et al. 2020a). Small-mouthed hardyhead remained present throughout the North and South Lagoons prior to the 2016/17 high (unregulated) flow event as salinities were below their osmoregulatory threshold (~130 $g.L^{-1}$). However, the restoration of salinities to below 100 $g.L^{-1}$ in 2010/11 and 2016/17 is likely to have improved recruitment (Ye et al. 2020a).

The coverage and density of *R. tuberosa,* an aquatic macrophyte, improved as a result of the high (unregulated) flow events in 2010/11–2011/12 and 2016/17 (Paton and Bailey 2012; Paton et al. 2017a). *R. tuberosa* provides not only habitat for small-mouthed hardyhead but also a sessile substrate for egg adhesion (Molsher et al. 1994). This enables eggs to be retained within favourable salinities that promotes egg survival and recruitment (Molsher et al. 1994).

High (unregulated) flow events also enhance pelagic productivity in the Coorong, with microinvertebrates and nutrients entrained in flow from the River Murray and Lakes transported to the terminal lagoon system (Shiel and Tan 2013; Furst et al. 2014; Giatas et al. 2018). Microinvertebrates entering the Coorong likely directly increase the availability of food resources for small-mouthed hardyhead, while stimulation of primary productivity following nutrient inputs may indirectly increase the availability of food resources (Ye et al. 2020a). Therefore, high (unregulated) flow events are important in facilitating greater food resource availability for small-mouthed hardyhead in the Coorong (Ye et al. 2020a).

Water for the environment

Water for the environement supports barrage outflow with its contribution proportionally greater in years of low flow (Stewardson and Guarino 2018, 2019). Water for the environment had the greatest impact on salinities in the Coorong during low flow years, such as 2017/18, when Commonwealth Environmental Water (CEW) comprised 89% of annual barrage outflow (Stewardson and Guarino 2019). Delivery of CEW in 2017/18 was critical to the maintenance of salinities below 100 $g.L^{-1}$ over the Coorong as in its absence up to 40% of the Coorong would have had salinities exceeding 100 $g.L^{-1}$ (Stewardson and Guarino 2019). As salinities above 100 $g.L^{-1}$ exceed the preferred salinity range for small-mouthed hardyhead (Noell et al. 2009; Ye et al. 2011; Ye et al. 2015) and potentially limited recruitment (Ye et al. 2020a), delivery of CEW was likely important in maintaining the distribution and recruitment of small-mouthed hardyhead over the North and South Lagoons. Furthermore, without CEW, it was modelled that an additional 20 million tonnes of salt would have been transported to the Coorong from July 2014 to June 2019 (Ye et al. 2020b). If such volumes of salt had entered the Coorong, salinities would have been comparable to those recorded at the end of the Millennium Drought (Ye et al. 2020b), when small-mouthed hardyhead were almost extirpated from the South Lagoon (Ye et al. 2011; Wedderburn et al. 2016).

9.6.2 Open Murray Mouth

An open Murray Mouth has helped to maintain habitat and salinities in a favourable range for small-mouthed hardyhead in the Coorong. A functional Murray Mouth is critical to the Coorong ecosystem as it enables water levels to be in part maintained by seawater ingression during low flow periods and provides a mechanism for salt export (Webster 2005; Brookes et al. 2009; Kingsford et al. 2009; Higham 2012). Volumes of barrage outflow since the adoption of the Basin Plan have been insufficient alone to maintain a functional Murray Mouth, and therefore, dredging has occurred during prolonged low flow conditions (i.e. 2014/15 to 2015/16 and 2017/18 to 2018/19) to ensure that an open Murray Mouth is present.

9.6.3 Salt Creek flows

Salt Creek and areas near its outlet when in flow provided refugia for small-mouthed hardyhead to persist and recruit during the peak of the Millennium Drought (Ye et al. 2011) when salinities elsewhere in the South Lagoon (up to 166 $g.L^{-1}$) exceeded their osmoregulatory threshold (Wedderburn et al. 2016). Since the adoption of the Basin Plan, extreme hypersalinity has not persisted throughout South Lagoon and therefore there was not the need for refugia at Salt Creek, as evidenced by widespread recruitment in the Coorong. However, localised habitat may have been established near the Salt Creek outlet during or immediately following periods of outflow when prevailing salinities elsewhere at the southern end of the South Lagoon were >100 $g.L^{-1}$.

9.7 Actions to achieve environmental outcomes

Ongoing actions to support maintain and/or improve the resilience of small-mouthed hardyhead populations include the management of barrage outflows and inputs (see section 9.7.1) and the maintenance of an open Murray Mouth to provide system connectivity, enhance system productivity and enable improvements in salinity conditions in the Coorong to support small-mouthed hardyhead recruitment. Although outside of current management influence, periodic high (unregulated) flow events are important and are needed more frequently to enable the maintenance or increase in extent of suitable habitat conditions (particularly following low flow years). High (unregulated) flow events also enhance the productivity in the system, which in turn supports increases in the distribution and recruitment of small-mouthed hardyhead.

9.7.1 Management of barrage outflows and inputs

The maintenance of freshwater flows to the Coorong and salinities below 100 $g.L^{-1}$ are important to maintain the extent of suitable habitat conditions to support small-mouthed hardyhead in the Coorong (Noell et al. 2009; Ye et al. 2011; Ye et al. 2018). The continued support of water for the environment to barrage outflow and maintenance of an open and functional Murray Mouth via dredging has been and will continue to be critical to achieving this environmental outcome, especially in low flow years (Ye Pers. Comm. 2020). In years of drought, discharge from Salt Creek may also play an important role in mitigating the effects of extreme hypersalinity in the South Lagoon and providing refugia for small-mouthed hardyhead (Ye et al. 2011).

For the inter-connected Lakes system, optimisation of lake level regimes should be considered to enhance productivity of freshwater derived biota (Ye et al. 2019). Lake levels may be surcharged throughout winter and spring to 0.8-0.9 m AHD, before discharge in early summer to transport nutrients, phytoplankton and zooplankton to the Coorong (Ye et al. 2019). This may increase the availability of food resources transported within barrage outflows to the Coorong for estuarine fish (Ye et al. 2019), including small-mouthed hardyhead.

9.7.2 Future investigations

Future management of the Coorong will be reviewed as part the Healthy Coorong Healthy Basin (HCHB) Program (DEW 2020). The HCHB Trials and Investigations Project will inform broader HCHB investigations into long-term management solutions (including infrastructure options) to support the health of the Coorong (DEW 2020). The investigations into restoring a functioning Coorong food web (as part of the Trials and Investigations Project) will determine how barrage inflows, flows from Salt Creek and dredging of the Murray Mouth should be managed in order to restore a functioning South Lagoon food web (DEW 2020), of which small-mouthed hardyhead is a critical component (Giatas and Ye 2016).

Measures to increase habitat availability for small-mouthed hardyhead through *R. tuberosa* restoration measures are detailed in section 6.6.

9.8 Conclusion

The implementation of the Basin Plan, including the delivery of water for the environment has contributed to a likely improvement in the extent of significant recruitment for small-mouthed hardyhead in the Coorong. The delivery of water, including water for the environment, has:

- supported the management of barrage outflows that have increased the extent of favourable salinity conditions (i.e. limit salinities exceeding 100 g.L^{-1}, the upper threshold of the preferred salinity range for small-mouthed hardyhead) in the Coorong to support small-mouthed hardyhead populations
- been critical in low flow years in ensuring that impacts to the recruitment and maintenance of the distribution of small-mouthed hardyhead have been mitigated
- increased the spatial and temporal extent of favourable salinity conditions leading to greater habitat availability and a broader distribution of small-mouthed hardyhead in the Coorong.

In future years it is expected that the extent of small-mouthed hardyhead recruitment will be maintained from 2019 as we continue to implement the Basin Plan. The peak benefits for small-mouthed hardyhead populations will likely occur during the next 10 years, due to greater water recovery and through easing of current water delivery constraints.

Key messages:

- The extent of small-mouthed hardyhead recruitment has likely improved from 2008/09 to 2018/19 and it is expected that the extent of recruitment will be maintained as we continue to implement the Basin Plan.
- The implementation of the Basin Plan, including the delivery of water for the environment, has contributed to the increased spatial and temporal extent of salinities within the preferred salinity range (<100 g.L^{-1}) for small-mouthed hardyhead.
- High (unregulated) flow events are important for maintaining or restoring water levels and salinities as well as enhancing productivity in the Coorong, which underpins the distribution and recruitment of small-mouthed hardyhead.

- Dredging has helped to maintain an open Murray Mouth since the adoption of the Basin Plan. An open Murray Mouth is critical to the Coorong ecosystem and maintenance of small-mouthed hardyhead habitat as it provides system connectivity, enhances system productivity and enables improvements in salinity conditions in the Coorong and recruitment of small-mouthed hardyhead.

10 Waterbirds

10.1 Introduction

The Coorong, Lower Lakes and Murray Mouth (CLLMM) Priority Environmental Asset (PEA) supports nationally and internationally significant populations of waterbird species (Paton et al. 2009), which is one of the main reasons for its listing as a Wetland of International Importance under the Ramsar Convention (Paton et al. 2018c). The wetland system supports large numbers of resident (e.g. stilts, avocet, plovers) and migratory shorebirds (e.g. stints, sandpipers), piscivores (e.g. cormorants, pelicans, terns), herbivores (e.g. swans, ducks, swamphen) and generalists (e.g. gulls, egrets, herons) (Paton et al. 2018c, 2019a), with numbers greatest during summer and in drought (Paton 2010; Paton et al. 2018c; Porter et al. 2019). During summer, the Coorong supports twice the number of waterbirds than the Lakes, with an average of 167,000 waterbirds in the Coorong, from 2000 to 2015, in comparison to 79,000 in the Lakes, from 2009 to 2015 (Paton et al. 2018c).

The waterbird communities supported in the Lakes and Coorong differ based on the abiotic (e.g. water level and salinity) and biotic (e.g. vegetation and food resources) characteristics of their habitats (Paton et al. 2015a; Paton et al. 2018c). The Lakes are characterised by freshwater lakes and adjoining wetlands with steep to shallow shorelines and reed beds around their margins, while the Coorong is characterised by estuarine to hypersaline waters that cover vast areas of shallow, gently sloping shorelines where emergent vegetation is absent (Paton et al. 2015a). The key difference between the waterbird communities is that large numbers of resident and migratory shorebirds are supported in the Coorong, whereas relatively small numbers are supported in the Lakes (Paton et al. 2015a; Paton et al. 2018c). The Lakes and Coorong both support large numbers of piscivores, herbivores and generalists, however, the species composition of these guilds differ between the Lakes and Coorong (Paton et al. 2018c). For example, far greater numbers of great cormorants, pied cormorants and pacific black duck use the Lakes, whereas hoary-headed grebes and chestnut teal are more numerous in the Coorong (Paton et al. 2018c). However, certain species such as Australian pelicans and black swan are prominent across both wetlands (Paton et al. 2018c).

The condition of waterbird populations in the CLLMM were assessed each summer, with annual counts having occurred in the Coorong since 2000 and in the Lakes since 2009 (e.g. Paton et al. 2019a). Three key parameters are used to evaluate the condition of waterbird populations in the Lakes and Coorong: abundance, area of occupation (AOO) and extent of occurrence (EOO) (Paton et al. 2017b). These measures of waterbird population condition are likely to be influenced by factors that affect the quantity, quality and accessibility of food and habitat (Paton et al. 2019a), including freshwater flows (Giatas and Ye 2016; Paton et al. 2019a), water levels (Paton et al. 2011b; Paton et al. 2019a), salinity (Paton et al. 2019a) and other water quality factors (i.e. nutrients and excessive growth of filamentous algae) (Paton et al. 2019a). However, factors outside of the CLLMM, including the availability and condition of wetlands over Australia (Porter et al. 2019) and internationally for migratory species (Clemens et al. 2016) are also likely to contribute to variance in the abundance of certain waterbird species between years (Paton et al. 2018c). Similarly, the breeding success of waterbird species at national (Porter et al. 2019) and international scale (for migratory species) (Rogers and Gosbell 2006; Minton et al. 2014) can also likely influence waterbird numbers in the CLLMM each summer (Paton et al. 2018c).

10.2 Ecological objective, targets and environmental outcomes

The ecological objective for CLLMM waterbirds from the SA River Murray LTWP (DEWNR 2015) is presented in Table 10-1. The ecological targets are those within the waterbird chapter of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and are also presented in Table 10-1.

The expected environmental outcomes for abundances, AOO and EOO for waterbirds in the CLLMM in 2019, 2029 and 2042 were determined by elicitation with key experts (Table 10-1).

Outcomes were developed using a subset of target species for assessment (based on target species within the ecological targets) and included 10 species from the Lakes (Table 10-2) and 19 species from the Coorong Table 10-3). The expert elicitation process also allocated the selected waterbird species to guilds (i.e. grouping of birds with similar diets). These expected environmental outcomes form the basis of the assessment of waterbird environmental outcomes in the SA River Murray CLLMM PEA.

Table 10-1. Ecological objectives of the SA River Murray LTWP for CLLMM waterbirds (DEWNR 2015), ecological targets are those within the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017) and the environmental outcomes are those developed for this assessment.

Characteristic	Description
Ecological objective	Maintain or improve waterbird populations in the Coorong and Lakes
Ecological targets	Exceed the recent (2013–2015) median value for abundance of each of 25 selected waterbird species in the Lakes in 2 of the last 3 years
	Exceed the lower 75% threshold for the recent (2013–2015) AOO for each of 25 selected waterbird species in the Lakes.
	Exceed the lower 75% threshold for the recent (2013–2015) EOO for each of 25 selected waterbird species in the Lakes.
	Exceed the long-term (2000–2015) median value for abundance of each of 40 selected waterbird species in the Coorong in 2 of the last 3 years.
	Exceed the 75% threshold for the long-term (2000–2015) AOO for each of 40 selected waterbird species in the Coorong.
	Exceed the 75% threshold for the long-term (2000–2015) EOO for each of 40 selected waterbird species in the Coorong
Environmental outcomes	Exceed the recent (2013–2015) median value for abundance of selected waterbird species within each guild in the Lakes in 2 of the last 3 years
	Exceed the 75% threshold for the recent (2013–2015) AOO for each selected waterbird species within each guild in the Lakes
	Exceed the 75% threshold for the recent (2013–2015) EOO for each selected waterbird species within each guild in the Lakes
	Exceed the long-term (2000–2015) median value for abundance of each selected waterbird species within each guild in the Coorong in 2 of the last 3 years
	Exceed the 75% threshold for the long-term (2000–2015) AOO for each selected waterbird species within each guild in the Coorong.
	Exceed the 75% threshold for the long-term (2000-2015) EOO for each selected waterbird species within each guild in the Coorong.

Table 10-2. Lakes waterbird species grouped by guild that were assessed.

Scientific name	Common name	Guild
Phalacrocorax varius	pied cormorant	Piscivores
Phalacrocorax carbo	great cormorant	
Pelecanus conspicillatus	Australian pelican	
Chlidonias hybrida	whiskered tern	
Cygnus atratus	black swan	Herbivores
Anas superciliosa	Pacific black duck	
Porphyrio porphyrio	purple swamphen	
Threskiornis spinicollis	straw-necked ibis	Generalists
Threskiornis moluccus	white ibis	
Platalea regia	royal spoonbill	

Table 10-3. Coorong waterbird species grouped by guild that were assessed.

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

*Captured in both the piscivore and migratory shorebird guilds.

10.3 Method

Annual waterbird censuses of the Lakes and Coorong are led by the University of Adelaide (Associate Professor David Paton). The census in the Coorong and Lakes are conducted in January and late January/early February, respectively. The methodology of the annual waterbird census of the Lakes and Coorong are detailed in Paton et al. (2017b) and summarised below.

10.3.1 Lakes method

The shoreline of Lake Alexandrina, Lake Albert and Goolwa Channel were divided into 1 km × 1 km cells. Within each 1 km^2 cell, the number of waterbirds present were recorded by surveyors on foot or by boat.

10.3.2 Coorong method

The Coorong and the Murray estuary was divided into 1 km sections that run perpendicular to the wetland direction. Within each 1 km section, waterbirds are counted on the eastern and western shorelines, around islands and over open water in the centre of the wetland. Waterbird counts in each 1 km section are conducted by a minimum of 2 surveyors on foot or by boat.

10.3.3 Trend assessment

Trend analysis was undertaken in R Studio (R version 3.5.0, R Core Team 2018) using Bayesian Generalized Linear Mixed Models (using the stan-glmer function in the rstanarm package, Goodrich et al. [2020], 4000 runs). Models aimed to determine the likelihood of trend (either positive or negative) in the abundance of selected species in both the Lakes and Coorong. Further models were run to determine the trend in abundance of selected species within each guild analyses in the Lakes and Coorong. The waterbird community model included time step (the number of years since the inaugural year of monitoring) as a fixed effect and species as a random effect (allowing species to have different slopes as well as intercepts), while the guild model included an interaction effect between time step and guild and included species as a random effect (again allowing different slopes).

10.3.4 Condition assessment

The condition assessment for the waterbirds in the Lakes and Coorong in 2019 was based upon the proportion of selected waterbird species from each guild that met their respective ecological targets for abundance, AOO and EOO during the annual census in early summer 2019 (see Paton et al. 2019a). Alignment of condition classes used for South Australian Trend and Condition Report Cards with the proportion of selected species from each guild meeting their Abundance, AOO and EOO targets is shown in Table 10-4, and were based on expert opinion. The alignment of results with Table 10-4 should start at 'Poor' and work up to 'Very good' until one of the target criteria are triggered, i.e. only one target (Abundance, AOO or EOO) needs to be reflective of a particular condition class for it to be triggered. This is done for each guild, and the guild with the lowest condition class is used to reflect the condition of the waterbird community as a whole.

Table 10-4. Alignment of condition classes used for Report Cards with the proportion of selected species from each waterbird guild meeting their respective Abundance, AOO and EOO targets.

Condition class	Abundance	AOO	EOO
Very good	1.00	1.00	1.00
Good	≥0.66–0.99	≥0.66–0.99	1.00
Fair	≥0.50–0.65	≥0.66–0.99	≥0.66–0.99
Poor	<0.50	<0.66	<0.66

10.3.5 Information reliability

The information reliability assessments for the waterbird communities of the Lakes and Coorong were conducted as per section 0.

10.4 Results

10.4.1 Lakes Environmental Outcome Assessment: Abundance

To meet this outcome all selected species from each guild had to exceed their recent (2013–2015) median abundance in 2 of the last 3 years (i.e. 2017–2019). The environmental outcome was not met in 2019, as the proportion of selected species from the herbivore and piscivore guilds was below 1.00 (Figure 10-1), meaning that selected species from these guilds did not exceed their recent (2013–2015) median abundance in 2 of the last 3 years as shown in Figure 10-2. Since the adoption of the Basin Plan, progression towards the achievement of the LTWP target has varied, the proportion of selected species that met their abundance targets increased for generalists and herbivores from 2013 to 2019, while piscivores improved from 2013 to 2016 and then declined from 2016 to 2019. The abundances of selected species from each guild over the assessment period (2009–2019) are shown in Figure 10-2.

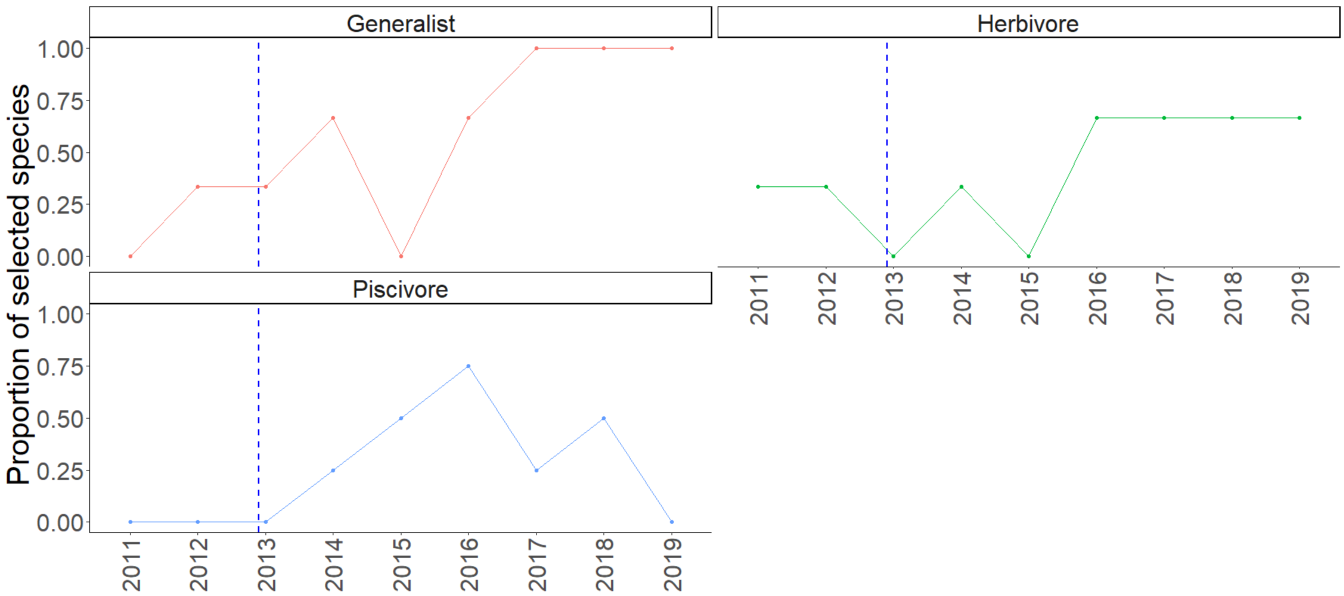

Figure 10-1. The proportion of selected species within each guild that were at or above their recent (2013–2015) median abundance in 2 of the last 3 years in the Lakes from 2011 to 2019. The adoption of the Basin Plan (November 2012) is shown by the vertical dashed blue line.

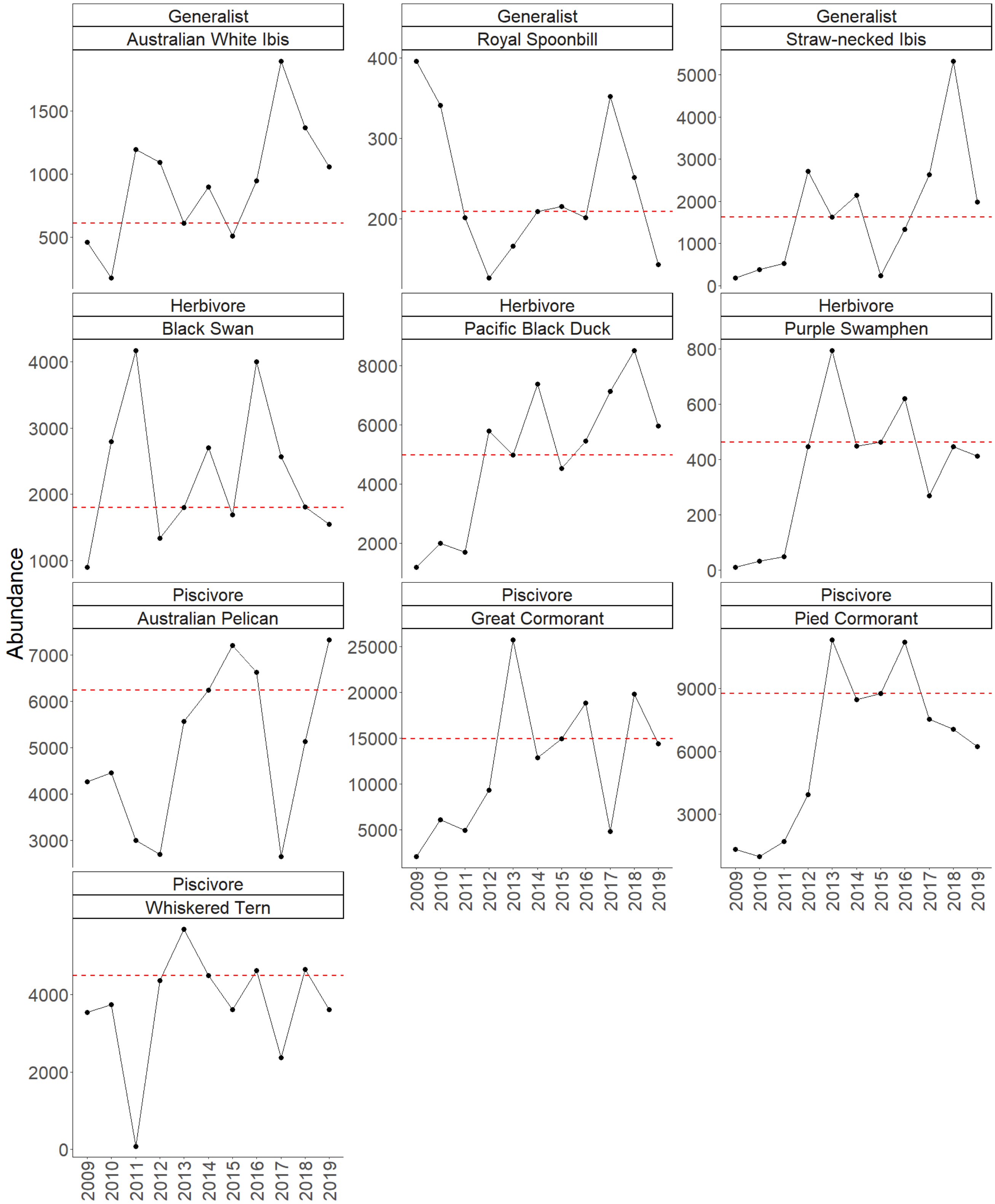

Figure 10-2. Abundance of selected waterbird species during annual late January/early February census' over the Lakes from 2009 to 2019 with reference to the recent (2013–2015) median abundance of each species (horizontal red dashed line). Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.2 Trend assessment: Abundance

The abundance of selected species in the Lakes waterbird community over the assessment period (2009–2019) were virtually certain (99% likelihood) to have increased (Table 10-5; Figure 10-3). There were similarities in the trends between guilds, with the abundance of selected species from the piscivore guild very likely (92% likelihood) to have increased, while it is was likely that selected species from the generalist (88% likelihood) and herbivore (89% likelihood) guilds have increased (Figure 10-4).

Table 10-5. Outcomes from the Bayesian modelling assessment of trend for all selected species and selected species within the piscivore, omnivore and herbivore guilds. The likelihood of improvement in annual late January/early February census counts of selected species within each guild and as a whole in the Lakes are provided in addition to their associated confidence rating (as per Mastrandrea et al. 2010). The Report Card trend category was aligned with the confidence rating (Table 3-2).

Guild/group	Outcome	Likelihood of outcome	Report card category
All selected species	Virtually certain increase	99%	Getting better
Piscivore	Very likely increase	92%	Getting better
Generalist	Likely increase	88%	Getting better
Herbivore	Likely increase	89%	Getting better

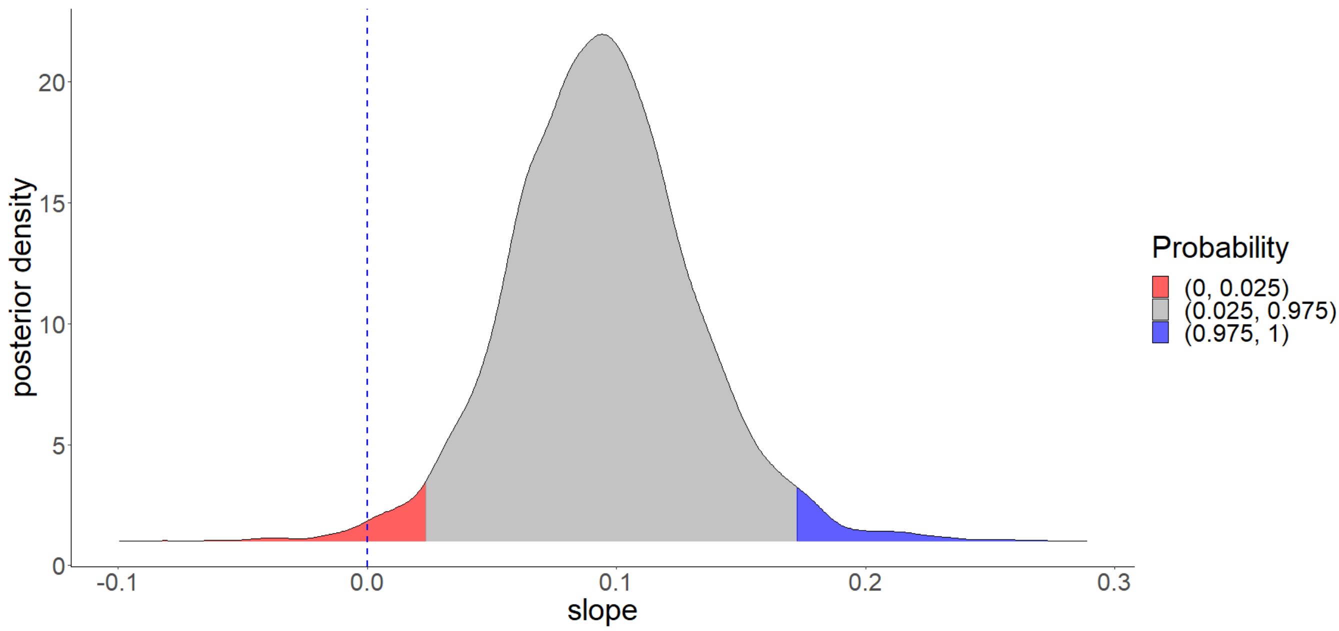

Figure 10-3. Estimated values for the slope generated from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species in the Lakes from 2009 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

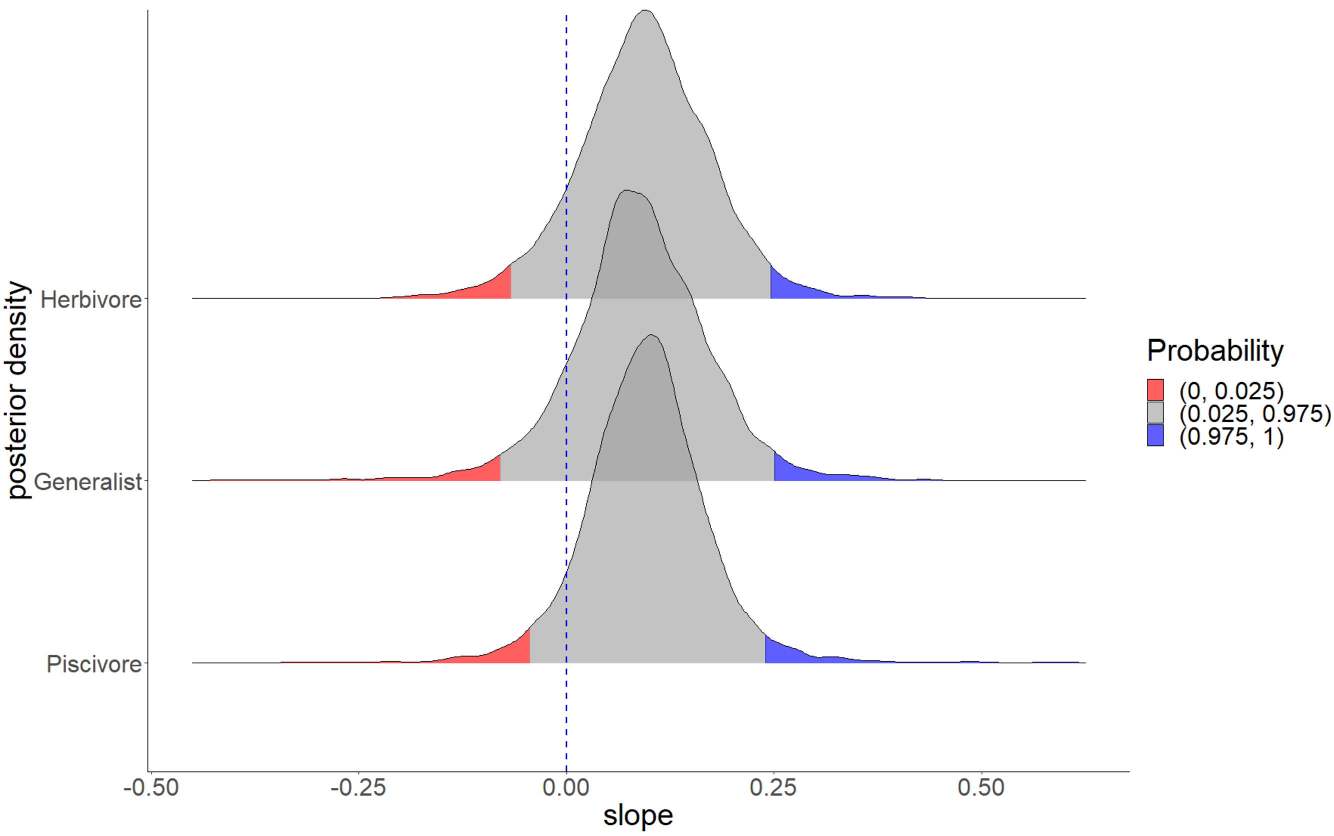

Figure 10-4. Estimated values for the slope generated from Bayesian modelling for the annual late January/early February census counts of all selected waterbird species from the piscivore, omnivore and herbivore guilds in the Lakes from 2009 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

10.4.3 Lakes Environmental Outcome Assessment: Area of Occupation (AOO)

To meet this outcome all selected waterbird species from each guild had to exceed their recent (2013–2015) 75% threshold for AOO. The environmental outcome was met in 2019, as all selected waterbird species from the generalist, herbivore and piscivore guilds exceeded their respective 75% AOO thresholds as shown in Figure 10-5.

Since the adoption of the Basin Plan, some progression towards the achievement of the LTWP has been made, with all selected species from all guilds having met their respective AOO targets in all but one year (Figure 10-5). In 2015, one selected generalist species (royal spoonbill) failed to meet its AOO target, while in 2017, one selected species (purple swamphen) from the herbivore guild and 2 selected species (Australian pelican and whiskered tern) from the piscivore guild failed to meet their AOO targets. The AOO of each selected species from 2009–2019 are shown in Figure 10-6.

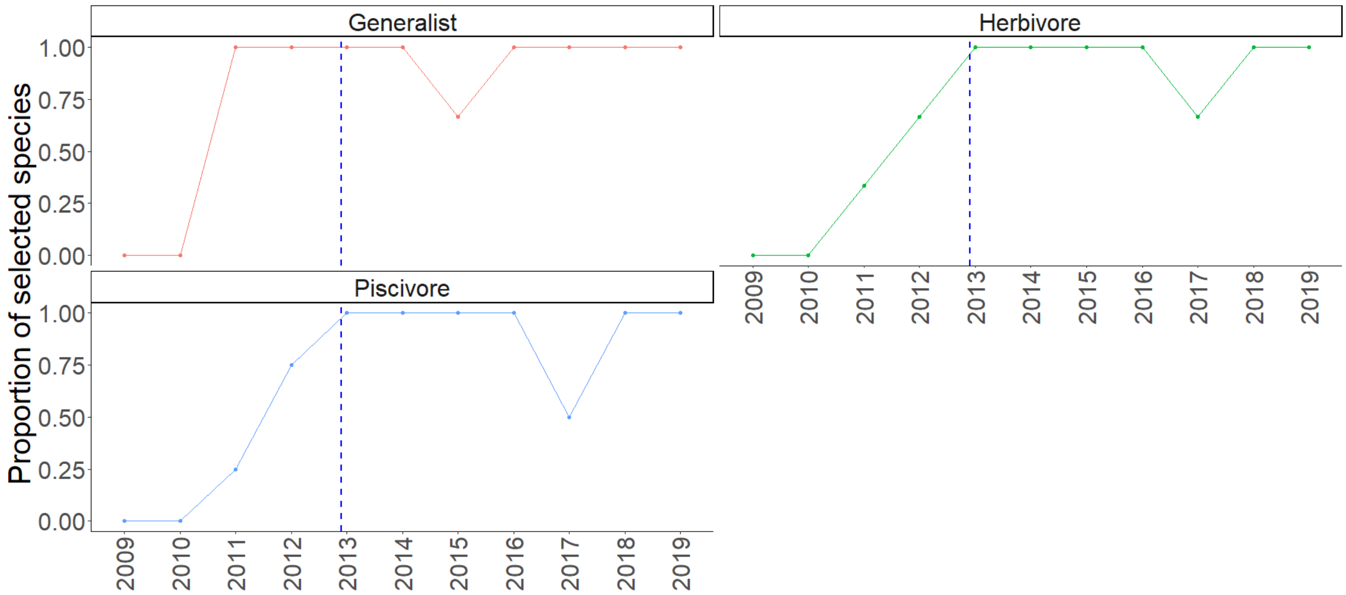

Figure 10-5. The proportion of selected species within each guild exceeded their respective recent (2013–2015) 75% thresholds for area of occupation (AOO). The adoption of the Basin Plan (November 2012) is shown by the vertical dashed blue line.

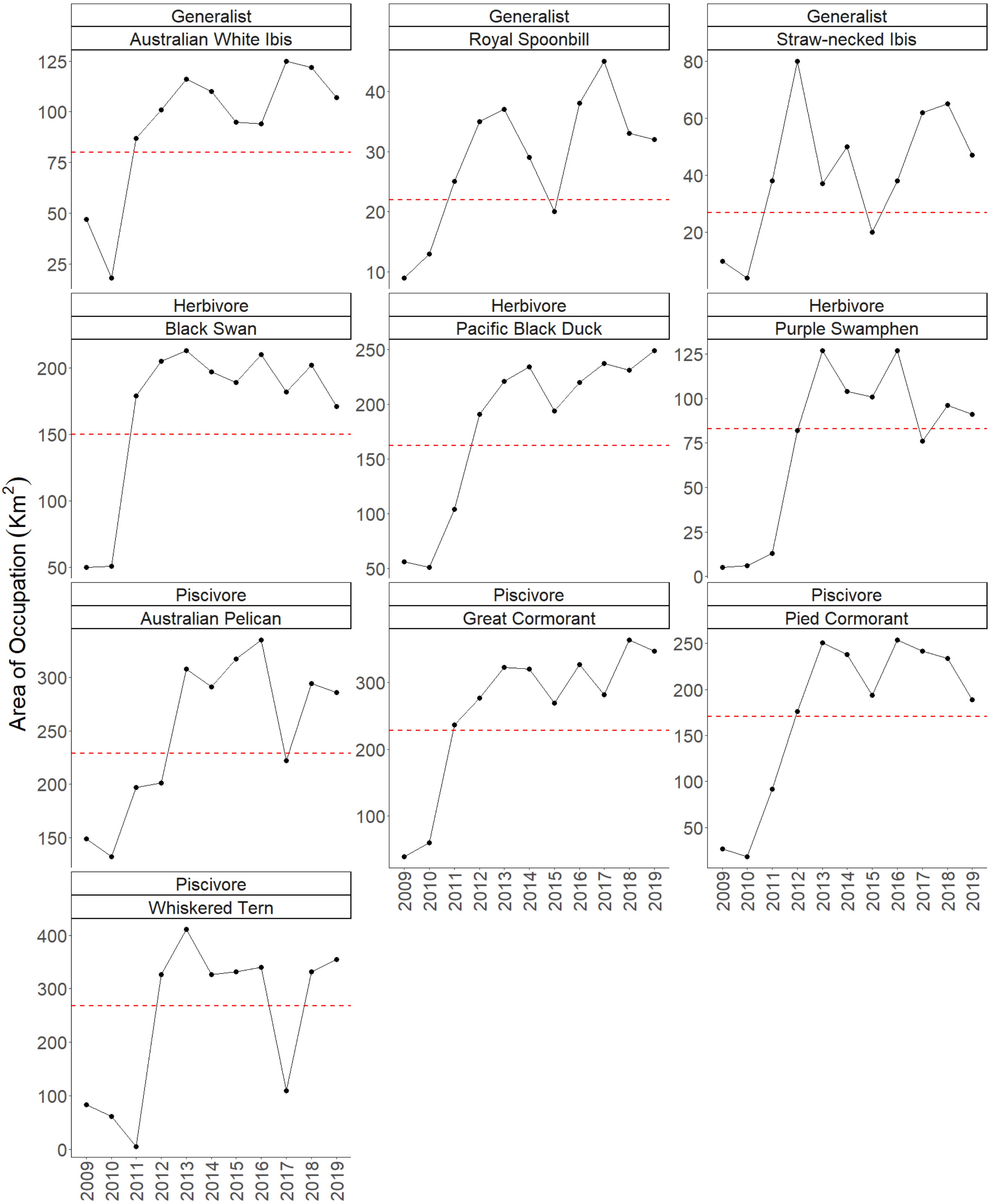

Figure 10-6. Area of occupation (AOO) (km2) of selected waterbird species during annual late January/early February census' over the Lakes from 2009 to 2019 with reference to the recent (2013–2015) 75% thresholds for AOO for each species (horizontal red dashed Line). Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.4 Lakes Environmental Outcome Assessment: Extent of Occurrence (EOO)

To meet this outcome all selected waterbird species from each guild had to exceed their recent (2013–2015) 75% threshold for EOO. The environmental outcome was met in 2019, as all selected species from the herbivore guild exceed their respective 75% threshold for long-term EOO for a given year (Figure 10-7).

Since the adoption of the Basin Plan, some progression towards the achievement of the LTWP target has been made (Figure 10-7). All selected species from the herbivore guild exceeded their respective EOO targets in all years since the adoption of the Basin Plan (Figure 10-7). All selected species from the piscivore guild met their respective EOO targets in all years since the adoption of the Basin Plan, except for 2017, when the EOO target for whiskered tern was not met. Similarly, all selected species from the generalist guild met their respective EOO targets in all years since the adoption of the Basin Plan, except for 2018, when the EOO target for royal spoonbill was not met. The EOO of each selected species from 2009 to 2019 are shown in Figure 10-8.

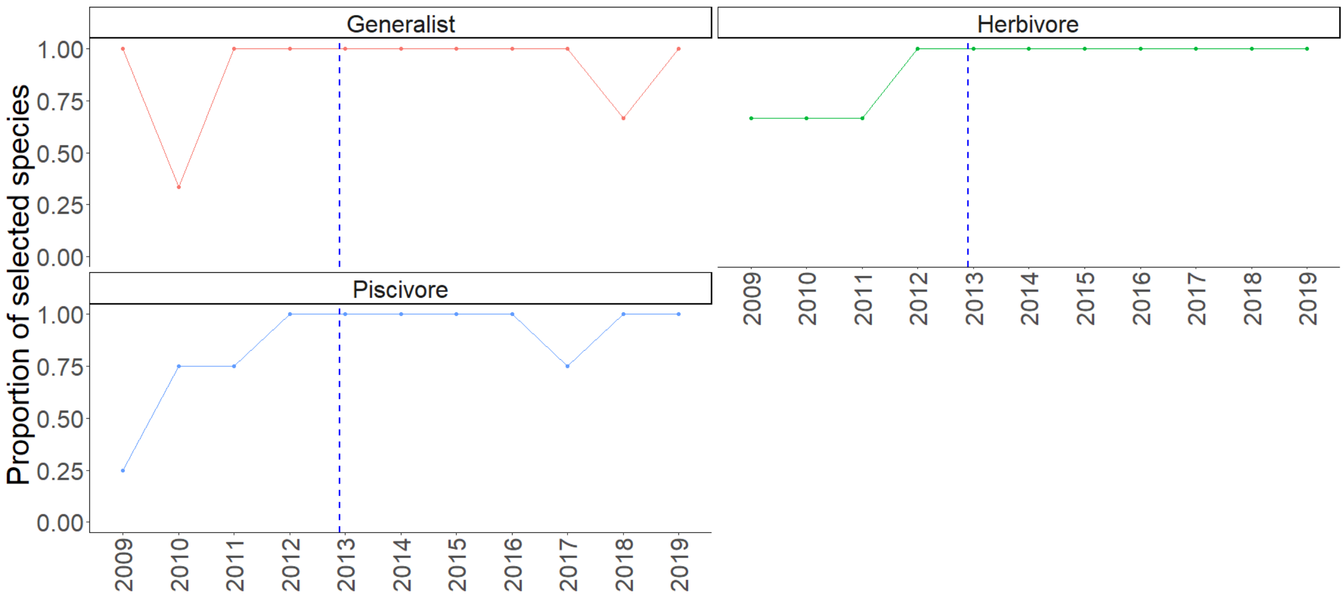

Figure 10-7. The proportion of selected species within each guild exceeded their respective long term 75% thresholds for extent of occurrence (EOO). The adoption of the Basin Plan (November 2012) is shown by the vertical dashed blue line.

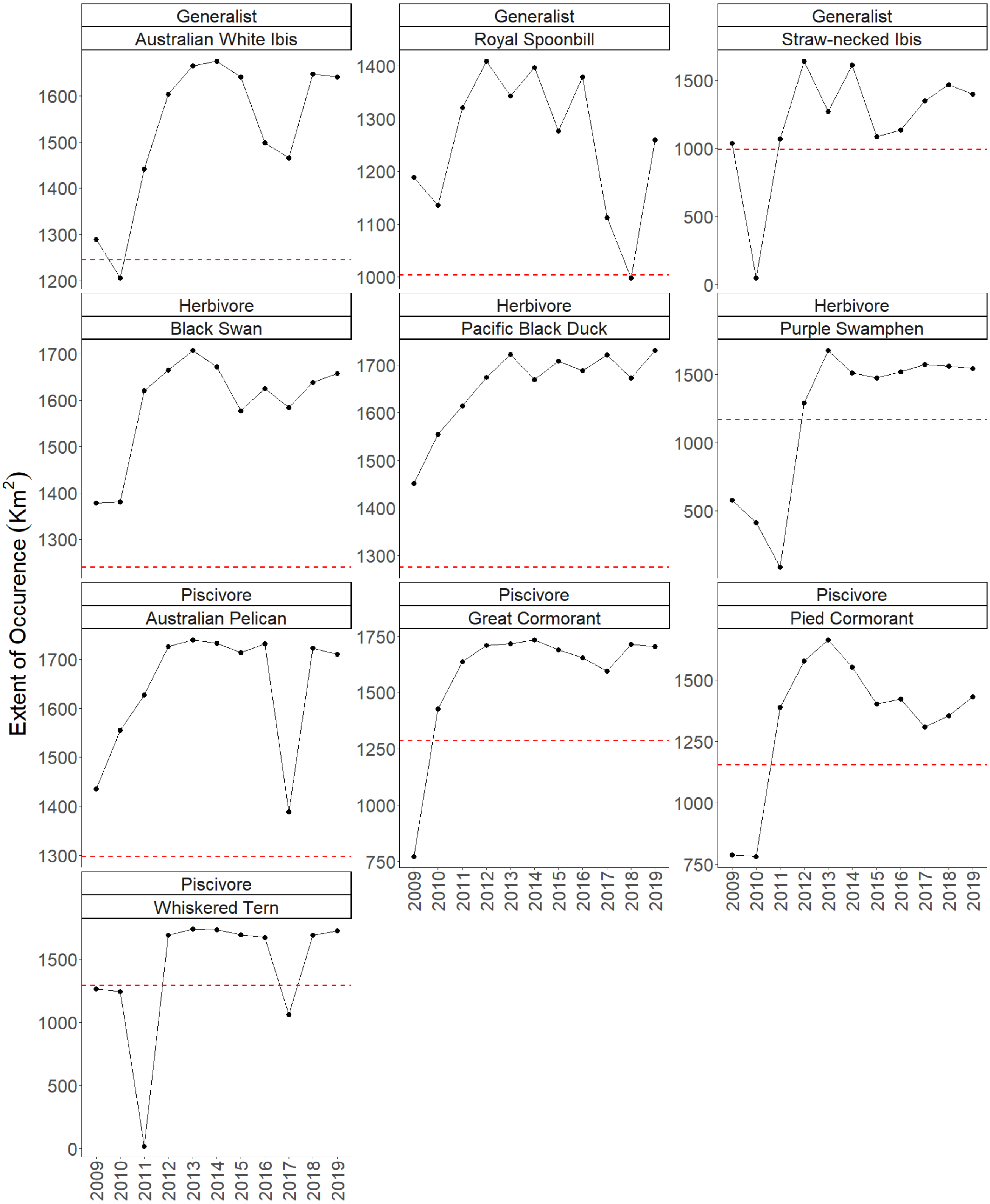

Figure 10-8. Extent of occurrence (EOO) (km2) of selected waterbird species during annual late January/early February census' over the Lakes from 2009 to 2019 with reference to the recent (2013-2015) 75% thresholds for EOO for each species (horizontal red dashed line). Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.5 Condition assessment

The condition of the Lakes waterbird community in 2019 is considered to be **poor**. The criteria for poor was triggered as all selected piscivorous species failed to exceed their short-term (2013-2015) median abundance in 2 of the last 3 years. Although, all selected species from all guilds met their respective targets for AOO and EOO in 2019.

10.4.6 Coorong Environmental Outcome Assessment: Abundance

To meet this outcome all selected waterbird species from each guild had to exceed their long-term (2000–2015) median value for abundance of each in 2 of the last 3 years (i.e. 2017–2019). The environmental outcome was not met in 2019, as the proportion of selected species from all guilds except for generalists was below 1.00 (Figure 10-9), meaning that some selected species from all other guilds did not exceed their long-term (2000–2015) median abundance in 2 of the last 3 years as shown in Figure 10-10.

Since the adoption of the Basin Plan, progression towards the achievement of the LTWP target has varied, with the proportion of selected species that have met their respective abundance targets increased for piscivores; remained stable for generalists, herbivores and resident shorebirds; and fluctuated greatly for migratory shorebirds (Figure 10-9). The abundances of selected waterbird species from each guild over the monitoring program (2000–2019) are shown in Figure 10-10.

Figure 10-9. The proportion of selected species within each guild that exceeded their long-term median abundance in 2 of the last 3 years in the Coorong from 2002 to 2019. The adoption of the Basin Plan (November 2012) is shown by the vertical dashed blue line.

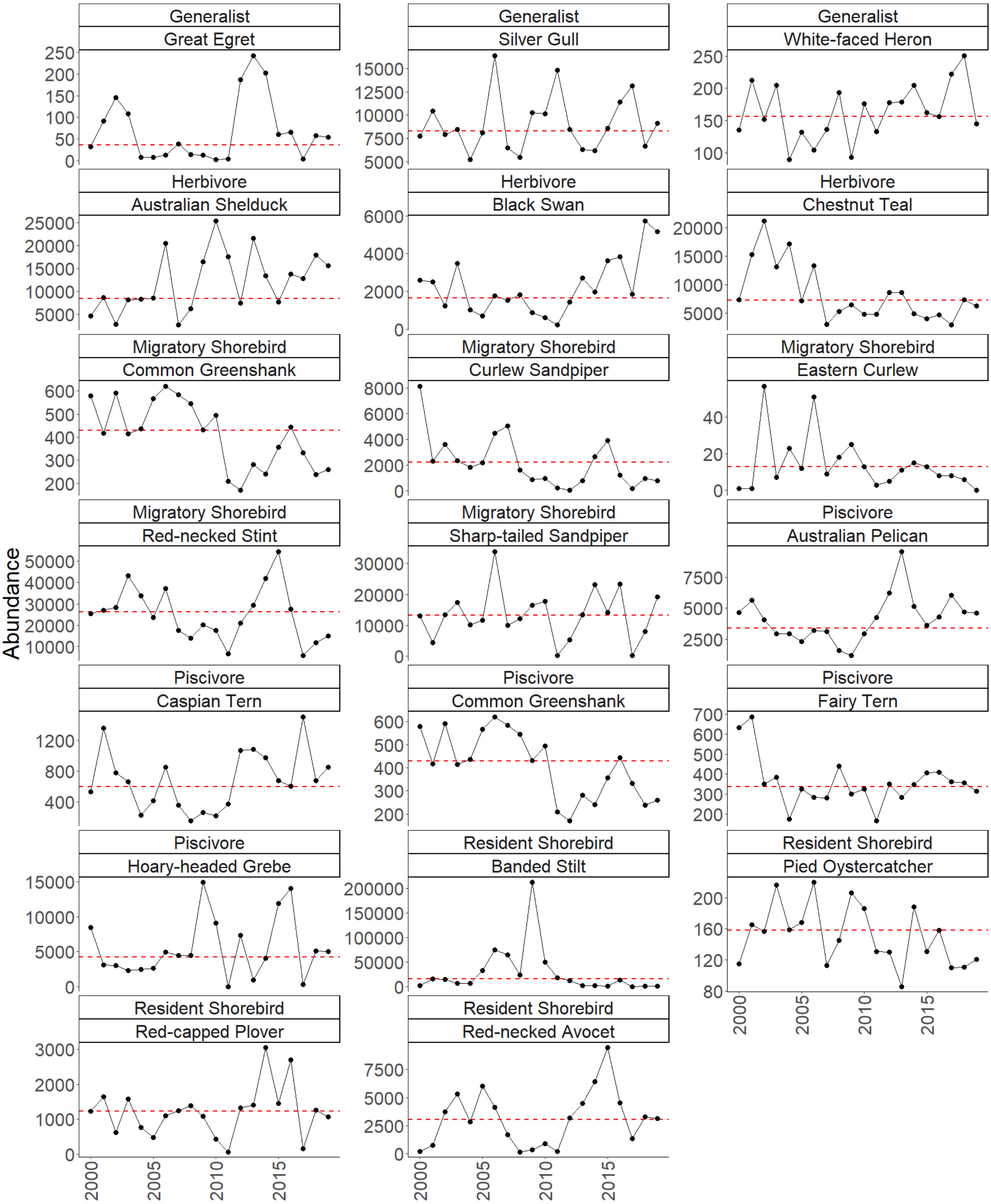

Figure 10-10. Abundance of selected waterbird species during annual January census over the Coorong from 2000 to 2019 with reference to the long-term (2010–2015) median abundance of each species (horizontal red dashed line). Note: to meet the ecological target, selected species must exceed their recent median abundance value in 2 of the last 3 years. Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.7 Trend assessment: Abundance

The abundance of selected species in the Coorong waterbird community over the monitoring program (2000-2019) were determined to have likely (75% likelihood) decreased (Table 10-6; Figure 10-11). However, there is significant variation in the trends between guilds. It is extremely likely (96% likelihood) and likely (68% likelihood) that selected species from the migratory and resident shorebirds have declined in abundance, while it is about as likely as not (51% likelihood) that selected species from piscivores have declined in abundance (Table 10-6; Figure 10-12). Conversely, it is likely that selected species from the generalist (69% likelihood) and herbivore (63% likelihood) guilds have increased in abundance. Caution needs to be taken when interpreting these trends as part of the assessment period included years within the Millennium Drought (i.e. 2002 to 2010), and therefore, a stable or increasing trend from 2000 to 2019 should be relatively easy to achieve.

Table 10-6. Outcomes from the Bayesian modelling assessment of trend for all selected species and selected species within the resident shorebird, piscivore, omnivore, migratory shorebird and herbivore guilds. The likelihood of improvement in annual January census counts of selected species within each guild and as a whole in the Coorong are provided in addition to their associated confidence rating (as per Mastrandrea et al. 2010). The Report Card trend category was aligned with the confidence rating (Table 3-2).

Guild/group	Outcome	Likelihood of outcome	Report card category
All selected species	Likely decrease	75%	Getting worse
Resident shorebird	Likely decrease	68%	Getting worse
Piscivore	About as likely as not to decrease	51%	Stable
Generalist	Likely increase	69%	Getting better
Migratory shorebird	Extremely likely decrease	96%	Getting worse
Herbivore	Likely increase	63%	Getting better

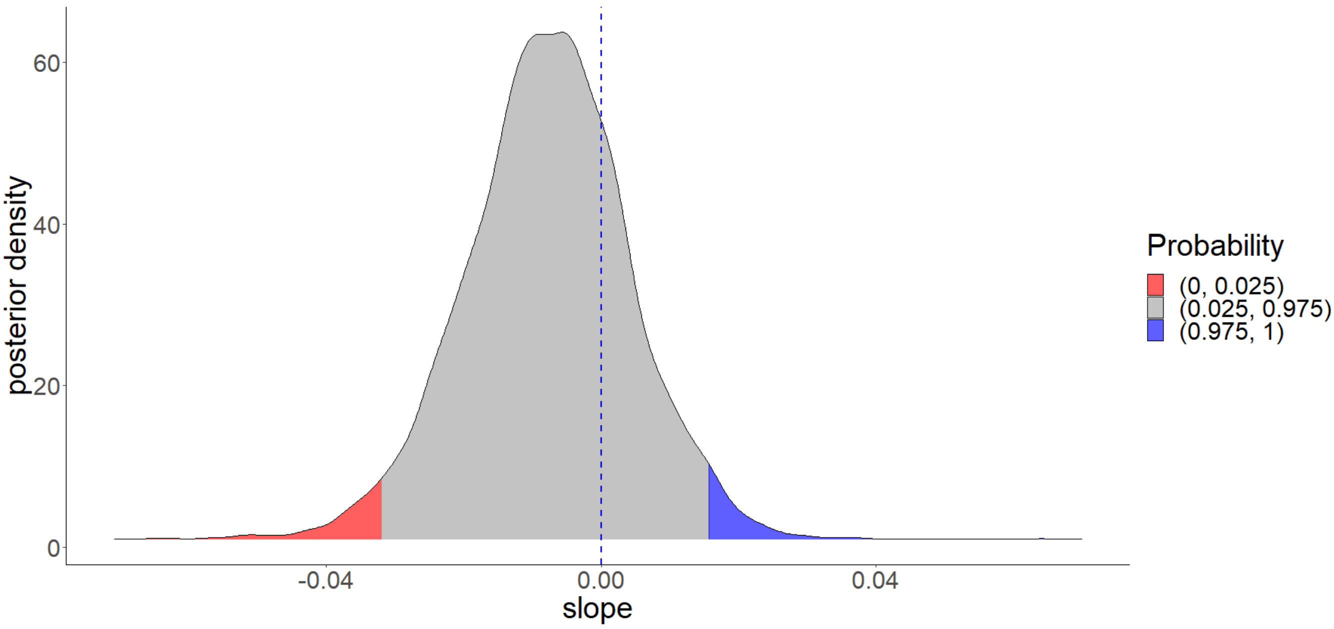

Figure 10-11. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species in the Coorong from 2000 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

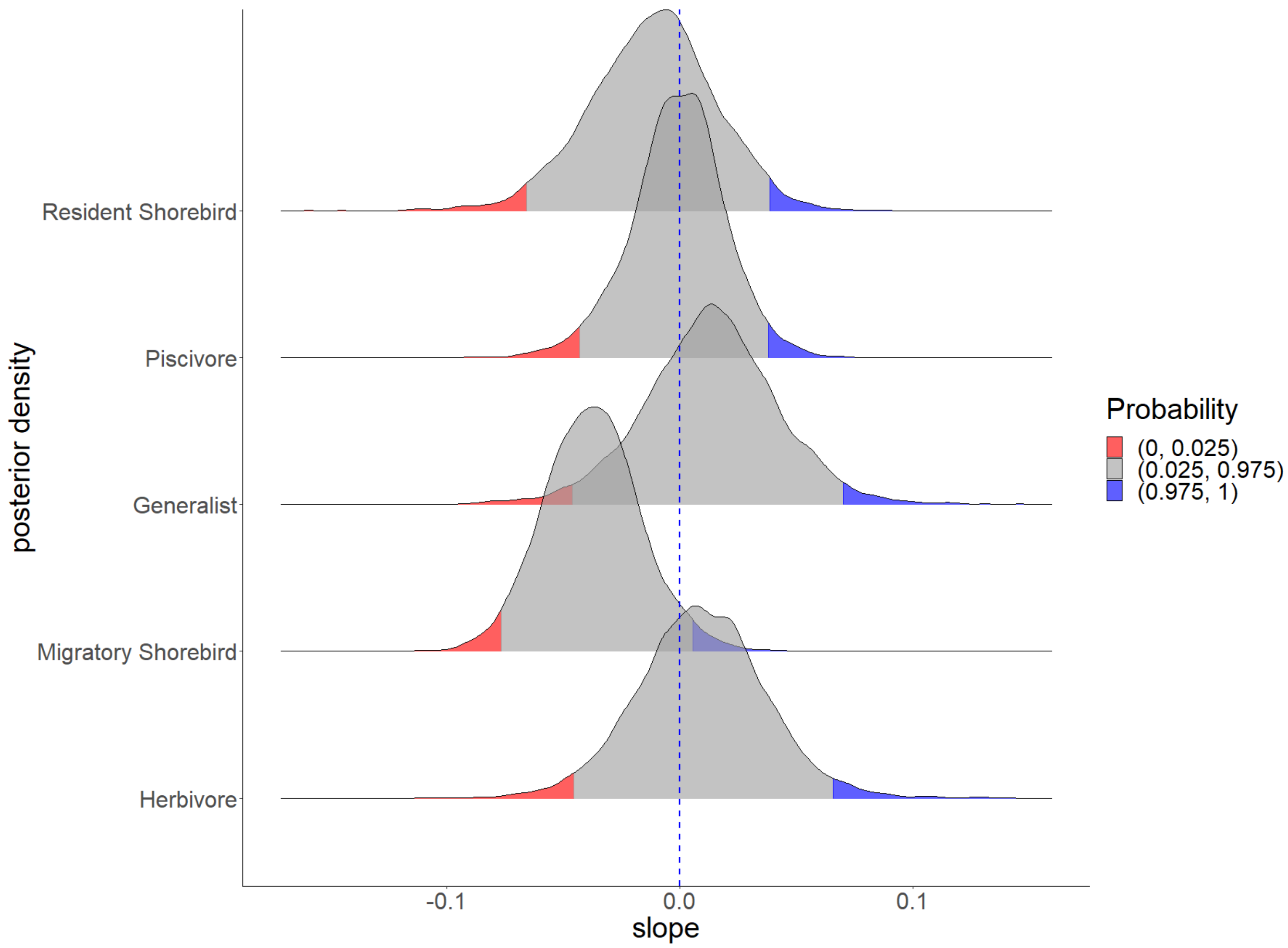

Figure 10-12. Estimated values for the slope generated from Bayesian modelling for the annual January census counts of all selected waterbird species from the resident shorebird, piscivore, omnivore, migratory shorebird and herbivore guilds in the Coorong from 2000 to 2019. Posterior slope values >0 infer a positive trend (getting better) and values <0 infer a negative trend (getting worse).

10.4.8 Condition assessment

The condition of the Coorong waterbird community in 2019 was considered to be **poor**. The criteria for poor was triggered as all selected migratory shorebird species failed to exceed their long-term (2000–2015) median abundance.

10.4.9 Coorong Environmental Outcome Assessment: Area of Occupation (AOO)

To meet this outcome all selected waterbird species from each guild had to exceed their long-term (2000–2015) 75% thresholds for AOO. The environmental outcome was not met in 2019, as not all selected species from the migratory shorebird and resident shorebird guilds exceeded their respective 75% AOO (Figure 10-13) as shown in Figure 10-14.

Since the adoption of the Basin Plan, progression towards the achievement of the LTWP target has varied, with all guilds, except for herbivores have had one or more selected species that have failed to exceed their respective AOO targets (Figure 10-13). From 2013–2015, a maximum of one selected species per guild did not meet their AOO target for a given year. The proportion of selected species in the migratory shorebird guild that met their AOO targets reduced greatly in 2016. Likewise, the proportion of selected species in the piscivore and resident shorebird guilds that met their AOO target reduced greatly in 2017. Proportions of selected species that met their AOO target increased for all guilds from 2017–2019, although only half of selected resident shorebirds met their AOO targets in 2018 and 2019. The AOO of each selected species from 2000–2019 are shown in Figure 10-14.

Figure 10-13. The proportion of selected species within each guild that exceeded their respective long term 75% thresholds for area of occupation (AOO). The adoption of the Basin Plan (November 2012) is shown by the vertical dashed blue line.

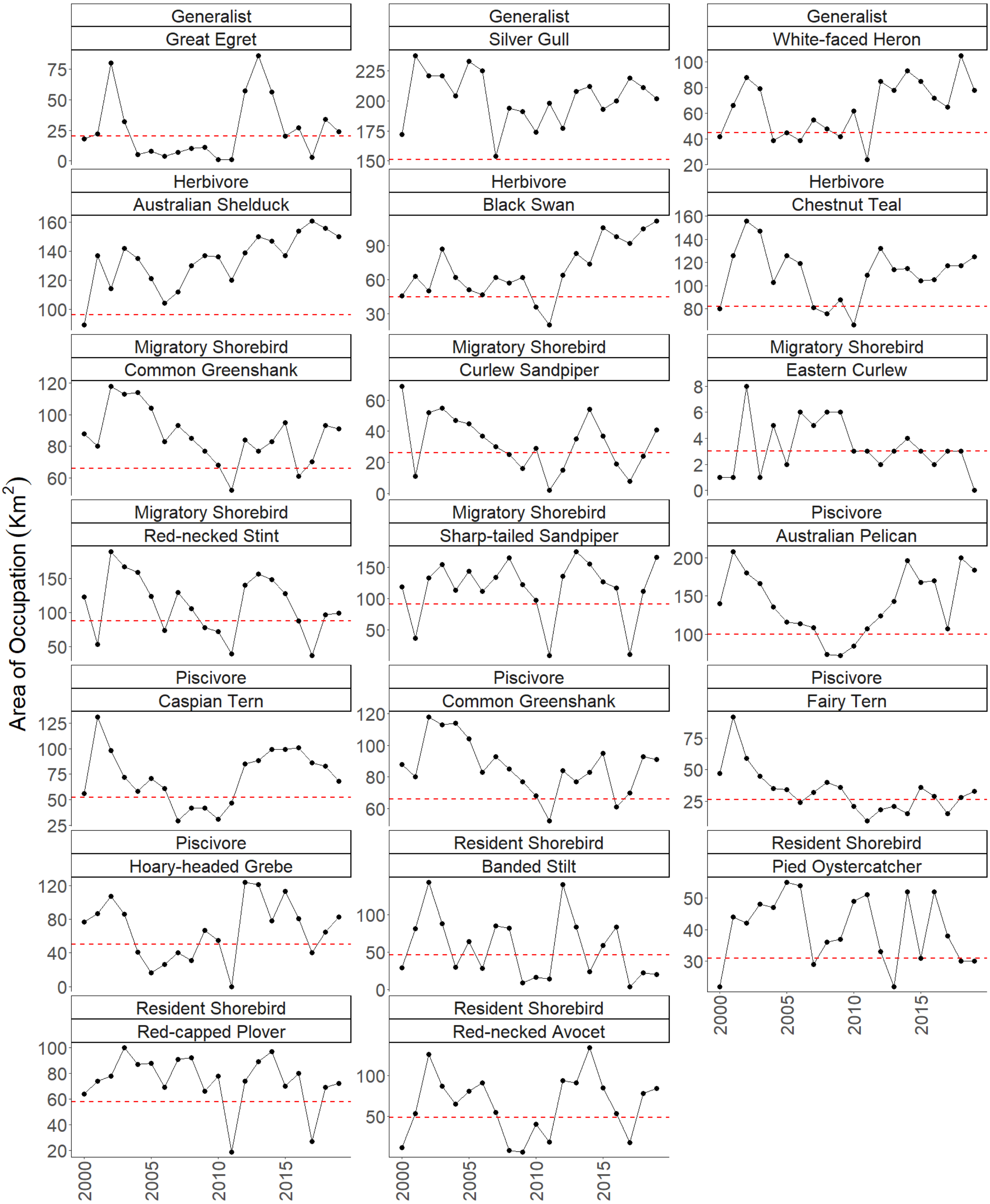

Figure 10-14. Area of occupation (AOO) (km2) of selected waterbird species during annual January census' over the Coorong from 2000 to 2019 with reference to the long-term (2000-2015) 75% thresholds for AOO for each species (horizontal red dashed Line). Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.10 Coorong Environmental Outcome Assessment: Extent of Occurrence

To meet this outcome all selected waterbird species from each guild had to exceed their long-term (2000–2015) 75% threshold for AOO. The environmental outcome was not met in 2019, as one selected species (eastern curlew) from the migratory shorebird guild did not exceed its EOO target (Figure 10-15) as shown in Figure 10-16.

Since Basin Plan adoption, progression towards the achievement of the LTWP target has generally improved (Figure 10-15). All selected species from the generalist guild except for great egret in 2017 met their EOO targets after the adoption of the Basin Plan. Similarly, all selected species from the resident shorebird guild, except for banded stilt in 2017, met their EOO targets after the adoption of the Basin Plan. A maximum of one selected species in the migratory shorebird guild failed to meet its EOO target in 2013, 2017 and 2019, and a maximum of one selected species in the piscivore guild failed to meet its EOO target in 2013 and 2017 since the adoption of the Basin Plan. The EOO of each selected species from 2000 to 2019 are shown in Figure 10-16.

Figure 10-15. The proportion of selected species within each guild that exceeded their respective long term 75% thresholds for extent of occurrence (EOO). Basin Plan adoption (November 2012) is shown by the vertical dashed blue line.

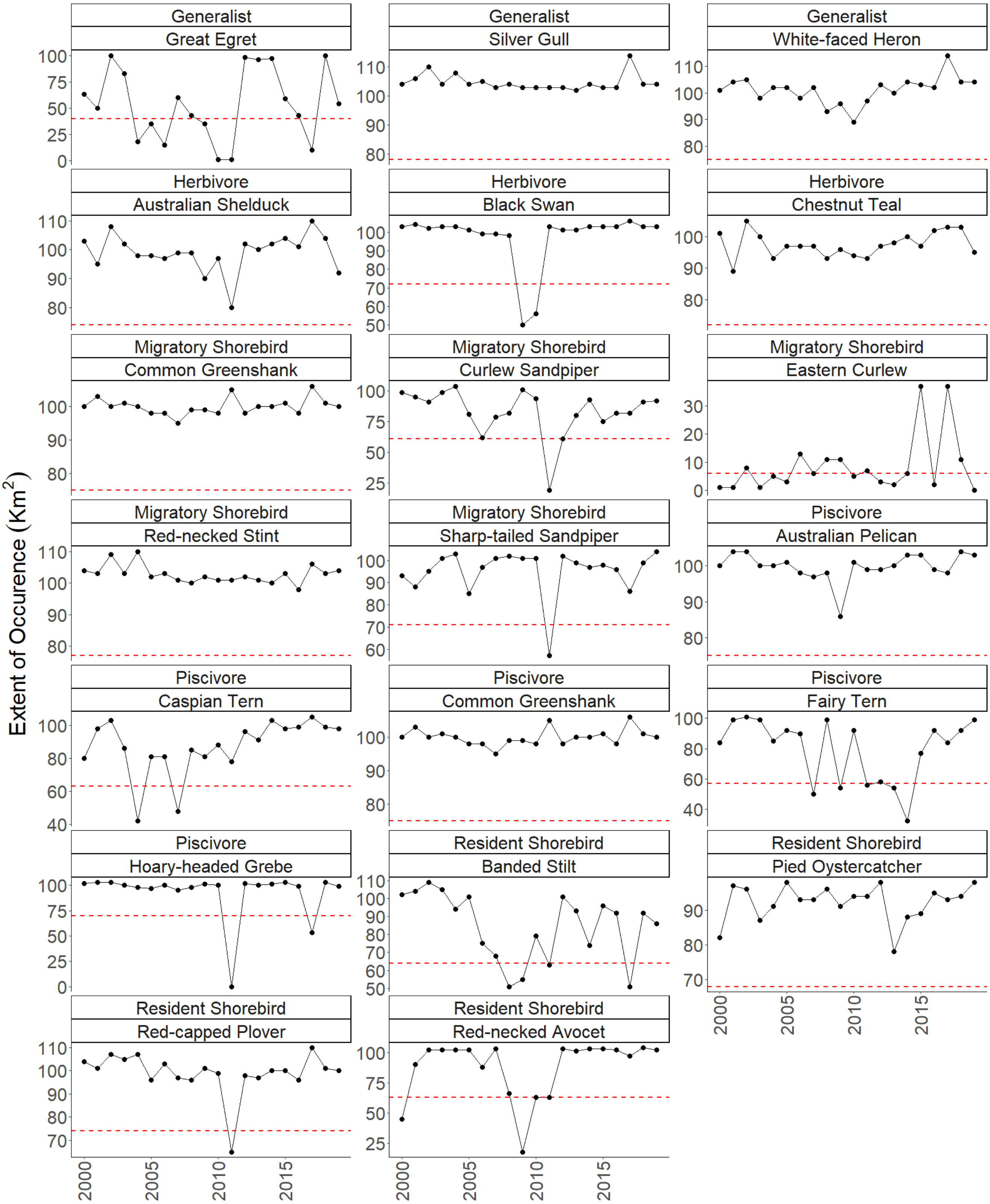

Figure 10-16. Extent of occurrence (EOO) (km2) of selected waterbird species during annual January census' over the Coorong from 2000 to 2019 with reference to the long-term (2000–2015) 75% thresholds for EOO for each species (horizontal red dashed line). Data source: University of Adelaide (Assoc. Prof. David Paton).

10.4.11 Information reliability

The information reliability rating for waterbird census of the Lakes and Coorong was **very good** (final score of 11). Justification for the scoring of waterbird data reliability is provided in Table 10-7.

Table 10-7. Reliability of data obtained from waterbird census of the Coorong and Lakes to assess the LTWP targets, trend in abundance of selected species and condition of the respective waterbird communities in 2019. The methods used in data collection as well as the representativeness and repetition of data were scored based upon the answers provided to questions related to each facet of data collection. Answers to questions regarding the methods, representativeness and repetition of data were scored 2 points – Yes, 1 point – Somewhat, 0 points – No.

Methods	Question	Answer and justification	Score
Methods used	Are the methods used appropriate to gather the information required for evaluation?	**Yes.** Methods were peer reviewed as part of the *LLCMM Icon Site Condition Monitoring Plan* (DEWNR 2017)	**2**
Standard methods	Has the same method been used over the assessment period?	**Yes.** Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary and each 1 km × 1 km cell of the Lakes and Goolwa Channel by surveyors on foot or by boat.	**2**
Representativeness			
Space	Has sampling been conducted across the spatial extent of the PEA with equal effort?	**Yes.** Waterbird counts were conducted over each 1 km section of the Coorong and Murray estuary and each 1 km × 1 km cell of the Lakes and Goolwa Channel.	**2**
Time	Has the duration of sampling been sufficient to represent change over the assessment period?	**Yes.** Censuses have been conducted in the Coorong from 2000 to 2019 and in the Lakes from 2009 to 2019, and therefore, includes years of monitoring pre- and post-Basin Plan adoption years and range of hydrological conditions.	**2**
Repetition			
Space	Has sampling been conducted at the same sites over the assessment period?	**Yes.** The same spatial extent of the Coorong and Lakes are counted for waterbirds each year of the respective monitoring programs.	**2**
Time	Has the frequency of sampling been sufficient to represent change over the assessment period?	**Somewhat.** Annual census data of waterbirds in the Coorong in January and the Lakes in late January/early February has largely been sufficient to represent change of the waterbird community over the assessment period. However, as these wetland systems are important habitat for waterbirds over autumn, spring and summer, the absence of both autumn and spring data is considered a weakness.	**1**
Final score			**11**

Methods	Question	Answer and justification	Score
Information reliability			Very good

10.5 Evaluation

10.5.1 Lakes

Over the duration of the assessment period from 2009 to 2019, the abundances of selected species from the herbivore, generalist and piscivore guilds were likely to have improved. Despite this, the environmental outcome for waterbird abundance in the Lakes was not met in 2019, due to decline in piscivore species (i.e. not meeting abundance targets) between 2016 and 2019. The environmental outcomes for AOO and EOO were met in 2019, and the proportions of selected species from all guilds that met their respective targets for AOO and EOO increased following the end of the Millennium Drought, having been maintained since the adoption of the Basin Plan.

The abundances and distributions of waterbirds in the Lakes increased over 2 to 3 years following the end of the Millennium Drought and are considered to have recovered (Paton et al. 2019a). Improvement in the abundances and distributions of herbivores, generalists and piscivores over the assessment period may have been influenced by factors relating to the delivery of water, including the protection of water for the environment. These factors have in turn improved the abundance and distribution of potential food resources for waterbirds and supported aquatic and fringing vegetation which provides key habitats for waterbirds, particularly for breeding. Other additional factors availability such as the irrigation of pasture adjacent to the Lakes and continental wetland may have also influenced the abundances and distributions of waterbirds in the Lakes.

Water delivery

The abundances, AOO and EOO of selected waterbird species in the Lakes have improved since the end of the Millennium Drought and are considered to have recovered. Improvements of guilds was influenced by the delivery of water, namely through:

- Management of lake levels:
    - Seasonal water level variability supports aquatic and fringing vegetation, which provides key habitat for waterbirds, particularly for breeding
    - Maintenance of lake levels above +0.4 m AHD provides permanently inundated habitats, which support key food resources and breeding of waterbirds
- Improved system connectivity and the restoration of salinities reflective of pre-drought conditions, which may have helped to:
    - Maintain food resource availability and distribution
    - Provided conditions to support waterbird breeding.

These factors are maintained through the planned (not licensed) environmental water (PEW) component of South Australia's Entitlement and unregulated flows. The implementation of the Basin Plan has also contributed to actions through the protection of water for the environment.

Lake level

The variations of water level in the Lakes over the assessment period (2009–2019) (Figure 10-17) likely had significant influence on the abundances and distributions of selected waterbird species in the Lakes, particularly from 2009–2011. Lake levels receded to below 0 m AHD during the height of the Millennium Drought between 2008 and 2010, which disconnected the water line from fringing vegetation. The disconnection of the water line from fringing vegetation may have reduced the overall biomass and distribution of food resources (Table 10-8) for herbivores, piscivores and generalists in the Lakes during the Millennium Drought.

Figure 10-17. Mean monthly lake levels (m AHD) at Lake Albert (A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2003 to 2019 with the adoption of the Basin Plan (BP) is shown by the dashed blue line.

Lake levels that receded below 0 m AHD, contributed to the following key changes to waterbird food resources:

- Submergent plants were replaced with terrestrial plants that colonised the littoral zone (Nicol et al. 2019)
- Frogs had low abundances (Mason and Durbridge 2015)
- Juvenile common carp had relatively low abundances (Bice and Zampatti 2011)
- Small-bodied fish had decreased habitat availability (Wedderburn et al. 2012)
- Catadromous fish were unable to move between freshwater, estuarine and marine environments to recruit, which led to very low abundances (Ye et al. 2016)
- Macroinvertebrates had low taxon richness and reduced habitat availability (Giglio 2011).

Food resources for waterbirds improved in Goolwa Channel during the Millennium Drought following the construction of the Goolwa regulator in August 2009. The regulator reconnected the waterline with fringing vegetation in the Goolwa weir pool (section managed by the regulator). The Goolwa weir pool supported mass recruitment of common carp, with abundances 250 to 1000 times greater than those present in Lake Alexandrina (Bice and Zampatti 2011) and benefited the condition of aquatic and littoral vegetation, including an increase in the abundance of submergent species (Gehrig and Nicol 2010). Furthermore, the Goolwa weir pool was the primary available habitat for frogs at the time (Mason 2014). The increased provisions of aquatic plant, fish and frog food resources in the Goolwa weir pool likely contributed to marked increases in the abundances of pisicivores (e.g. Australian pelican, great cormorant and little black cormorant) and herbivores (e.g. black swan) in the Goolwa

Channel between 2009 and 2010 (Paton et al. 2011b). The increased water levels and availability of food also provided an opportunity for herbivores (e.g. pacific black duck and black swan) to breed, which was not provided elsewhere in the Lakes (Paton et al. 2011b).

High (unregulated) flows that broke the Millennium Drought led to improvement in food resources (Table 10-8) for waterbirds in the Lakes. Lake levels were restored to managed levels (+0.4–+0.85 m AHD) by late 2010, which contributed to following changes in food resources for waterbirds:

- The recolonisation of submergent, emergent and amphibious taxa in the aquatic and littoral plant community (Nicol et al. 2019)
- Improved abundances and species richness of frogs (Mason 2014; Mason and Durbridge 2015)
- En masse recruitment of common carp (Wedderburn and Barnes 2013)
- Increased habitat availability for small-bodied fish (Wedderburn and Barnes 2013)
- Recruitment and increased abundances of catadromous fish (e.g. congolli and common galaxias) (Ye et al. 2016)
- Increased taxon species richness of macroinvertebrates (Giglio 2011).

The maintenance of lake levels above +0.4 m AHD since the adoption of the Basin Plan has ensured that water levels and fringing vegetation remain connected, which in turn, means that permanently inundated habitats are available for food resources, including submergent plants (e.g. Nicol et al. 2019), frogs (e.g. Mason and Durbridge 2015), fish (e.g. Wedderburn and Barnes 2013) and invertebrates (e.g. Giglio 2011) for herbivores, generalists and piscivores. Furthermore, lake levels have been adequate to support barrages flows in each year (Figure 4-2) following adoption of the Basin Plan, which was critical to the recruitment and improved populations of catadromous fishes (Bice et al. 2019).

Breeding activity and success of waterbirds in the Lakes is likely to have also been influenced by water levels in the Lakes (O'Connor et al. 2013). In January 2009, there was no evidence of waterbirds breeding in the Lakes, while in January 2010, there was limited breeding of black swans, pacific black ducks and little pied cormorants all nesting in the Goolwa Channel region (Paton et al. 2011b). With flood in 2010/11, the number of cygnets (black swan fledglings) increased 10-fold and were detected throughout the Lakes (Paton et al. 2011b). A further 9 waterbird species were recorded breeding in 2010/11, including 4 colonial nesting species (Paton et al. 2011b). Following the end of the Millennium Drought, breeding events have been supported for all selected waterbird species, except for whiskered terns (Paton et al. 2011b; O'Connor et al. 2013; Paton et al. 2016b; Paton et al. 2017c; Paton and Paton 2018; Paton et al. 2019a), which do not breed in the CLLMM (Paton et al. 2018c). Since the adoption of the Basin Plan, breeding activity was detected in 4 or more years for Australian white ibis, straw-necked ibis, black swan, pied cormorant and royal spoonbill (Paton et al. 2011b; O'Connor et al. 2013; Paton et al. 2016b; Paton et al. 2017c; Paton and Paton 2018; Paton et al. 2019a). Connection of the water line with fringing vegetation (i.e. at water levels +0.4–+0.9 m AHD) may have been important in supporting regular breeding of selected species of waterbirds in the Lakes.

Salinity

Substantial increases in electrical conductivity (EC) (used to describe salinity) of the Lakes from 2007 to 2010 (Figure 10-18) may have impacted food resources for waterbirds in the Lakes (Table 10-8), and therefore, may have contributed to the low abundances and distributions of selected species from all guilds. At the height of the Millennium Drought, salinities in Lake Alexandrina and Lake Albert exceeded 5,000 $\mu S.cm^{-1}$ and 15,000 $\mu S.cm^{-1}$ (Figure 10-18). Elevated salinities contributed to the following changes to food resources for waterbirds in the Lakes:

- Increased abundances of estuarine and small-bodied generalist freshwater fish species (Wedderburn et al. 2012; Ye et al. 2016)
- Low taxon richness of invertebrates (Giglio 2011)
- Sole dominance of the submergent plant, *Potamogeton pectinatus*, in the Goolwa weir pool where water levels were regulated and remained suitable for the occurrence of submergent plants (Gehrig and Nicol 2010).

In addition, it is likely that salinities in Lake Albert (up to ~15,000 µS.cm^{-1}) adversely impacted recruitment of frogs, as the larval survival of 2 common frog species in the Lakes, the brown tree frog and spotted grass frog significantly decrease at salinities of 16% seawater (i.e. ~8,000 µS.cm^{-1}) (Chinathamby et al. 2006; Kearney et al. 2012).

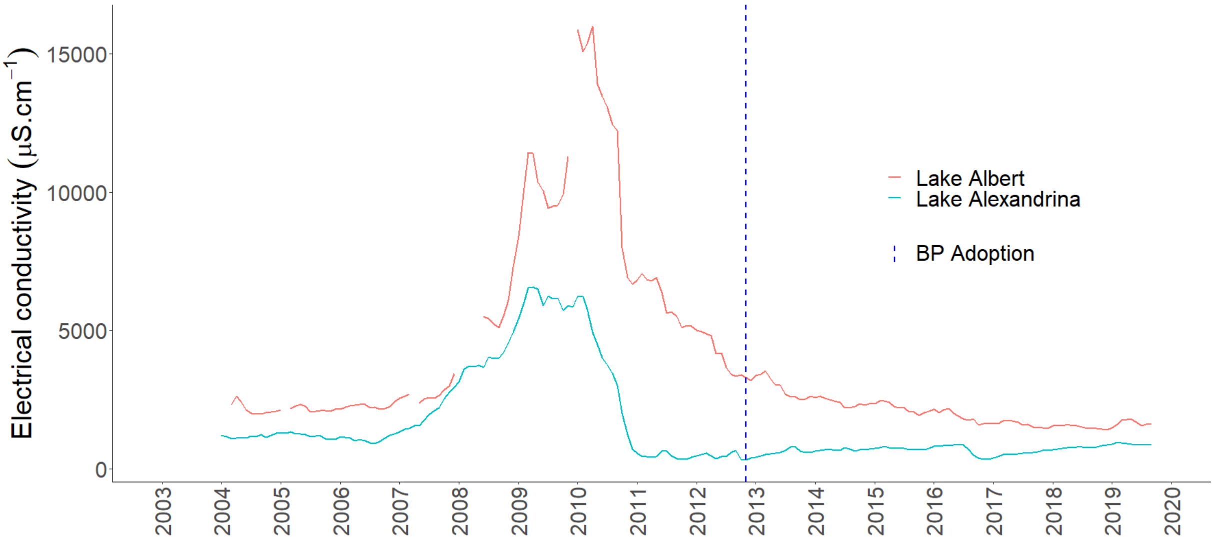

Figure 10-18. Mean monthly electrical conductivity (µS.cm-1) in Lake Albert (A4261155, A4260630, A4261153, A4261155, A4260630, A4261153) and Lake Alexandrina (A4260574, A4260524, A4261156, A4261133) from 2003-2019. The adoption of the Basin Plan (BP) in November 2012 is shown by the dashed blue line.

High (unregulated flows) between 2010/11 and 2012/13 greatly reduced salinities in Lake Alexandrina and Lake Albert (Figure 10-18). The significant reduction in salinity contributed to the following changes to food resources for waterbirds in the Lakes:

- Reduced abundances of estuarine and small-bodied generalist freshwater fish species, although increased species richness of small-bodied fish species (Ye et al. 2016)
- Increased diversity of submergent plant species adapted to lower salinity environments in the Goolwa weir pool after the regulator was breached (Nicol et al. 2019)
- Increased taxon species richness of macroinvertebrates (Giglio 2011).

It is also likely that such flows restored salinities to those suitable (≤6,000 µS.cm^{-1}) for high larval survival of brown tree frogs and spotted grass frogs (Chinathamby et al. 2006; Kearney et al. 2012).

Salinities conducive to more diverse fish (Ye et al. 2016), aquatic plant (Nicol et al. 2019) and invertebrate (Giglio 2011) communities have been supported since the adoption of the Basin Plan, however, how this has directly impacted food resource availability for waterbirds and consequent changes in the abundances and distributions of selected species is unknown.

Food availability

The Millennium Drought adversely impacted the distribution and abundance of food resources consumed by all waterbird guilds in the Lakes. In 2009, when lake levels fell below 0 m AHD and salinities exceeded 5,000 µS.cm^{-1} and 15,000 µS.cm^{-1} in Lake Alexandrina and Albert, respectively, food resources for waterbirds were limited in abundance and/or distribution (Table 10-8). These impacts likely contributed greatly to the failure of selected species from all guilds in achieving their respective Abundance, AOO and EOO ecological targets. Since the end of the Millennium Drought (and following the adoption of the Basin Plan), the distributions and abundance of food resources improved (Table 10-8), which likely contributed to greater success of selected species from all guilds in meeting their respective Abundance, AOO and EOO targets.

Table 10-8. The abundance and distribution of food resources consumed by each waterbird guild at the peak of the Millennium Drought (2009–2010) and following the Millennium Drought (2010–2019).

Food resource	2009–2010 Very low lake levels and elevated salinities during the Millennium Drought	2010–2019 Post Millennium Drought	Guilds that consume prey item
Submergent plants	Submergent taxa were largely extirpated by spring 2008 (Marsland and Nicol 2009). The completion of the regulator in spring 2009 led to the establishment of extensive beds of *Potamogeton pectinatus* in the Goolwa Channel (Gehrig and Nicol 2010).	Since the return to flows, submergent taxa recolonised and there has been an increase in their abundance and diversity (Nicol et al. 2019).	Herbivores
Amphibious and emergent plants	Amphibious taxa declined in abundance and diversity and stands of emergent taxa were disconnected from remaining water (Marsland and Nicol 2009).	Since the return to flows, there has been an increase in the abundance and diversity of amphibious and emergent taxa (Nicol et al. 2019).	Herbivores
Pasture	Not assessed	Not assessed	Herbivores
Fish	Common galaxias and congolli had very low abundances (Ye et al. 2016). Habitat availability for small-bodied fish declined with receding lake levels, however, the abundance of small-bodied freshwater generalist species increased (Wedderburn et al. 2012). Juvenile common carp had relatively low abundances, except in the Goolwa weir pool, which supported mass recruitment of common carp, with abundances 250 to 1000 times greater than those present in Lake Alexandrina (Bice and Zampatti 2011).	Following return to flows, common carp recruited en masse and habitat availability for small-bodied fish increased (Wedderburn and Barnes 2013). Since the drought, there has been increased species richness of small-bodied fish, increased proportional catch of freshwater native fishes (bony herring and golden perch) in commercial fishery catch, and increased abundance of catadromous fish (congolli and common galaxias). However, abundances of estuarine and small-bodied generalist freshwater fish species reduced (Ye et al. 2016).	Piscivores

Food resource	2009–2010 Very low lake levels and elevated salinities during the Millennium Drought	2010–2019 Post Millennium Drought	Guilds that consume prey item
Amphibians (frogs and tadpoles)	Abundance and species richness of regional frog species at sampled sites was relatively low (Mason and Durbridge 2015). Furthermore, the Goolwa weir pool was the primary available habitat for frogs at the time (Mason 2014).	Abundance of regional frog species at sampled sites increased until 2012/13 and was comparable in 2013/14, and 2014/15 (Mason and Durbridge 2015). Species richness of frogs improved from 2009/10 to 2010/11 and was comparable in 2012/13, 2013/14 and 2014/15 (Mason and Durbridge 2015).	Piscivores
Terrestrial invertebrates	Not assessed	Not assessed	Generalists
Aquatic invertebrates	Mean number of taxa collected across 8 sites in February and March 2010 was 31, and represented only salt tolerant taxa (Giglio 2011).	Mean number of taxa collected across 8 sites was 63 in September and October 2010, 49 in November and December 2010 and 58 in February 2011. Over this period, there was an increase in sensitive taxa associated with freshwater and a decline of tolerant taxa associated with brackish water taxa (Giglio 2011).	Generalists

Additional factors: Rainfall and irrigation

Rainfall and irrigation likely also influence the availability of food resources, including pasture and terrestrial invertebrates, present on irrigated land adjacent to wetland areas of the Lakes (Paton et al. 2018c). These foraging grounds support certain species of generalists (e.g. ibis), piscivores (e.g. whiskered tern) and herbivores (e.g. pacific black duck, Australian shelduck and black swan), with generalists and piscivores foraging for terrestrial invertebrates and herbivores grazing on pasture (Paton et al. 2018c). These foraging grounds likely increased in extent following the Millennium Drought due to greater rainfall and an easing of restrictions on irrigators.

10.5.2 Coorong

Over the duration of the assessment period, from 2000 to 2019, the abundances of selected species in the Coorong waterbird community have declined, with abundances of selected species having likely increased for generalists and herbivores, remained stable for piscivores, likely declined for resident shorebirds and extremely likely to have declined for migratory shorebirds. The environmental outcomes for abundance, AOO and EOO were not met in 2019 for Coorong waterbirds, with only the generalist guild having all selected species meeting each target.

The population condition of selected waterbird species in the Coorong were influenced by hydrological and water quality factors, including water level, salinity, and nutrients and filamentous algae. These factors (described in m more detail below) affected the availability and accessibility of food resources for waterbirds, and for certain selected species, affected breeding activity and success. Extrinsic factors also likely influence the abundance and composition of waterbirds in the Coorong, including the availability of wetlands at a continental scale and subsequent breeding success of waterbirds at these wetlands and for migratory shorebirds, the loss and degradation of staging sites of migration in the Yellow Sea and their nesting success at northern hemisphere breeding grounds.

Water level

Water levels in the Coorong influence the availability (Dittmann et al. 2018; Paton et al. 2019b) and accessibility (Paton and Bailey 2011; Paton et al. 2017c) of food resources as well as the protection of breeding colonies of island nesting waterbirds from terrestrial predators (Paton et al. 2017c). The maintenance of adequate water levels in the southern Coorong through spring and in to summer is critical to *R. tuberosa*, a key food resource for herbivores, shorebirds and generalists (Table 10-10). In order for *R. tuberosa* to complete reproduction and increase vigour (i.e. total plant material) plants need to be covered by 30 cm of water to prevent wind seiches exposing plants and making them prone to desiccation (Paton et al. 2019b). As most *R. tuberosa* beds that establish in winter are at elevations between 0.0 and 0.2 m AHD and that these plants require 0.3 m of water cover for reasons aforementioned, it is imperative that water levels over spring and in to summer do not fall below 0.3 m AHD (Paton et al. 2019b). A fall in water levels below 0.3 m AHD over spring or early summer exposes beds of *R. tuberosa* to desiccation before plants had set seed or produced turions and limits the growth of plants (Paton et al. 2019b), which subsequently limits food for herbivores (shoots and turions) and shorebirds (seed and turions) (Paton et al. 2019b). Low water levels also can adversely impact macroinvertebrates in the northern reaches of the Coorong by causing the long-term exposure of mudflat sediments that subsequently makes them uninhabitable for certain benthic macroinvertebrates (i.e. polychaetes) (Dittmann et al. 2018), limiting food for shorebirds. The volumes (and timing) of water delivered, including water for the environment, on their own are not sufficient to prevent water levels dropping in spring in years without high (unregulated) flow events.

High water levels (~0.7m AHD) can also limit the accessibility of food resources to waterbirds (Paton and Bailey 2011; Paton et al. 2017c). Shorebirds, both resident and migratory, are particularly sensitive to water level (Rogers and Paton 2009). Water depths suitable for a shorebird to forage are limited by leg length (Norazlimi and Ramli 2015), and therefore, foraging habitat is restricted to shallow water depths. For example, *Calidris* species in the Coorong forage in very shallow water depths, with red-necked stints able to forage in water depths up to 4 cm and sharp-tailed sandpipers and curlew sandpipers at water depths up to 7 cm (Rogers and Paton 2009). Due to the shallow depths at which *Calidris* species forage, even small increases in water depth (2–3cm) can cause a decline in foraging performance (Rogers and Paton 2009). Therefore, high water levels associated with the high (unregulated) flow events in 2010/11 and 2016/17 largely prohibited access to mudflats for shorebirds to forage, and contributed to the very low abundances of shorebirds (Paton and Bailey 2011; Paton et al. 2017c). Similarly, the low abundances of selected generalist and herbivorous species in these years, were likely in part attributed to high water levels that limited access to food resources around the shores of the Coorong (Paton and Bailey 2011; Paton et al. 2017c).

Breeding activity and success of colonial nesting waterbirds in the Coorong can be affected by water level changes (Paton and Rogers 2009; O'Connor and Rogers 2013; Paton et al. 2017c). The impact of water level on nest activity and success is dependent on bathymetry and the elevation of the island, and in turn, whether the island remains isolated from the mainland over the course of the breeding season. The larger islands that support Australian pelican breeding remained isolated from the mainland during the Millennium Drought in 2009/10 (DENR 2010), however, smaller islands that support fairy tern colonies are more sensitive to water level fluctuations (Paton et al. 2017c). For example, in 2016/17, islands that were used by fairy terns for breeding in previous years were inundated by high water levels, which forced fairy terns to breed on an islands at a higher elevation and at the Murray Mouth (Paton et al. 2017c). In January 2017, water levels rapidly dropped by 0.6 m in the South Lagoon in late summer and reconnected the island with the mainland, which provided access for foxes, which subsequently destroyed the colony prior to any chicks hatching (Paton et al. 2017c).

Salinity

Salinity is an important driver of habitat conditions and key food resource distributions and abundance for all waterbird guilds in the Coorong, which in turn, influences their distribution and abundance (Paton et al. 2009). When barrage flow ceased from 2007 to 2010, salinities in the South Lagoon regularly exceeded 100 $g.L^{-1}$ (Gibbs et al. 2018) and at times were above 130 $g.L^{-1}$ (Ye et al. 2020a). Meanwhile salinities in the Murray estuary were reflective of a marine rather than estuarine environment (Bice et al. 2019). These salinities were often above the tolerable or favourable salinities for key food resources in the Coorong (Table 10-9), which contributed to the adverse effects to the Coorong foodweb as detailed in Table 10-10. Consequently, relatively low proportions of selected species from all guilds met their respective Abundance, AOO and EOO targets from 2007 to 2010.

Table 10-9. Summary of biota tolerance and performance under different salinity environments in the Coorong.

Biota	Salinity
Ruppia tuberosa	See Figure 10-19.
Benthic invertebrates (e.g. Polychaetes, Molluscs, Crustaceans)	Species specific tolerances to salinity (Dittmann et al. 2018). Salinities >60 $g.L^{-1}$ prevent the establishment of diverse and abundance benthic invertebrate communities (Brookes et al. 2018).
Chironomid larvae	Low densities recorded at 125 $g.L^{-1}$ (Dittmann et al. 2010) and tolerable salinities range from 0–140 $g.L^{-1}$ (Dittmann et al. 2018). However, densities of chironomid larvae are typically higher when salinities are ≥80 $g.L^{-1}$ (Paton et al. 2019a). Salinities <80 $g.L^{-1}$ in the South Lagoon promote the formation of mats of filamentous algae that impede the emergence of adult chironomid from aquatic environments (Paton et al. 2018b). Note that the key chironomid in the South Lagoon, *Tanytarsus barbitarsis*, is a salt-tolerant species and that it is likely that other chironomid species occur in the estuarine water near the Murray Mouth (Paton et al. 2019a).
Sandy Sprat	Highly abundant in the Murray estuary and northern part of the North Lagoon and absent from the South Lagoon. Spatial variation driven by salinity gradient during assessment period (November 2013–March 2014, Murray estuary: 2–30 $g.L^{-1}$, North Lagoon: 11–75 $g.L^{-1}$ and South Lagoon: 40–85 $g.L^{-1}$) (Hossain et al. 2016).
Small-mouthed hardyhead	Recorded in the South Lagoon at salinities up to 130 $g.L^{-1}$ (Noell et al. 2009). Salinities <100 $g.L^{-1}$ help to mitigate impacts to recruitment and maintain their distribution over the Coorong (Ye et al. 2020a).
Filamentous algae	Growth occurs in late spring and summer. Optimal salinities for growth are 10–40 $g.L^{-1}$ and suboptimal salinities are <10 $g.L^{-1}$ and 40–80 $g.L^{-1}$. Filamentous algae suffer high mortality in salinities >80 $g.L^{-1}$ (Collier et al. 2017).

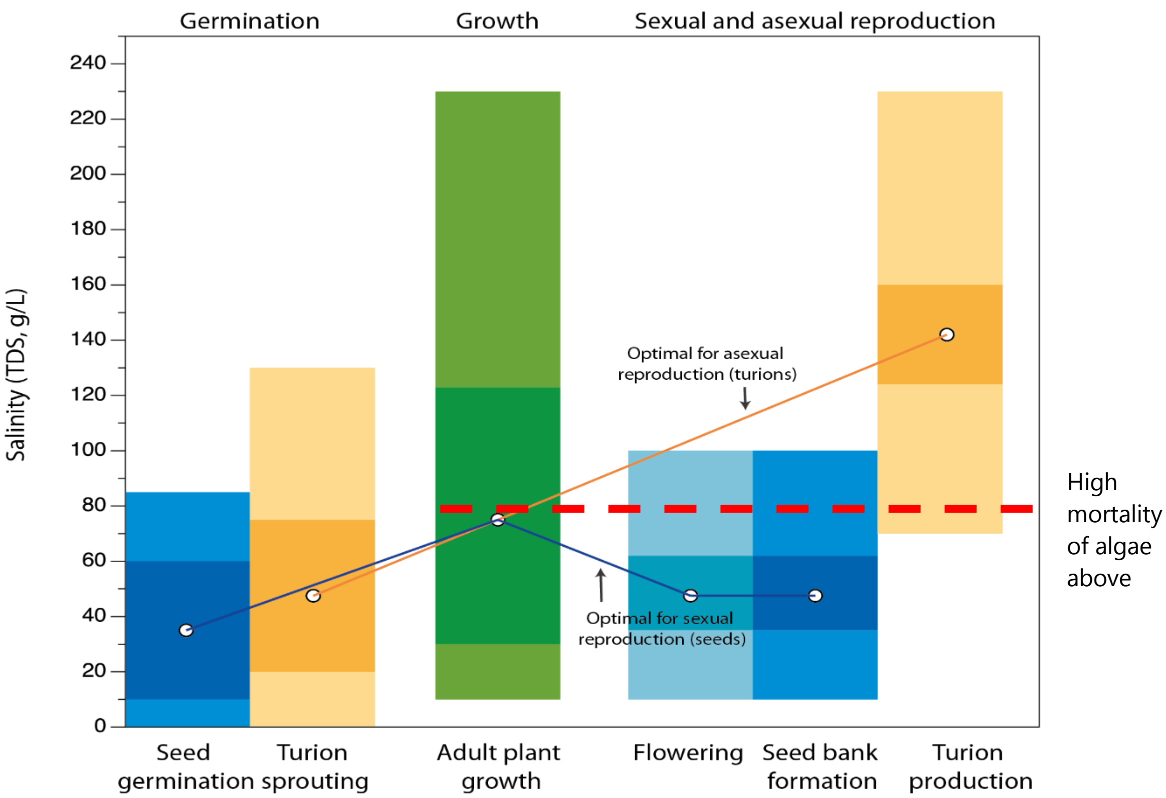

Figure 10-19. Summary of optimal (darker shades) and sub-optimal (lighter shades) salinity ranges for different stages of the *R. tuberosa* life cycle, with conditions separated for sexual reproduction shown in blue and asexual reproduction shown in orange. Salinity ranges for seed germination and turion sprouting were derived from laboratory experiments, and salinity ranges for adult growth, flowering, seed bank formation and turion production were derived from a combination of in-situ, laboratory and mesocosm data. As such, the salinity ranges for seed germination and turion sprouting for which in-situ data is unavailable should be treated with caution. It should be recognised that under current hyper-eutrophic conditions in the southern Coorong that excessive filamentous algal growth when salinities are below 80 g.L-1 means that *R. tuberosa* flowering and seed bank formation are adversely impacted. Unsuitable conditions are not included in this figure (Source: Collier et al. 2017).

Since the end of the Millennium Drought, increased flows from the barrages supported by water for the environment have freshened the Murray estuary and Coorong, and flows from Salt Creek have further freshened the southern sector of the South Lagoon. The influence of flows (Table 10-10) from the barrages (see from Salt Creek) on the salinity environments of the Coorong and the resultant impacts to food resources for waterbirds are detailed below.

Improved barrage flows since the end of the Millennium Drought have maintained estuarine conditions over the Murray estuary (Bice et al. 2019) and have helped to limit the temporal and spatial scales of the Coorong where salinities exceeded 100 g.L^{-1} (Gibbs et al. 2018). This has resulted in salinities in the Murray estuary and Coorong that are either tolerable or more favourable for key food resources of all waterbird guilds (Table 10-9). In turn, these salinities helped to restore the distributions and improve the abundance and/or biomass of key food resources for all waterbird guilds (Table 10-10).

High (unregulated) flows that occurred in 2010/11–2011/12 and 2016/17 greatly reduced salinities throughout the Murray estuary and Coorong (Ye et al. 2020a). These flows increased the extent of estuarine conditions throughout the Murray estuary and in to the North Lagoon (Ye et al. 2020a), which likely contributed to increased abundances of macroinvertebrates (Dittmann et al. 2017) and in association with improved pelagic productivity likely enhanced the recruitment of small-mouthed hardyhead (Ye et al. 2020a) and sandy sprat (Bice et al. 2019). Subsequently, it is likely that food resource availability for shorebirds, generalists and piscivores in the Murray estuary and North Lagoon improved following the flows in 2010/11–2011/12 and 2016/17. In the South Lagoon, high (unregulated) flows in 2010/11 and 2011/12 reduced salinities to those tolerable, if not, favourable for *R. tuberosa*, chironomid larvae and small-mouthed hardyhead (Table 10-9), which contributed to their post drought recovery or improvement (Table 10-10). As such, these high (unregulated) flows mediated salinity induced effects on food resources for all waterbird guilds, which increased their post-Millennium Drought availability. In 2016/17, high (unregulated) flows were again thought to be beneficial to small-mouthed hardyhead through the restoration of salinities below 100 $g.L^{-1}$, which is likely to have improved recruitment and their distributions (Ye et al. 2020a). As such, food resource availability may have improved for piscivores, however, high water levels would have limited selected species from other guilds that consume small bodied fish from foraging on small-mouthed hardyhead. The high (unregulated) flows in 2016/17 also freshened the South Lagoon below 80 $g.L^{-1}$, which enabled filamentous algae to proliferate. Excessive growth of filamentous algae has been detrimental to *R. tuberosa* reproduction and vigour (Collier et al. 2017) and may have impeded the emergence of chironomids, contributing to their declining densities in recent years (Paton et al. 2019a).

Since the adoption of the Basin Plan, the contribution of water for the environmental to salinity conditions in the Murray estuary and Coorong during years of high (unregulated) flows (i.e. 2016/17) was low (Stewardson and Guarino 2018, 2019). However, Commonwealth environmental water (CEW) was delivered in years without high (unregulated) flow events, helping to maintain salinities more favourable for the function of the Coorong food web. For example, CEW helped to export salt from the Lakes and Coorong, and also limit import of salt from seawater ingression (Ye et al. 2020b). Without CEW, it was modeled that an additional 20 million tonnes of salt would have entered the Coorong between 2014 and 2019 (Ye et al. 2020b). If such volumes of salt had entered the Coorong, salinities would have been comparable to those recorded at the end of the Millennium Drought (Ye et al. 2020b) even with flow from Salt Creek considered. The delivery of environmental water (in addition to the high unregulated flow events) has therefore helped to support the function of the Murray estuary and Coorong food web by limiting the exceedance of sub-optimal and tolerable salinities and increasing the extent of more favourable salinities for key food resources of waterbirds across all guilds (see Table10-9).

Flows from Salt Creek, have at times, disrupted the salinity gradient of the Coorong and have freshened (<80 $g.L^{-1}$) the southern South Lagoon in spring and summer. Such changes to the salinity regimes of the South Lagoon may have been detrimental to food resource availability and accessibility for herbivores, generalists and shorebirds. For example, flows from Salt Creek contributed to salinities in the southern South Lagoon in April to June being similar to or greater than those in mid-summer, which could limit *R. tuberosa* seeds from germinating and turions from sprouting (Paton et al. 2019a), as a reduction in salinity may be required to trigger germination or sprouting (Kim et al. 2013). Furthermore, flows from Salt Creek (in conjunction with flow from the barrages) have freshened the southern South Lagoon below the upper salinity tolerance (80 $g.L^{-1}$) of filamentous algae (Collier et al. 2017). Such freshening has likely contributed to the growth of filamentous algae (Paton et al. 2019a), with the lagoon's current hyper-eutrophic state primarily driving this impact (Mosley and Hipsey 2019; Waycott et al. 2020).

Nutrients and filamentous algae

Excessive growth of filamentous algae is thought to be in response to the hyper-eutrophic conditions that now persist in the Coorong (Mosley and Hipsey 2019; Waycott et al. 2020). Nutrients in the Coorong can accumulate from the inputs of freshwater inflows from the barrages (River Murray) and Salt Creek, although it's the lack of flows to flush the system that are thought to be the primary driver of the hyper-eutrophic conditions (Mosley and Hipsey 2019). Recent research (Mosley 2020; Waycott 2020) has been investigating whether the loss of *R. tuberosa* during the Millennium Drought contributed to or exacerbated the hyper-eutrophic state of the southern Coorong, where slow-growing *R. tuberosa* that retain nutrients for relatively long periods (weeks to months) were replaced by fast-growing phytoplankton and filamentous algae that retain nutrients for short periods (days to weeks). Deposition of this organic material (i.e. phytoplankton, filamentous algae and other organic matter) to the sediment can lead to the release of nutrients from the sediment to the water column, and promote the formation of monosulfidic materials (i.e. 'black oozes') (Mosley and Hipsey 2019). Excessive filamentous algal growth was detected in the North Lagoon in 2011 when water levels returned to the Coorong following the Millennium Drought (Paton et al. 2011a), however, were not recorded in the South Lagoon until 2014 (Frahn and Gehrig 2015). Filamentous algae are co-associated with *R. tuberosa* beds in the southern Coorong, as the beds provide a substrate for attachment (Waycott et al. 2020). The overlap of filamentous algae with *R. tuberosa* beds has been particularly prominent in recent years (Paton et al. 2016a, 2017a, 2018a, 2019b).

Filamentous algae mats adversely impact waterbirds in the southern Coorong by reducing the availability and accessibility of food resources (Paton et al. 2019a). The mats have reduced the vigour and reproduction of *R. tuberosa* and likely the accessibility of shoots for grazing (Paton et al. 2018b; Paton et al. 2019b). This has, in turn, limited the availability of seed, turions and shoots for consumption by shorebirds and herbivores, respectively. Furthermore, while it is likely that filamentous algae are consumed by herbivores, it is a less nutritious food resource (Moore 2014). Therefore, the incidental or deliberate consumption of filamentous algae attached to *R. tuberosa* shoots or the sole consumption of filamentous algae could adversely impact time energy budgets (Paton et al. 2018b). The mats formed by filamentous algae also likely reduced the abundance and accessibility of benthic macroinvertebrates (Dittman et al. 2017; Paton et al. 2018b), by causing (in association with high densities of phytoplankton and high organic matter) hypoxic conditions in pore water (Dittman et al. 2017) and impeding the emergence of adult chironomid from aquatic environments (Paton et al. 2018b). Moreover, the algal mats reduce the access to the mudflat surface that shorebirds forage upon (Paton et al. 2018b), and as a consequence have reduced the accessibility of food resources. Lastly, mats of filamentous algae floating on the water's surface would also be expected to limit suitable foraging areas for diving piscivores, such as fairy terns, and also impede foraging movements of other waterbirds either swimming or wading through waters.

Food availability

The Millennium Drought had severe consequences on the distribution and abundance of key food resources consumed by all waterbird guilds in the Coorong. During the Millennium Drought, from 2002 to 2010, especially when barrage flows ceased, from 2007 to 2010, key food resources for waterbirds shifted northward in their distributions and declined in abundance and/or biomass (Table 10-10). These impacts likely contributed greatly to the failure of selected species from all guilds failing to achieve their respective Abundance, AOO and EOO ecological targets. Since the end of the Millennium Drought (and following the adoption of the Basin Plan), the distributions and abundance and/or biomass of key food resources has improved, however, the magnitude and time scales for improvement varied between key food resources (Table 10-10). The availability of key food resources has likely contributed to the success and failure of selected species from all guilds in meeting their respective Abundance, AOO and EOO ecological targets.

Table 10-10. The abundance, biomass and distribution of key food resources for waterbirds during the peak of the Millennium Drought (2007–2010) and following the Millennium Drought (2010–2019). The waterbird guilds that consume each prey item are listed. An asterisk (*) denotes that the food resource is unlikely to be particularly important to the guild or is not consumed by all selected species within the guild.

Key food resource	2007–2010 No barrage flow during Millennium Drought	2010–2019 Post Millennium Drought	Guilds that consume prey item
Ruppia tuberosa	*R. tuberosa* were extirpated from the South Lagoon and colonised the southern 20 km of the North Lagoon (Paton and Bailey 2012). However, populations in the central sections of the North	With the return of barrage outflows to the system, *R. tuberosa* were lost from the northern Coorong where they colonised during drought (Paton and Bailey 2012) and	Herbivores, Migratory shorebirds, Resident shorebirds, Generalists*

Key food resource	2007–2010 No barrage flow during Millennium Drought	2010–2019 Post Millennium Drought	Guilds that consume prey item
	Lagoon had very limited set seed during the Millennium drought (see section 6).	there was a slow and limited recovery of *R. tuberosa* in the southern Coorong that continued until 2014 (Paton et al. 2019b). Since 2014, the condition of *R. tuberosa* in the Coorong has not improved and therefore recovery has been limited since the Millennium Drought (Paton et al. 2019b).	
Benthic invertebrates (e.g. Polychaetes, Molluscs, Crustaceans)	Species richness and biomass was low in the Murray estuary and North Lagoon (Dittmann et al. 2017).	The benthic invertebrate community recovered over 5 to 6 years following the Millennium Drought, with species richness and biomass continually improving until 2015 and 2016, respectively (Dittmann et al. 2019). Both abundance and biomass of benthic invertebrates declined in 2017/18 and 2018/19, while species richness has been maintained (Dittmann et al. 2019).	Resident shorebirds, Migratory shorebirds
Chironomid larvae	Salt-tolerant chironomid (*Tanytarsus barbitarsis*) contracted northward in its distribution and was extirpated from the South Lagoon (Paton et al. 2019a).	Chironomid larvae, recovered within half a year (Paton and Bailey 2012) and maintained similar densities until 2017 before declining and remaining low in 2018 and 2019 (Paton et al. 2019a).	Resident shorebirds, Migratory shorebirds
Sandy sprat	Distributions constricted to near the Murray estuary (Giatas and Ye 2016) where low in abundance (Bice et al. 2019).	Increased in distribution to include Murray estuary and North Lagoon (Giatas and Ye 2016). Varied in abundance in response to flow, with very high abundances in 2010/11, 2011/12 and 2016/17, and much lower abundances in intervening years (Bice et al. 2019).	Piscivores
Small-mouthed hardyhead	South Lagoon of the Coorong became almost fishless, with the most salt tolerant species, the	There was a one-year lag in the response of small-mouthed hardyhead	Piscivores, Generalists, Migratory

Key food resource	2007–2010 No barrage flow during Millennium Drought	2010–2019 Post Millennium Drought	Guilds that consume prey item
	small-mouthed hardyhead, becoming restricted to Salt Creek and its area of influence when in flow and the North Lagoon (Ye et al. 2011).	abundance following the flood in 2010/11 (Ye et al. 2020a). Abundance has been highly variable in response to flow and predator-prey interactions, with years of high abundance recorded in 2011/12, 2015/16 and 2018/19 (Ye et al. 2020a). Small-mouthed hardyhead have been distribution over the North and South Lagoons of the Coorong following the break of the Millennium Drought (Ye et al. 2020a).	shorebirds*, Resident shorebirds*

Additional factor: Continental wetland availability

The number and composition of waterbirds support in the CLLMM each year vary based upon the availability of wetlands across the continent and the subsequent breeding success at these wetlands (Paton et al. 2015a). Wetland availability over eastern Australia in October from 2000 to 2019 was greatest in 2010, 2011, 2012 and 2016 (Porter et al. 2019) (Figure 10-20). The largest breeding events of waterbirds over eastern Australia occurred in years where there was a significant increase in the wetland area index, i.e. 2010 and 2016 (Figure 10-20) (Porter et al. 2019). These water years (2010/11 and 2016/17) coincided with an exodus of waterbirds that breed inland from the CLLMM, however, the extent to which these species use alternate wetland habitats remains a knowledge gap. For example, there were no hoary-headed grebes recorded in January 2011 (2010/11 water year) and only 288 individuals were recorded in January 2017 (2016/17 water year) (Figure 10-10), and therefore, their abundances in the Coorong fell well below their long-term median abundance of 4,218 individuals. It should be also recognised that feeding opportunities in the Coorong were reduced in January 2011 and January 2017 due to high water levels, while excess filamentous algal growth also occurred in January 2017. The total numbers of waterbirds over eastern Australia showed a marked increase in the year following these large breeding events (Porter et al. 2019) (Figure 10-20). The increased number of waterbirds over eastern Australia following large breeding events (Porter al. 2019) may subsequently influence the numbers of waterbirds present within the Lakes and Coorong in the following summer (Paton et al. 2018c).

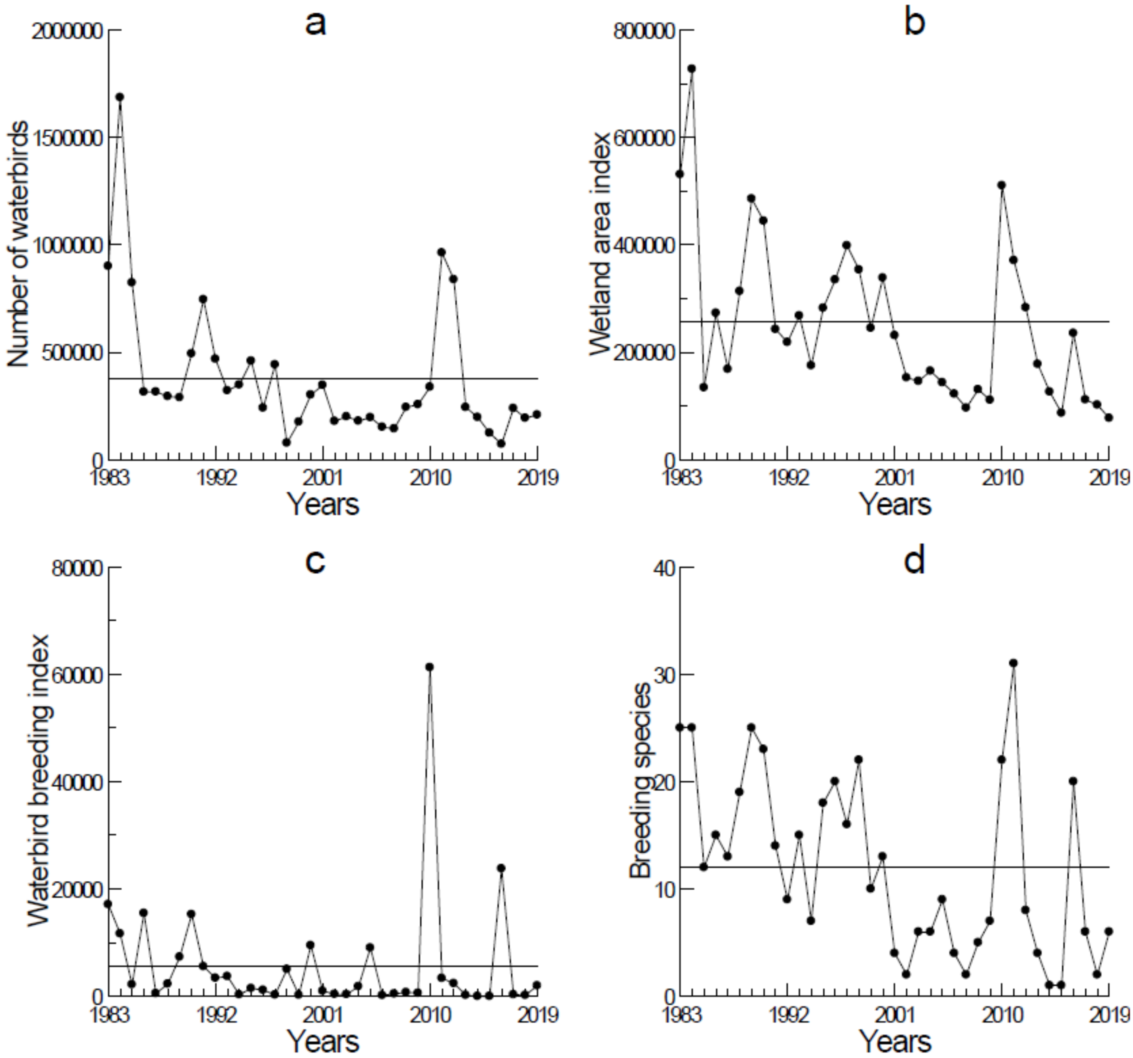

Figure 10-20. Changes over time in a) total abundance of waterbirds, b) wetland area, c) breeding and d) number of breeding species recorded over eastern Australia during the Eastern Australian Waterbird Survey (1983-2019); horizontal lines show long-term averages. Source: Porter et al. (2019).

Additional factor: Habitat loss and climatic conditions over the East Asian-Australasian Flyway

The abundances of migratory shorebirds in the Coorong are declining more rapidly than elsewhere in Australia (Clemens et al. 2016). However, despite this, decreases in migratory shorebird populations in the East Asian Australian Flyway are largely being driven by factors outside of Australia (Clemens et al. 2016), especially habitat loss and degradation of key staging sites in the Yellow Sea (Szabo et al. 2016). The Yellow Sea provides important staging sites for migratory shorebirds as they migrate from their non-breeding grounds (including Australia) to their breeding grounds in the eastern Siberia and vice versa (Barter et al. 2002). The tidal foraging grounds of the Yellow Sea provide an opportunity for migratory shorebirds to 're-fuel' and improve their body condition to complete their migration (Meltofte et al. 2007). The reclamation of tidal foraging grounds in the Yellow Sea as well as their continued degradation by invasive plants, pollution and increased human disturbance (Hua et al. 2015) has likely impaired the ability of migratory shorebirds to sufficiently improve body condition. Consequently, this may have reduced the survivorship of adult migratory shorebirds completing their migration to breeding grounds and their subsequent breeding success (Duijns et al. 2017). Similarly, the ability of migratory shorebirds to complete their migrations to breeding grounds may be adversely impacted by the inadequate conditions in the Coorong.

Climatic conditions at northern hemisphere breeding grounds also influence the breeding success of migratory shorebirds (Saalfield et al. 2019). Snowmelt has a strong influence on the availability of invertebrate food resources for nesting migratory shorebirds and subsequently greatly influences nest success (Saalfield et al. 2019). Variance in nest success is great, with the proportions of juvenile red-necked stint and curlew sandpipers captured in south-eastern Australia varying tenfold between years (Rogers and Gosbell 2006; Minton et al. 2014). Therefore, the survival and breeding success of migratory shorebirds outside of Australia is likely to influence their abundances in the Coorong.

10.6 Actions to achieve environmental outcomes

10.6.1 Lakes

The improvement in abundance and distributions of waterbirds in the Lakes over the assessment period suggests that current hydrological and salinity regimes have helped the Lakes waterbird community recover from the period of low water levels from 2007–2010. Therefore, it is recommended that current hydrological and salinity regimes, including the management of lake levels, need to be maintained to support the continual improvement of key waterbird habitats and food resource availability in the Lakes. Although outside of current management influence, periodic high (unregulated) flow events are important and are needed more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes. Furthermore, releases of Lakes water via the barrage in early summer following surcharges in winter and spring may enhance productivity in the Murray estuary and Coorong that promotes estuarine fish recruitment (Ye et al. 2019), improving food resources for piscivorous waterbirds over the CLLMM.

10.6.2 Coorong

The Coorong South Lagoon appears to have entered an alternate and undesirable stable state, with a shift from macrophyte (i.e. *R. tuberosa*) to filamentous algae and phytoplankton dominated primary production (D Rogers personal communication, 20 August 2020; Waycott 2020). In order to improve environmental outcomes in the South Lagoon, increased flushing is required to export nutrients, algae, and organic matter that will enable healthy nutrient cycling and improve water quality and light penetration (Mosley 2020). In addition, an adequate water-level regime (+0.3 m AHD) through spring and into summer is required to improve the seed bank and vigour of *R. tuberosa* populations (Collier et al. 2017; Paton et al. 2019b), which would help to provide an alternative nutrient pathway that would retain nutrients for longer time periods (i.e. weeks to months) (Waycott 2020). As volumes of water currently delivered under the Basin Plan are insufficient to meet these requirements (Paton et al. 2019b), high (unregulated) flow events are needed more frequently and, in addition to an open Murray, are important to support the maintenance of key processes in the Coorong, particularly the flushing of salt and nutrients to support suitable water quality conditions.

Future investigations

Future management of the Coorong will be reviewed as part of the Healthy Coorong Healthy Basin (HCHB) Program (DEW 2020). The HCHB Trials and Investigations Project will inform broader HCHB investigations into long-term management solutions (including infrastructure options) to support the health of the Coorong (DEW 2020). The investigations into restoring a functioning Coorong food web (as part of the Trials and Investigations Project) will determine how barrage inflows, flows from Salt Creek and dredging of the Murray Mouth should be managed in order to restore a functioning South Lagoon food web (i.e. one that is able to produce and supply energy to key biota) to in turn support viable waterbird populations (DEW 2020). The HCHB On-Ground Works project is proposing small-scale infrastructure upgrades at priority sites in the Lower Lakes to improve or increase availability of preferred habitat for key species of waterbirds at risk in the Coorong South Lagoon.

10.7 Conclusion

10.7.1 Lakes

The waterbird community in the Lakes has recovered since the Millennium Drought. The abundances of selected species from the herbivore, generalist and piscivore guilds all were likely to have improved over the duration of the assessment period, from 2009 to 2019. Similarly, the distributions of selected species within these guilds also improved. These improvements have been influenced by the delivery of water, namely through the management of lake water levels, improved system connectivity and the restoration of salinities reflective of pre-drought conditions. These have in turn improved habitat conditions, potential food resource availability and regular breeding opportunities for waterbirds in the Lakes.

Key messages:

- The waterbird community in the Lakes improved since the end Millennium Drought and is considered to have recovered.
- Water delivery since the adoption of the Basin Plan has supported the management of lake levels, including seasonal water level variability and the maintenance of Lake levels above +0.4 m AHD that have provided key habitats, and supported food resources and breeding of waterbirds.
- Improved system connectivity and the restoration of salinities to those reflective of pre-drought conditions may have also helped to maintain food resource availability and distribution for waterbirds and provided conditions to support waterbird breeding.
- High (unregulated) flows were important for restoring lake levels above +0.4 m AHD in 2010/11 and flushing salt from the system. These flows are important and are needed more frequently to support the maintenance of key processes in the Lakes, particularly the flushing of salt to support suitable salinity regimes.
- Maintaining current hydrological and salinity regimes will be important in providing conditions that support the continual improvement of key waterbird habitats in the Lakes.

10.7.2 Coorong

Recovery of the waterbird community in the Coorong since the Millennium Drought has varied between guilds, with the abundances of herbivores, generalists and piscivores having either remained stable or improved, while resident and migratory shorebirds have declined in abundance and their distributions have remained stable. Differences in improvement or lack thereof between guilds was influenced by hydrological and water quality factors, including water levels, salinity, nutrients and filamentous algae, and the impact these conditions have on the accessibility and availability of food resources, and for certain species the ability to breed (and success of breeding).

Key messages:

- Recovery of waterbirds since the Millennium Drought has varied between guilds, with the abundance and distribution of herbivores, omnivores and piscivores having either remained stable or improved, while resident and migratory shorebirds have declined in abundance and their distributions have remained stable.
- While the delivery of water for the environment and high (unregulated) flow events have prevented salinities in the Coorong from becoming reminiscent of the Millennium Drought, inadequate water levels and poor water quality have hampered the recovery of key waterbird habitats and food resources, and subsequently the abundances and distributions of waterbirds in the Coorong.
- Excessive filamentous growth over the Coorong has adversely impacted key food resources for waterbirds, including *R. tuberosa* and benthic macroinvertebrates (i.e. chironomid larvae) and has also reduced the accessibility of food resources, particularly for shorebirds.
- An open Murray Mouth along with periodic high (unregulated) flow events are important and are needed more frequently to support the maintenance of key processes in the Coorong, particularly the flushing of salt and nutrients to support suitable water quality conditions.
- Migratory shorebirds have declined in the Coorong at a rate greater than elsewhere in Australia. However, factors outside of Australia, particularly, the loss and degradation of the key staging sites in the Yellow Sea are considered to be the primary drivers of decline in migratory shorebird populations in the East Asian-Australasian Flyway. In turn, these population declines would have impacted the number of migratory shorebirds present at the Coorong each summer.

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