

Healthy Coorong, Healthy Basin

Trials and Investigations Project key findings

Scientific evidence-base to inform restoration of the Coorong
2023



Foreword

The Coorong is a wetland of local, national and international importance and one of the most significant waterbird habitats in the Murray-Darling Basin. The ecological condition of the Coorong has been in decline for many decades, mainly due to over-extraction of River Murray flows and extensive modifications to flow pathways. The extreme drought conditions experienced across southern Australia during the Millennium Drought (2001-2010), had disastrous effects on the Coorong, and exacerbated the decline in its condition.

Post-drought increases in natural and managed inflows to the Coorong have supported the recovery of some ecological characteristics to pre-drought conditions, but many have not recovered or continue to decline. In particular, the long-term accumulation of salt and problematic nutrients, in association with low water levels over late spring and summer, particularly in the South Lagoon, have prohibited the recovery of the system to a desired healthy state.

In recognition of the Coorong South Lagoon's declining condition and the Ramsar-listed wetland's importance to the health of the Murray-Darling Basin, the *Healthy Coorong, Healthy Basin* (HCHB) Program is working to improve the ecology, knowledge and management of the Coorong.

In 2019, the South Australian Government released the *Healthy Coorong, Healthy Basin* Action Plan, which outlined the short, medium and long term on-ground works, scientific trials and investigations, management tools and infrastructure activities required from the program to get the Coorong back on track for a healthy future.

Since then, HCHB has completed an unprecedented science program in partnership with the Goyder Institute for Water Research, which addressed scientific knowledge gaps and provided the scientific evidence base to inform management actions to improve the long-term health of the Coorong.

In order to restore the southern Coorong to a state that meets the aspirations of the community, current scientific knowledge needs to be summarised in ways that can guide management actions to achieve it. This *HCHB Scientific Trials and Investigations Key Findings* presents an overview of the key findings and outcomes that have been and will continue to be critical in informing management actions, including the design and implementation of restoration strategies for the Coorong.

Restoring a healthy Coorong is critical for the environment, First Nations, local communities, the South Australian tourism industry, the overall health of the Murray-Darling Basin and the success of the Murray-Darling Basin Plan.

Respect and reconciliation

Aboriginal people are the First Peoples and Nations of South Australia. The Coorong connected waters and surrounding lands have sustained unique First Nations cultures since time immemorial.

The *Healthy Coorong, Healthy Basin* Program acknowledges the range of First Nations' rights, interests and obligations for the Coorong and connected waterways and the cultural connections that exist between First Nations peoples across the region and seeks to support their equitable engagement.

Aboriginal peoples' spiritual, social, cultural and economic practices come from their lands and waters, and they continue to maintain their cultural heritage, economies, languages and laws, which are of ongoing importance.

The Department for Environment and Water works across the State with Aboriginal South Australians to conserve and sustain Country. Through this work we seek to improve the relationship between Aboriginal and non-Aboriginal Australians and build respect based on mutual understanding and acceptance of each other.



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Acknowledgements

The Scientific Trials and Investigations Project was part of the South Australian Government's *Healthy Coorong, Healthy Basin* Program, which is jointly funded by the Australian and South Australian governments.

The Goyder Institute for Water Research was the delivery partner for research components of *Healthy Coorong, Healthy Basin*, providing independent research to inform future management decisions for the region.

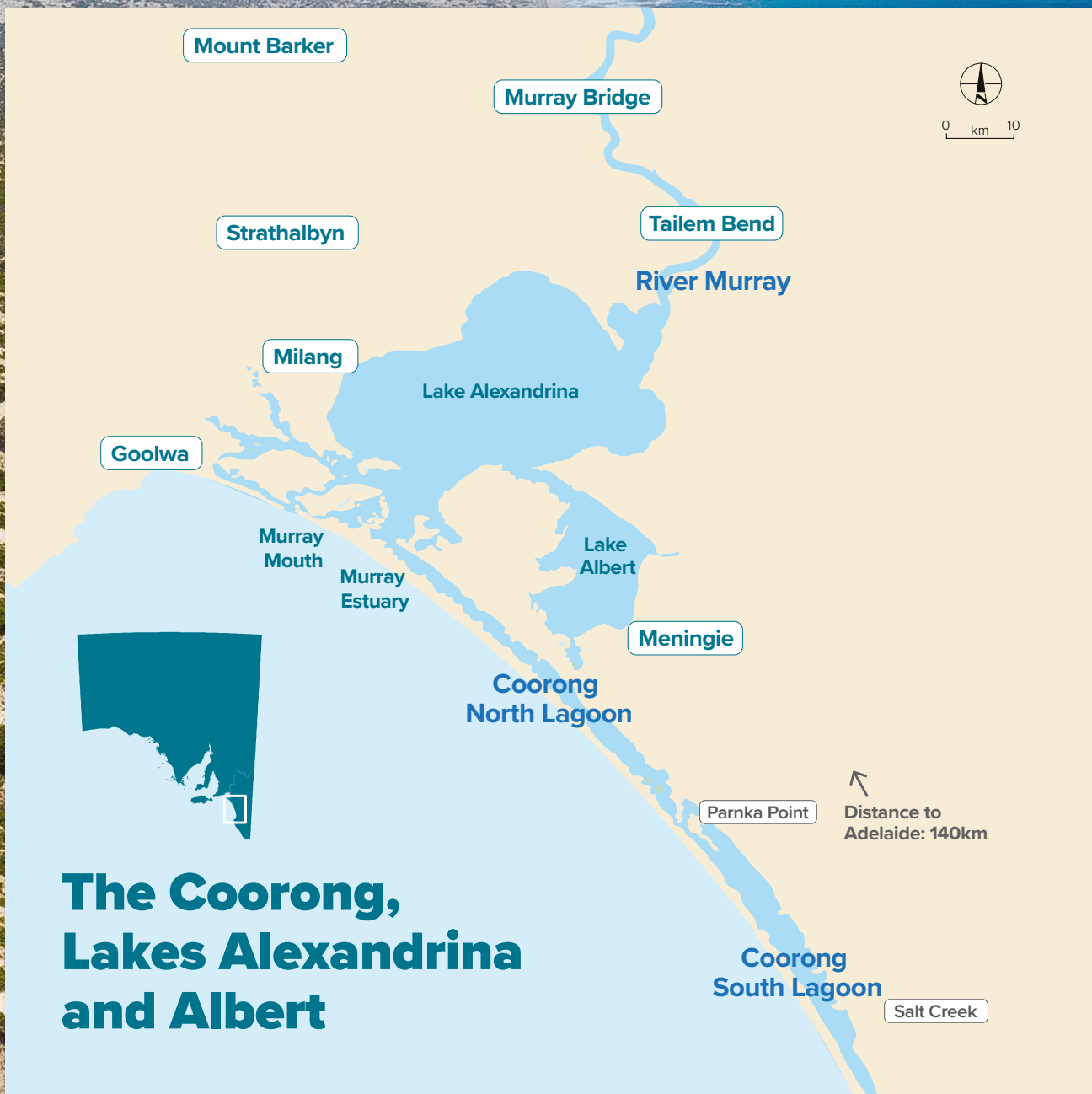
The Ngarrindjeri Aboriginal Corporation was the delivery partner for the Ngarrindjeri knowledge component of *Healthy Coorong, Healthy Basin*, providing a voice for Ngarrindjeri Peoples cultural knowledge, values and interested to shaping, informing and implementing initiatives across the *Healthy Coorong, Healthy Basin* Program.

Healthy Coorong, Healthy Basin

The *Healthy Coorong, Healthy Basin* (HCHB) Program is a commitment to restore the long-term health of the Coorong that is jointly funded by the Australian and South Australian governments.

The HCHB Program seeks to provide evidence-based solutions to both immediate threats and to future conditions anticipated under a changing climate. This is done through a combination of activities to meet short, intermediate and long-term restoration objectives for the Coorong.

The Scientific Trials and Investigations Project was one of six HCHB Phase 1 (2019-2022) Projects, alongside: On-ground works, Water Resource Optimisation, Long-term Operational Infrastructure Investigations, First Nations Partnerships and Community Partnerships.



Scientific Trials and Investigations

Through two decades of monitoring and research conducted under The Living Murray Program (since 2002) and Coorong, Lower Lakes and Murray Mouth Recovery Project (2011-2016), we have built a good understanding of the Coorong and its role in supporting a unique diversity of fish, plants and waterbirds.

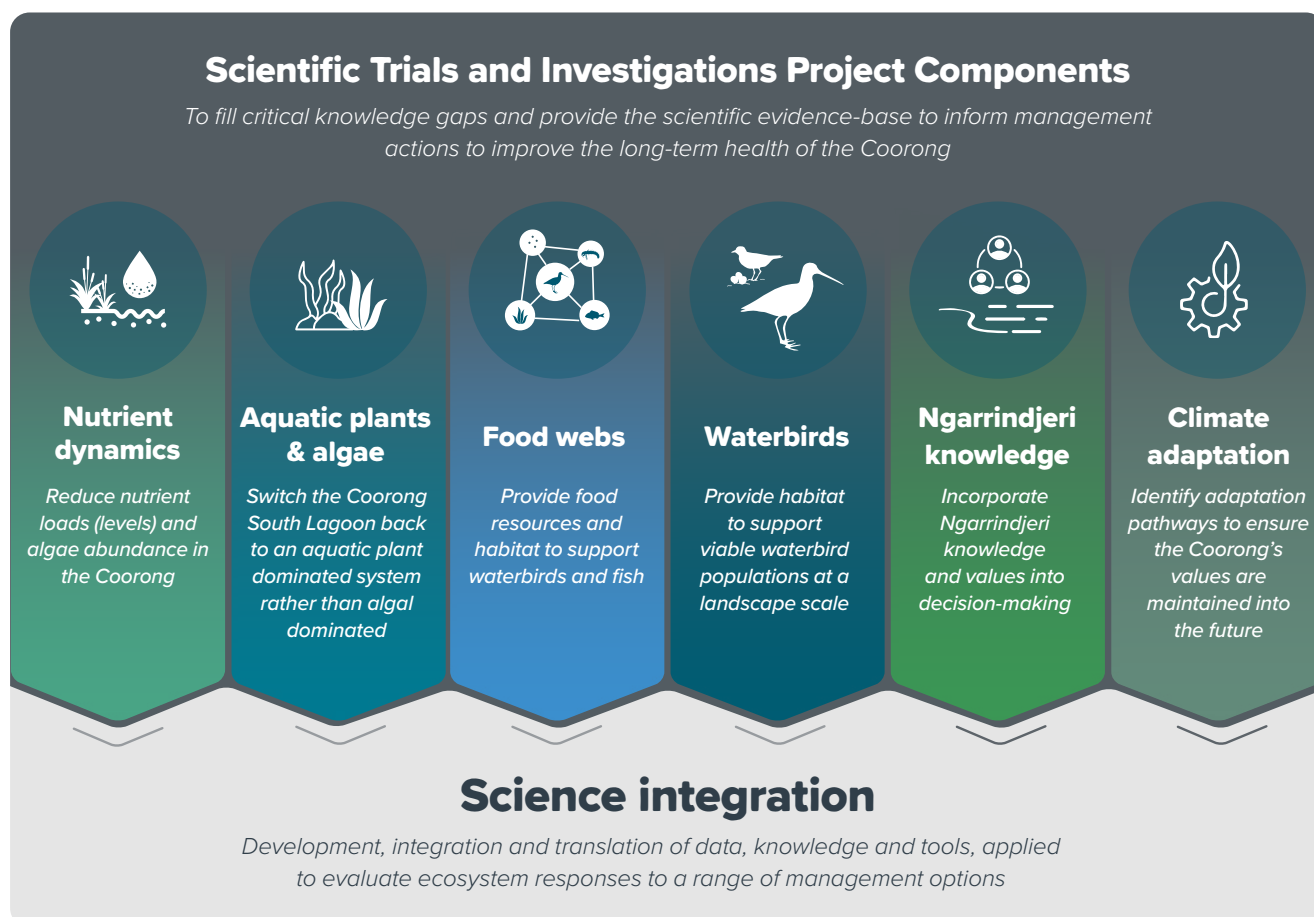
However, some elements of the Coorong ecosystem have now undergone a number of long-term changes and a number of new threats to the ecosystem present new management challenges for which we need to find solutions.

The Scientific Trials and Investigations Project (2019-2022) was specifically designed to identify and address scientific knowledge gaps to inform the development of targeted and effective management actions for the Coorong. The Project priorities and goals were developed in partnership with the Goyder Institute for Water Research, including scientists from CSIRO, Flinders University, The University of Adelaide,

the University of South Australia and the South Australian Research and Development Institute (SARDI). The First Nations knowledge project was led and delivered by the Ngarrindjeri Aboriginal Corporation.

The delivery of the Project included more than 70 researchers and 20 government scientists, with a strong focus on early career researchers to build capacity in SA. The Project drew on interdisciplinary expertise across hydrology, biogeochemistry, aquatic ecology, quantitative modelling, First Nations Peoples knowledge and social science; facilitating innovative science to help solve complex problems in the Coorong.

The Scientific Trials and Investigations Project had seven components: *Nutrient dynamics, Aquatic plants and algae, Food webs, Waterbirds, Ngarrindjeri knowledge, Climate adaptation and Science integration*. Science delivered across components addressed critical knowledge gaps and tested assumptions to determine how to transform the Coorong from its current vulnerable state to a healthier and more resilient ecosystem. Collectively the project has provided the scientific evidence-base to inform management actions to improve the long-term health of the Coorong.



Key outcomes of the Trials and Investigations

The Scientific Trials and Investigations Project filled critical knowledge gaps and provided the scientific evidence-base to inform the development of targeted and effective management actions to restore key Coorong ecosystem functions.

Collectively, the Trials and Investigations Project significantly improved our ability to manage the Coorong in a way that is supported by scientific evidence and tools, providing managers and the community with improved confidence. Key findings and the data sets that underpin them, have provided an evidence base that is supporting plans for the future.

- Improved understanding of the relationship between hydrology, nutrient dynamics, and plant-algae interactions filled fundamental gaps in our understanding of the system and is critical for how we manage the site in the future
- Scientific findings, model development and interpretation were undertaken to integrate historical and current scientific data and information directly informing policy and program decisions at the whole-of-system scale



Unprecedented **\$10.9 million investment** in scientific research to **inform restoration** and future management of the Coorong



Significant collaboration across 13 organisations, with **>90 scientists**



Interdisciplinary expertise – across hydrology, biogeochemistry, aquatic ecology, quantitative modelling, Indigenous knowledge and social science



Strong focus on early career researchers to **build capacity in SA**



Encourage and facilitate **innovative science** to help solve complex problems



Managers and policy-makers embedded within the research components



Coorong ecosystem at a glance



Murray-Darling Basin

Located at the **end** of Australia's largest river system, the Coorong is an important part of the Murray-Darling Basin.



Geomorphology

Coorong is a **140 km** long, coastal lagoon system, including two lagoons (North and South), separated by a narrow constriction at Parnka Point.



Hydrodynamics

A **shallow inverse estuary** with dynamic interactions between freshwater and oceanic influences of tides, waves, currents and winds.



River Murray Water

Primary source of freshwater flows into the Coorong and Southern Ocean.

*Average barrage outflows
3663 GL/yr (1990 – 2022)*



Marine Exchange (Murray Mouth)

Inflows of tidal marine waters flow through the Murray Mouth into the Coorong.

*Only connection to the sea in the
Murray-Darling Basin*



South East Flows

Fresh/brackish water flows from South East SA into the Coorong South Lagoon.

Average 11.4 GL/yr (1990-2020)



Water Quality

Salinities range from brackish (~25 g/L, Murray estuary), hypersaline (>40 g/L North Lagoon), extremely hypersaline (>60 g/L, South Lagoon).

*South Lagoon predominantly **hyper-eutrophic***



Sediment Conditions

Sediment quality in the southern Coorong is degraded with high nutrient levels.

*50 times more nutrients in the top 5 cm
compared to the water column*



Aquatic plants

Play critical keystone ecological roles and are an important resource in the ecosystem.

*Southern Coorong community
consists of at least **3 species***



Benthic macroinvertebrates

Key food resources for fish and waterbirds, and oxygenate sediments.

*Only **28%** of the species found
in the Coorong occur in the South Lagoon
and >**50%** of them are insect larvae*



Fish

Supports important commercial, recreational and cultural fish species.

*Majority of South Lagoon
fish community are
small-mouthed hardyhead*



Waterbirds

Supports national and international threatened and migratory species.

*Regularly supports over **100,000**
waterbirds annually, including over **30,000**
migratory shorebirds each summer*



Internationally significant

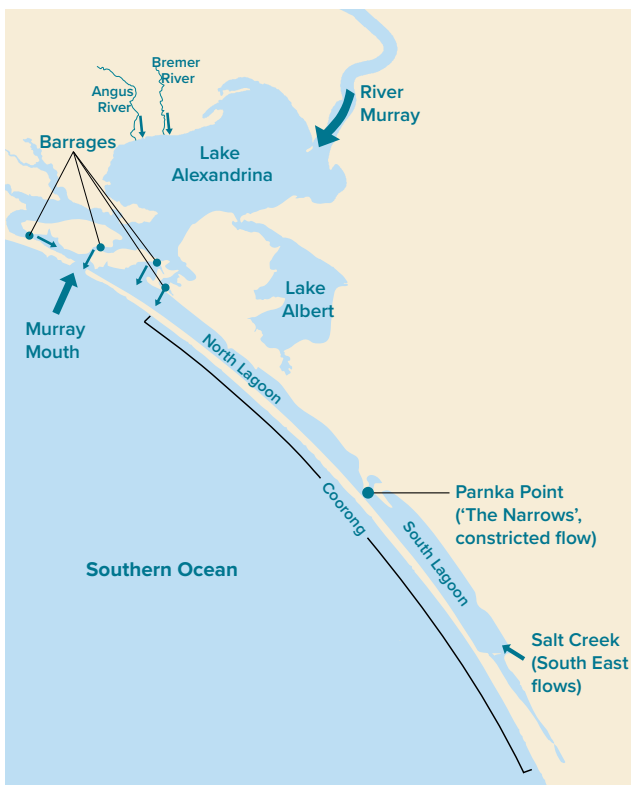
Part of the Coorong, Lakes Alexandrina and Albert Wetland (Ramsar site).

People and industry need a healthy Coorong wetland system to thrive



Hydrology: Coorong Inflows and Outflows

The River Murray is the primary source of freshwater inflows to the Coorong. River Murray flows are released to the Coorong and Murray Mouth via the barrages. Barrage outflows to the Southern Ocean are critical in ensuring the maintenance of tidal exchange and ensuring the Murray Mouth remains open, which are both crucial to the Coorong's hydrodynamics.



Inflows from the *River Murray* provide the primary source of flows to the Murray estuary and Coorong. These inflows are generally highest between September-November, and lowest between February-April; median annual flow of 4077 GL (Lock 1).

Small volumes of freshwater-brackish water flow directly into the South Lagoon, at Salt Creek via drainage networks in the *upper south-east of SA*. SE inflows peak between August-November; median annual flow 11 GL. There are also minor contributions of inflows into Lake Alexandrina from a number of small tributaries in the *Eastern Mount Lofty Ranges*; median annual flow of 73 GL. *Groundwater* inflows to the Lakes and Coorong are very minor.

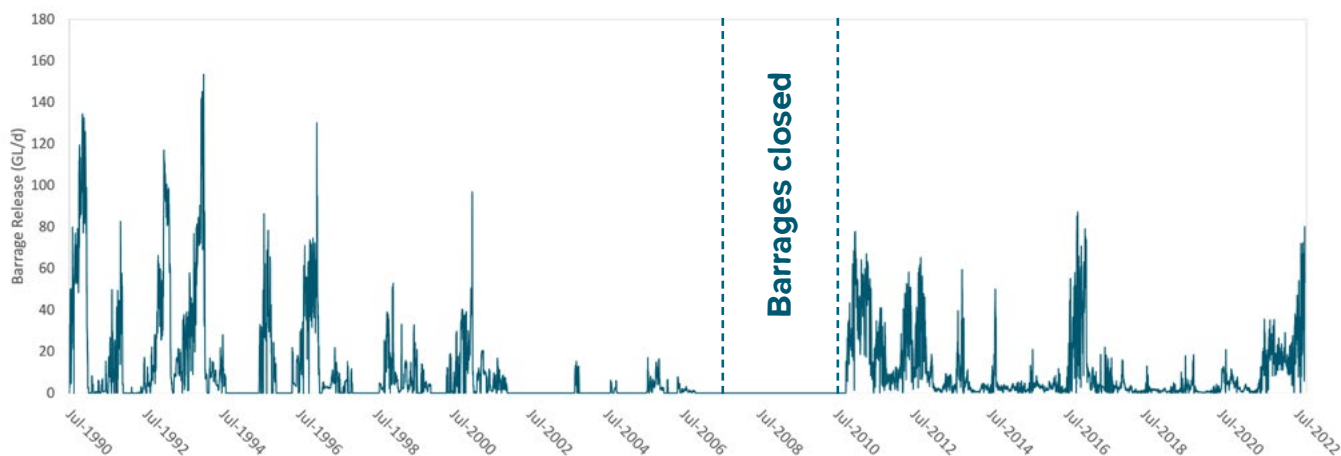
The *Murray Mouth* provides the connection between freshwater environments (River Murray and Lakes), the Murray estuary, Coorong and Southern Ocean. It is the only point in the Murray-Darling Basin where the river system connects to the sea. This connection is important to allow flushing of excess salts, nutrients and sediment from the river system, as well as supporting marine productivity and maintaining water quality in the Coorong.



Flows to the Coorong are dependent on the magnitude of River Murray flows delivered via five barrages, spanning 7.6 km. There were no barrage outflows between 2007 and 2010 during the Millennium Drought (2001-2010), preventing connectivity to the Murray Estuary and Coorong and causing significant increases in Coorong salinity. Releases have averaged 3417 GL/yr in the decade since 2011.

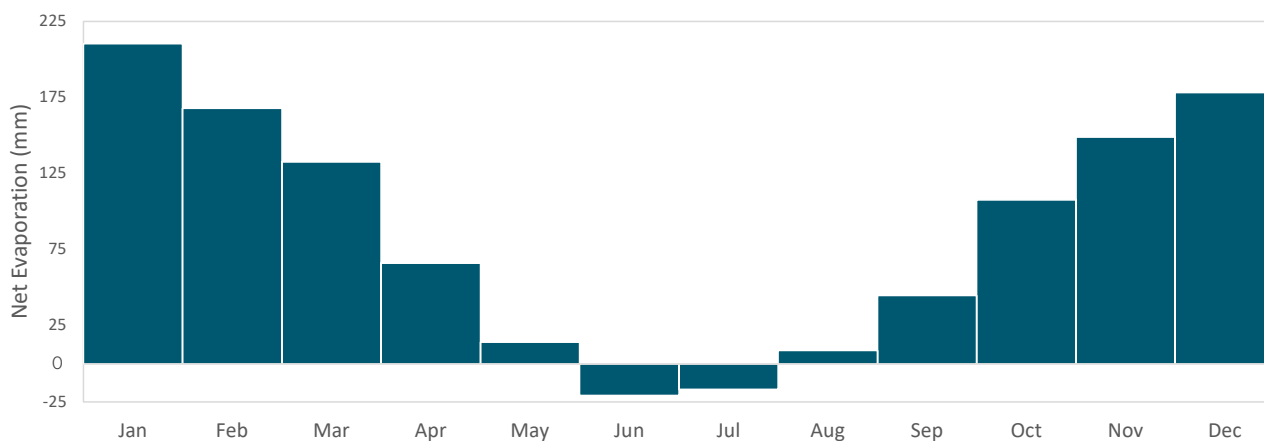
Annual evaporation is significantly greater than rainfall over the Coorong. Net evaporation (evaporation minus rainfall) is highest during summer, reducing water levels and causing evapo-concentration of salinity and nutrients.

Barrage outflow



Calculated total barrage flow between 1990 and 2022 (Source: Water Data SA (<https://water.data.sa.gov.au/>)).

Net evaporation

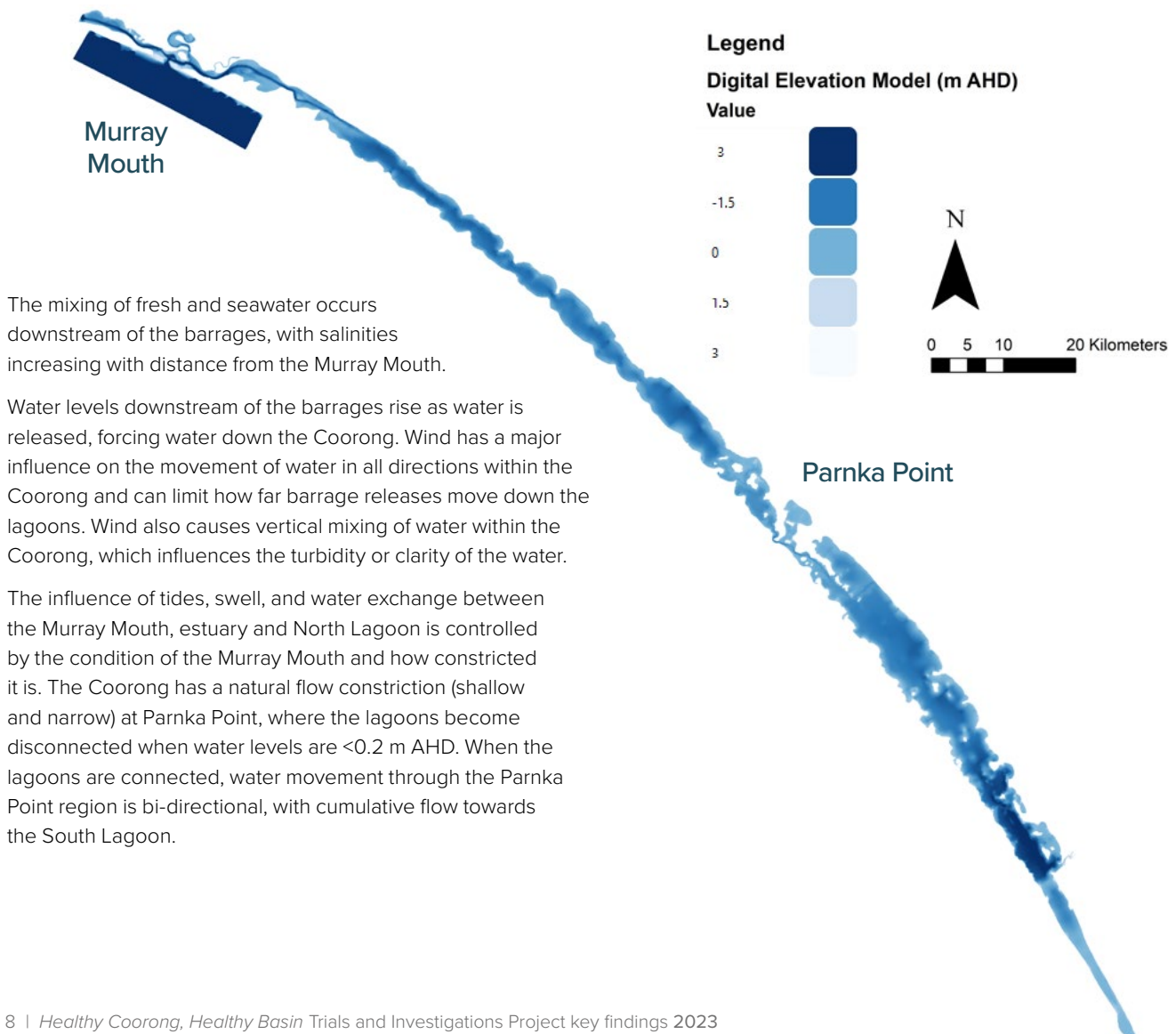


Net evaporation (evaporation minus rainfall) calculated for a SILO climate site in the Coorong. (Source: SILO Australia climate database <https://www.longpaddock.qld.gov.au/silo/>).



Hydrodynamics: how does water move in the Coorong

The Coorong is a shallow and narrow lagoon with a constricted channel connection to the ocean at the Murray Mouth. Ocean water level variations and barrage releases are key drivers of Coorong hydrodynamics, with seasonal water movement influenced by the volume of barrage outflows, contributions from the Southeast drainage networks, tidal exchange through the Murray Mouth, wind, and evaporation.

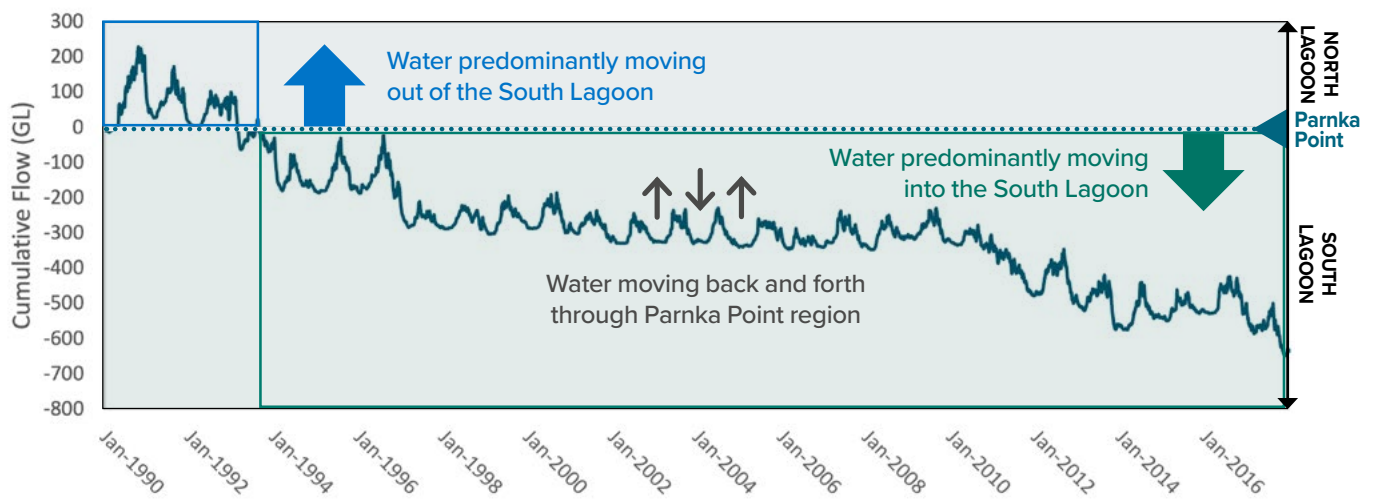




Cumulative flow

Modelled daily flow across a cross-section at Parnka Point helps us to understand the predominant direction of water movement at that point in the Coorong. The pattern of flow indicates constant movement in both directions but with flow

predominantly towards the Coorong South Lagoon. This indicates a lack of flushing, which is required to export salt and nutrients out of the South Lagoon.

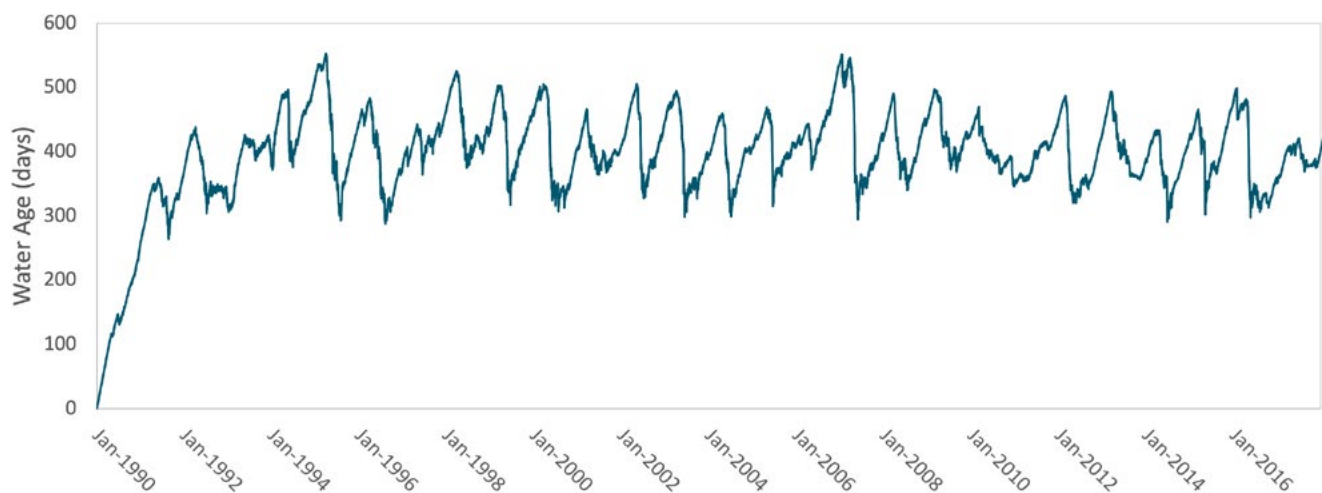


Cumulative flow across a model cross section at Parnka Point. (Source: TUFLOW-FV historical base case model run).

Water residence time

The average modelled water residence time for the South Lagoon (Woods Well) is greater than one year, indicating

a lack of water exchange between the South and North Lagoons, and minimal flushing of the South Lagoon .



Modelled water age at Woods Well in the Coorong South Lagoon (Source: TUFLOW-FV historical base case model run).

Water levels and salinity in the Coorong

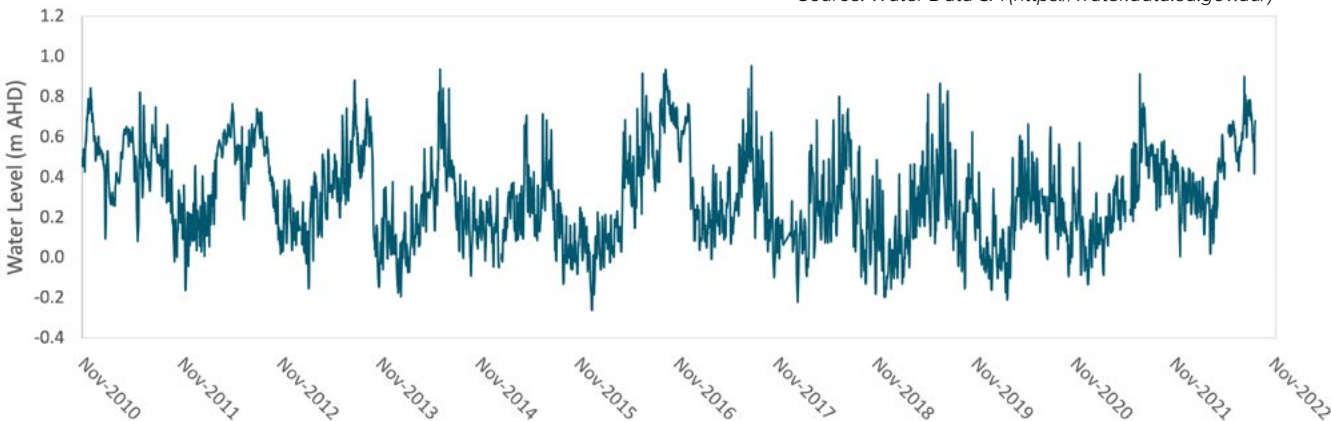
Water levels and salinity in the Coorong vary in response to both seasonal and long-term climate cycles and water delivery. Key biota in the ecosystem, including aquatic plants, invertebrates, fish and waterbirds, are greatly impacted by water levels and salinity, which affect habitat suitability, reproduction and survival.

Water levels in the Coorong can vary hourly, influenced by tides and wind. Seasonal variation in water levels are primarily influenced by barrage flows, ocean inflows and evaporation. North Lagoon water levels are influenced by the interaction of barrage outflows and the condition of the Murray Mouth, and are typically lowest in late summer/early autumn and highest

in winter. Water levels in the South Lagoon are less variable due to the absence of tidal influence. South Lagoon water levels show a strong seasonal cycle due to evaporation and exchange with the North Lagoon, and are highest in winter and lowest in late summer.

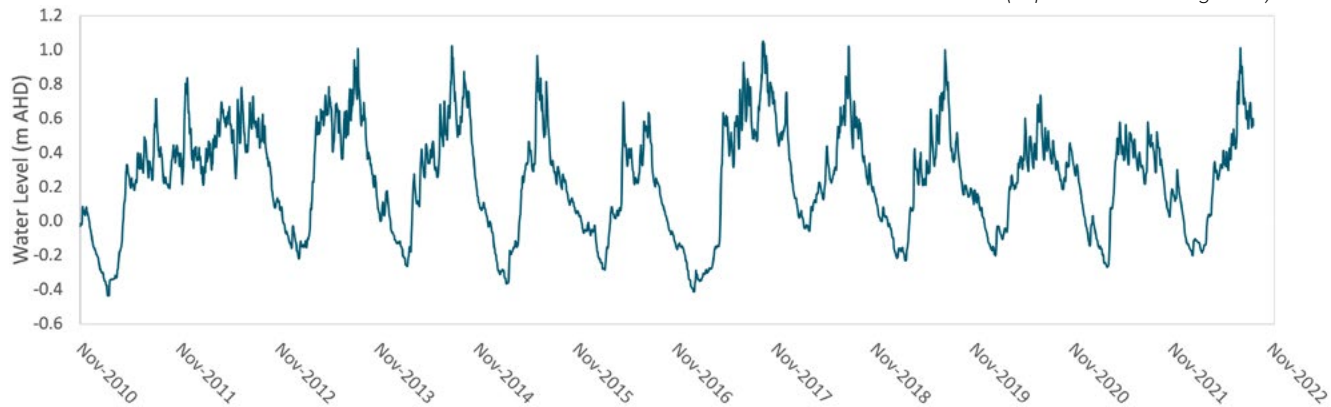
North Lagoon (Long Point) water level

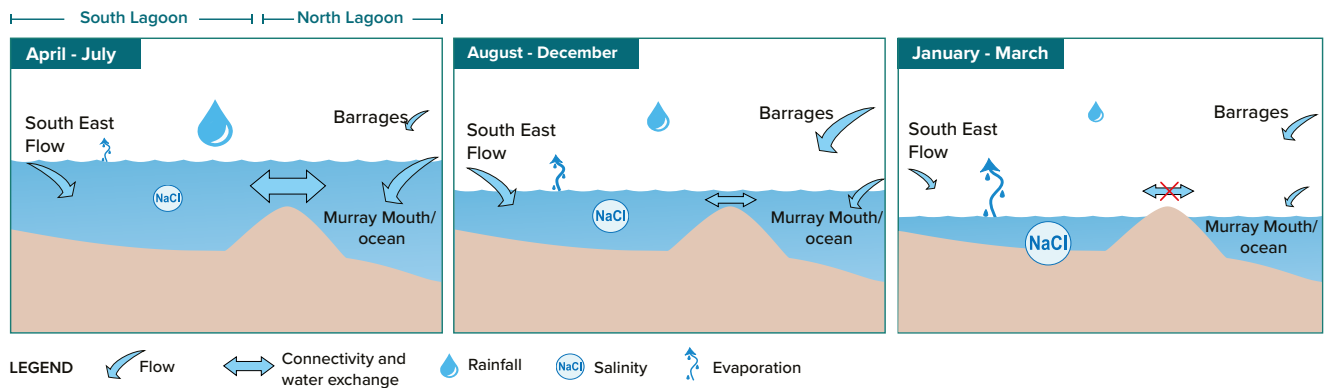
Source: Water Data SA (<https://water.data.sa.gov.au/>)



South Lagoon (Woods Well) water level

Source: Water Data SA (<https://water.data.sa.gov.au/>)



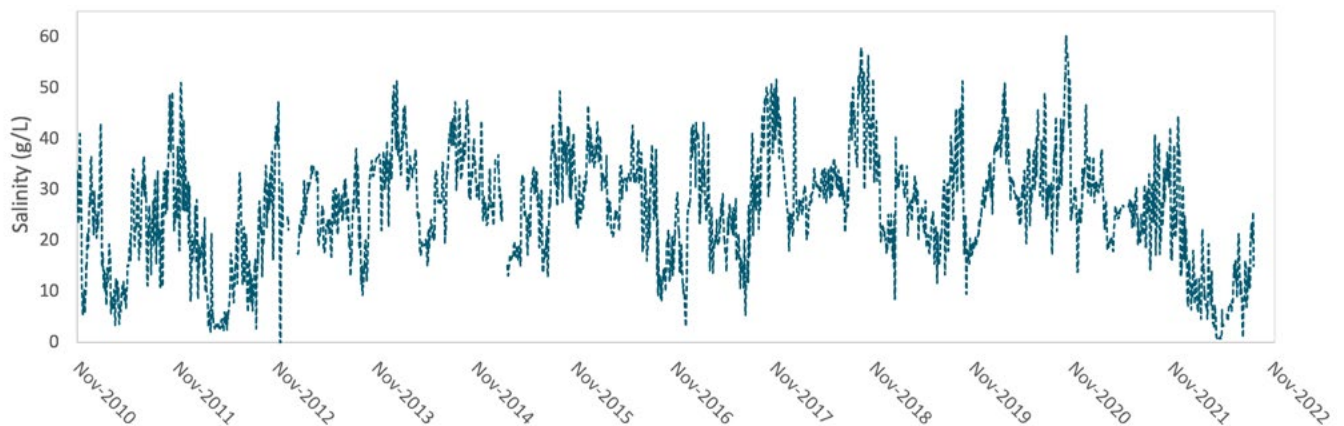


Salinity in the Coorong (North and South Lagoons) follows a seasonal cycle, which is magnified in the South Lagoon. Salinity is always higher in the South Lagoon, with salinity in the North Lagoon reduced due to the proximity to the freshening influence of barrage outflows and seawater

exchange (from the Murray Mouth). Salinity in the South Lagoon is greatest in late summer/early autumn in response to high evaporative rates and reduced connectivity throughout summer.

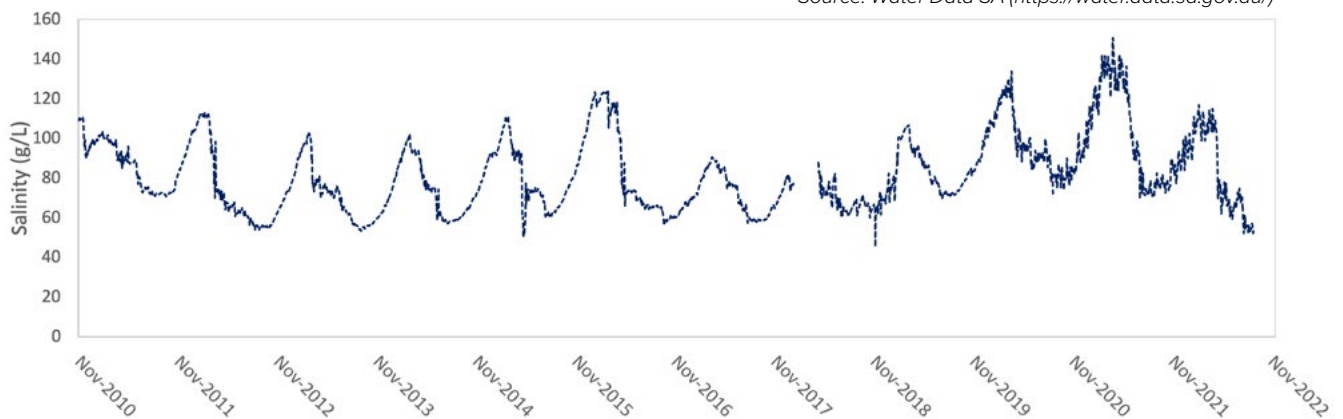
North Lagoon (Long Point) salinity

Source: Water Data SA (<https://water.data.sa.gov.au/>)



South Lagoon (Woods Well) salinity

Source: Water Data SA (<https://water.data.sa.gov.au/>)





Nutrient Dynamics

Nutrient levels and cycling processes in the Coorong are in an unhealthy, hyper-eutrophic state, with excess nutrients accumulating and promoting the growth of phytoplankton and filamentous algae.

Priority research questions

- What are the sources and amounts of nutrients coming into the Coorong and where do they reside?
- What forms of nutrients are present and how are these influencing ecological processes and function?
- What are the pathways for restoring healthy nutrient cycling and nutrient export?

Key findings

Nutrient sources

- The majority of nutrients entering the South Lagoon come from the River Murray and Southern Ocean via the North Lagoon, with Salt Creek a minor (<1%) input on average.
- Groundwater is a minor source of nutrients, but provides locally important freshwater lenses
- Import and export of nutrients in the Coorong is strongly influenced by hydrology:
 - areas flushed by River Murray flows and tidal exchange generally exported nutrients and areas of hydrological restriction, such as the South Lagoon, imported nutrients
- Nutrients were continuously imported into the South Lagoon for the past decade, except under periods of high barrage flows (2016/17, 2022/23)

Nutrient concentrations

- The South Lagoon is in an unhealthy, hypereutrophic (nutrient-rich) state, containing high nutrient (nitrogen and phosphorus) and organic matter loads (plankton and algae)
- Concentrations of Nitrogen and Phosphorus were greater in the South Lagoon than North Lagoon due to the hydrological restriction, a lack of flushing and evaporative concentration
- A very small proportion of water column nutrients were inorganic, suggesting that phytoplankton and filamentous algae rapidly uptake any immediately bioavailable nutrients

Nutrient cycling and flux

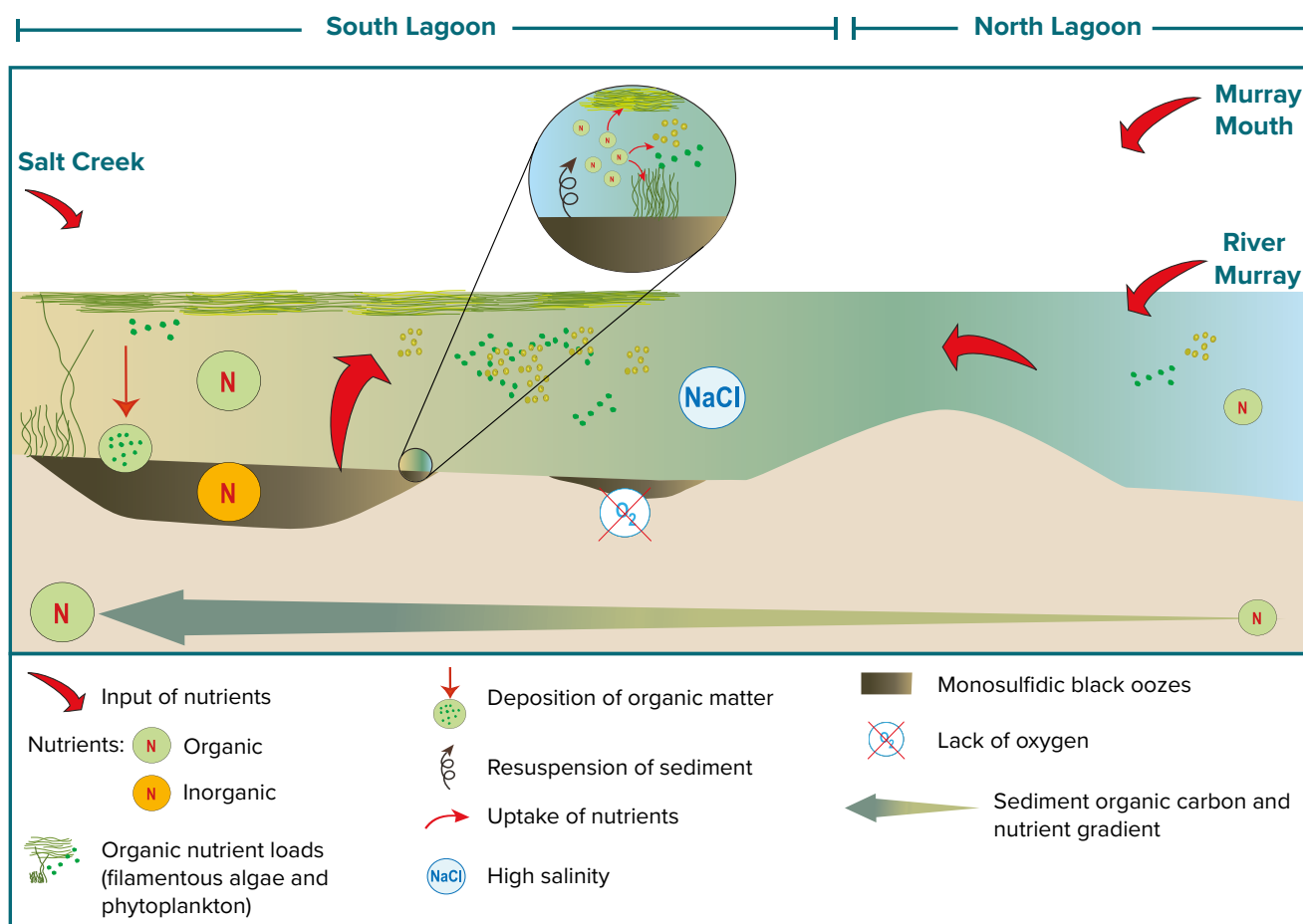
- 40-50% of the nutrients in the South Lagoon water column came from the sediment due to the breakdown

and release of nutrients from high amounts of organic matter that has been deposited

- Oxygen-poor and sulfide-rich sediments of the South Lagoon have impaired healthy nutrient cycling and led to an accumulation of nitrogen and phosphorus.
- Nutrient release from the sediment to water column is likely to continue, even under higher flushing scenarios, due to long-term nutrient accumulation
- Aquatic plants and burrowing macroinvertebrates oxygenated sediments, which improved nutrient cycling and sediment condition. Note that bioturbating macroinvertebrates are currently absent from the South Lagoon.
- High salinities are impacting aquatic plants and burrowing macroinvertebrates, limiting their ability to improve sediment condition

Sediment condition

- The organic carbon and nutrient content of Coorong sediments increased along a gradient from the Murray Mouth to the South Lagoon
- Nitrogen and phosphorus were concentrated in surface sediments, with up to 50 times more nutrients in the top 5 cm of sediment compared to the whole water column in the Coorong
- High organic matter (e.g. from algal deposition) and a lack of oxygen in sediments have led to the formation of monosulfidic black ooze (MBOs) in the Coorong
- MBOs were the dominant sediment type throughout the South Lagoon and southern region of the North Lagoon



Ideas for improvement

- Frequent large flows from the River Murray are needed to flush the South Lagoon
- Improved lagoon flushing and connectivity to dilute and export salt and nutrients, and help to reinstate healthy nutrient cycling
- Enhanced lagoonal flushing, via increased freshwater inflows and seawater exchange, to reduce organic matter (e.g. from decaying algae), deposition of organic matter to the sediment, and promote healthy, oxygenated sediments
- Reduced salinity (<60 g/L) and nutrient concentrations in the South Lagoon to promote aquatic plant and macroinvertebrate recolonisation, and reinstate the critical functions they play to improve sediment and water quality conditions

Restoring the South Lagoon to a mesotrophic (moderate nutrient) state requires an integrated management approach, but is critical for the recovery of ecological functions, including healthy nutrient cycling.

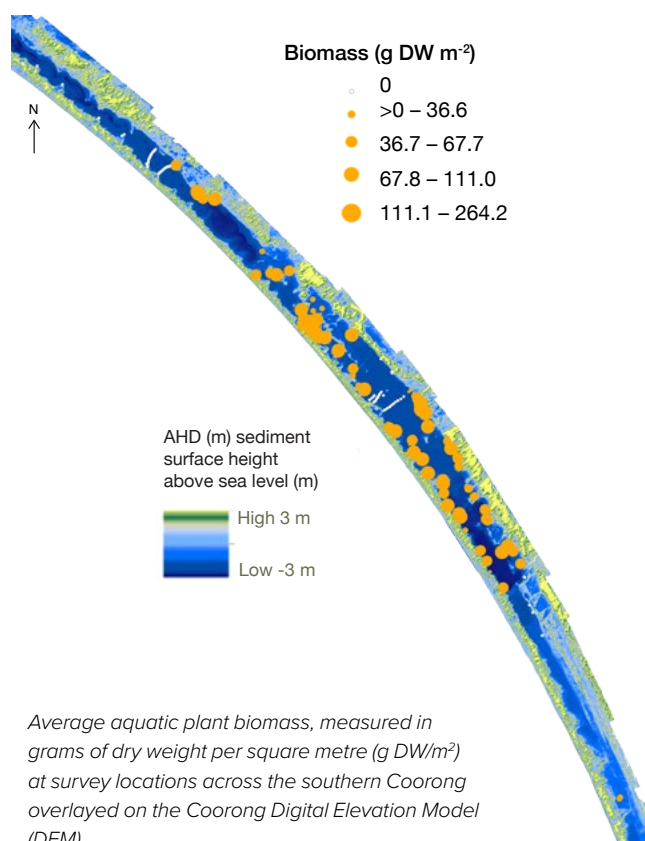


Aquatic plants of the southern Coorong

The current poor condition of the southern Coorong's aquatic plant community is putting at risk its keystone role in maintaining critical ecological functions including stabilising and oxygenating sediments, and providing food and shelter for other organisms and nutrient cycles.

Priority research questions

- What is the current composition and extent of the aquatic plant community in the southern Coorong?
- What are the effects of salinity, temperature and nutrients on aquatic plant growth that inform our ability to optimise habitat that favours longer lived, higher biomass aquatic plants over algae?
- What are the critical elements required to provide long term, large scale, successful restoration of Ruppia communities in the southern Coorong?



Key findings

- What has been commonly known as *Ruppia tuberosa* is in fact a community of at least three species of aquatic plant; the 'Ruppia Community'
 - Species detected to date are *Ruppia tuberosa*, *Althenia cylindrocarpa* and another, possibly new, *Ruppia* species. *Ruppia megacarpa* is found in adjacent water and its seeds are found throughout the southern Coorong
- The presence of the Charophyte, *Lamprothamnium papulosum* in the Coorong was confirmed from laboratory experiments, where it grew from Coorong sediments placed in experimental tanks under conditions of lower salinity, lower nutrients and clearer water (seawater)
- In 2021-22, surveys indicated that of available habitat, the Ruppia Community is currently present from south of Long Point to past Salt Creek, although most sites have low biomass and reduced seed banks
- Ruppia Community seed bank was observed to be low, however turion density was high in late 2021 sampling, likely due to environmental conditions (sustained high water levels with relatively high salinity)

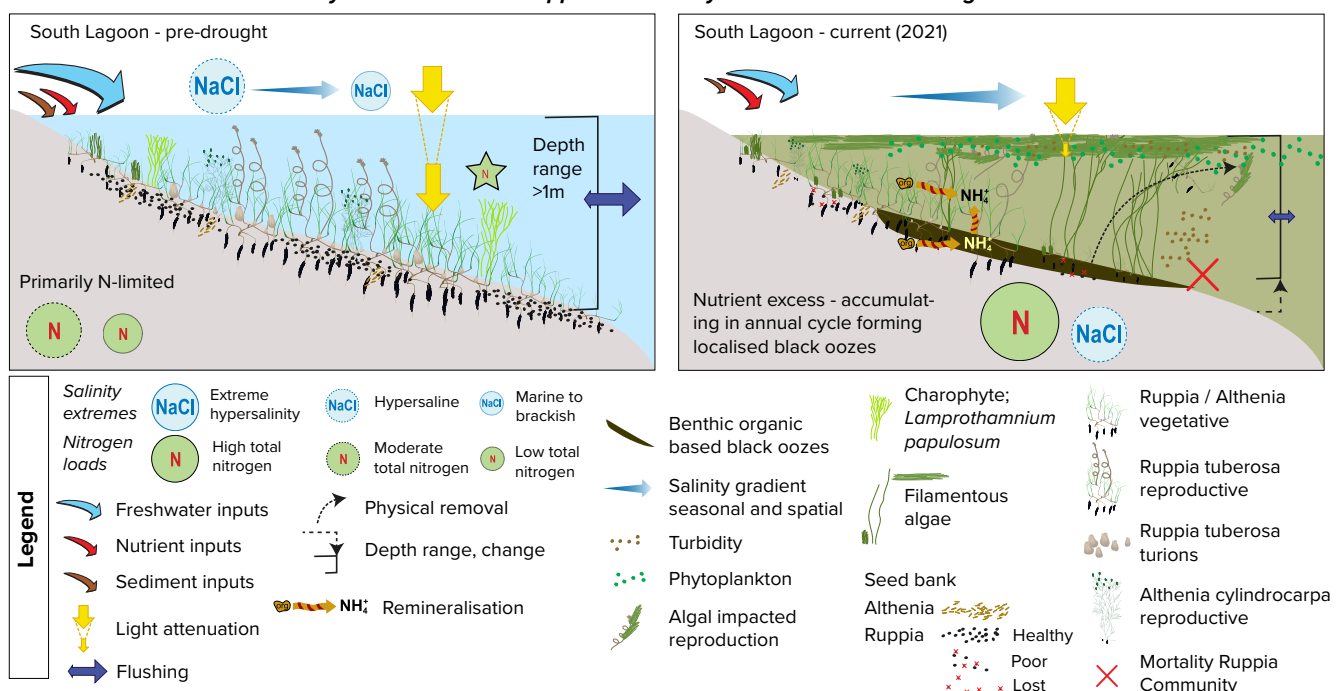


- Experimental evidence for the Ruppia Community indicated that species within it were capable of actively growing (i.e. increasing biomass) at or below marine salinities through to salinity of 90 g/L
- Lifecycle studies of the Ruppia Community indicated plants develop strong root structures first enabling survival under the extreme seasonal conditions
- Below ground plant biomass supported increased sediment oxygenation reducing anoxia, provided sediment stabilisation, increased retention of nutrients and shifted the nutrient balance away from shorter lived organisms
- Microbial communities can support aquatic plant survival in monosulfidic black ooze sediments
- Meadow-scale impacts were caused by shading of plants by dense phytoplankton-laden or turbid (cloudy) water, along with the filamentous algal mats

Ideas for improvement

- Provision of environmental conditions (including maintaining water levels in late spring-summer) which support a range of aquatic plant species
- Improvements to water clarity are required to reduce light stress on the Ruppia Community and for charophytes to recover in the system
- Reduced nutrient loads are essential to minimise the relative advantage the filamentous algae have over the Ruppia Community
- Implement restoration actions for the Ruppia Community if seed banks continue to be depleted (i.e. four years in a row)

Key attributes of the Ruppia Community in the southern Coorong





Algae, a symptom of the problem

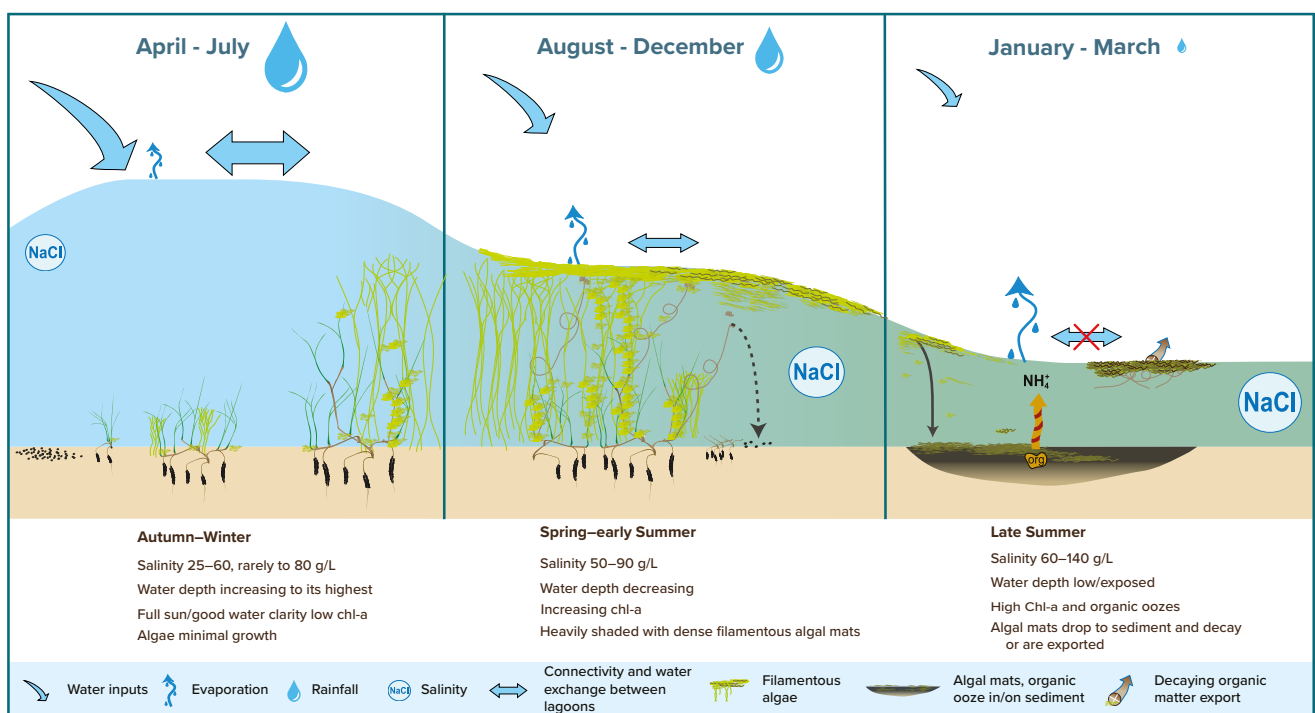
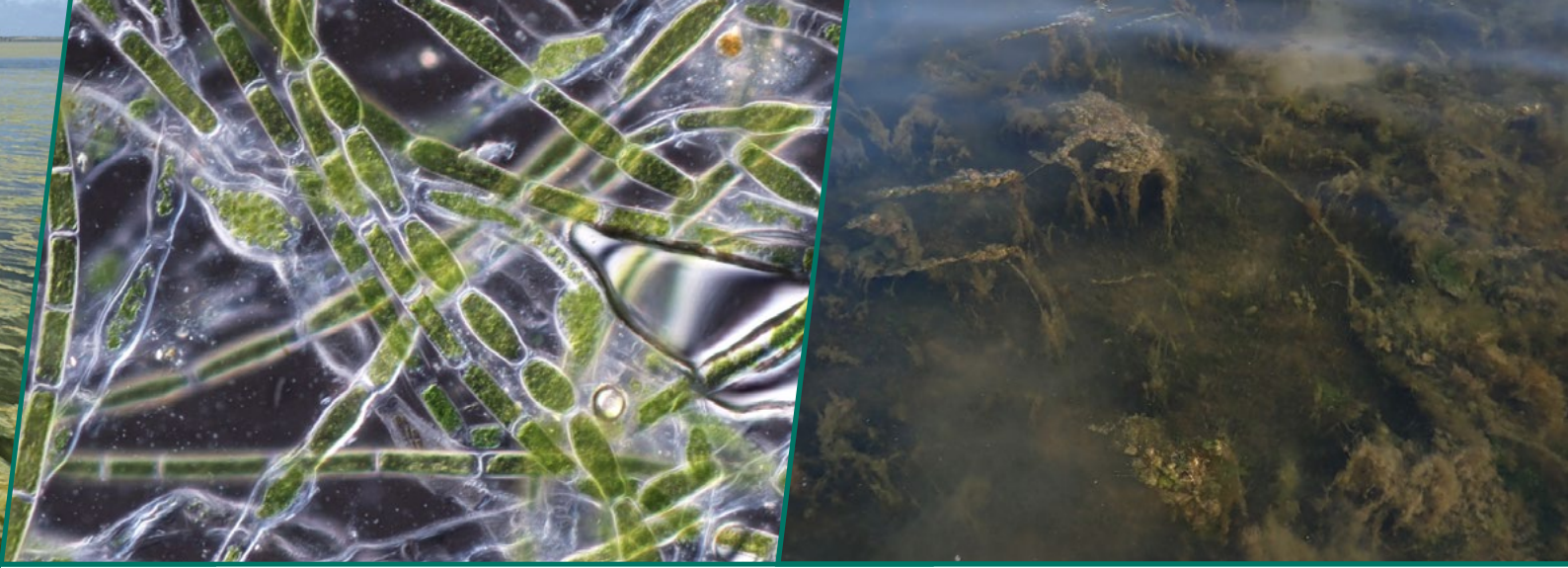
Algal blooms, caused by higher nutrient loads, have been prevalent in spring and summer in the Coorong — filamentous algal blooms interfere with the ability of aquatic plants to produce seed and waterbirds to forage.

Priority research questions

- What are the thresholds of survival for the southern Coorong filamentous algal community?
- Does reducing the algae levels improve Ruppia Community abundance and distribution in the Coorong?
- How can we manage algae to support recovery of aquatic plants?
- Can conditions in the Coorong be managed to return to an aquatic plant dominated system rather than algal dominated, without intervention?

Key findings

- Filamentous algae and the Ruppia Community were co-associated in the southern Coorong; likely due to the Ruppia Community providing a physical substrate for the algae to thrive
- Hyper-eutrophic (nutrient-rich) conditions in the South Lagoon supports the domination of algal blooms, including mat forming filamentous algae
- Salinity and temperature thresholds for high growth of filamentous algal mats align with those of the Ruppia Community
- Investigations determined lower salinities (<40 g/L) for maximum filamentous algal biomass, loss of biomass at salinities ≥ 90 g/L, and upper threshold of 90 g/L to stop filamentous algal growth
- Algal mats (especially biomass greater than 100 g DW/m²) disrupt the Ruppia Community's ability to flower and set seeds, and cause stress due to shading the plants
- Algal mats and dense phytoplankton led to the formation of organic sludges and unhealthy sediments that were anoxic, develop MBOs and made them unsuitable for waterbird foraging
- Picophytoplankton (small phytoplankton) dominate biomass in the South Lagoon, associated with extreme hypersalinity and blooms in summer months
- Microalgal species including blue-green algae, known to be able to form harmful blooms, were found but no blooms were detected
- Trials for manual harvesting of algal mats from the water surface resulted in an unacceptably high level of disturbance to the Ruppia Community and cannot be applied at the scale of the whole southern Coorong ecosystem



Typical seasonal filamentous algae lifecycle of the southern Coorong

Ideas for improvement

- System-wide, nutrient loads need to be significantly reduced, ideally by more than 50 times
- Improved water movement in shallow littoral zone would assist in preventing algae from forming mats
- Reduce the occurrence of high levels of filamentous algal biomass which exceeds 100 g DW/m²
- Small-scale manual removal of filamentous algae is possible but would significantly disturb the Ruppia Community, however is not feasible at large-scale
- Monitoring microalgal communities for changes in community composition can provide early warning evidence of functional changes in sediments



Coorong food webs

A functioning and resilient food web is critical to the Coorong ecosystem. Decades of deteriorating ecological conditions have simplified the food web of the Coorong South Lagoon, which has adversely affected invertebrate and fish communities.

Priority research questions

- What are the primary food sources for key fish and waterbird species in the Coorong South Lagoon and their relative importance?
- How does the availability of zooplankton, macroinvertebrate and fish food vary with key environmental drivers?
- How energy rich and nutritious are the major food items for key fish and waterbird species?
- Can we quantify food web links and develop an integrated food web model for the Coorong ecosystem?

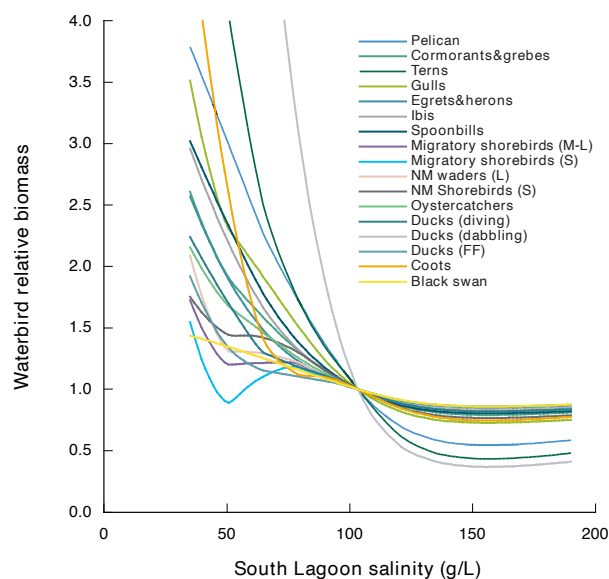
Key findings

Diets of key Coorong fish and waterbirds

- Most Coorong fish feed on benthic macroinvertebrates; e.g. lagoon goby in the Murray estuary and North Lagoon almost exclusively amphipods
- Diets of shorebirds (sharp-tailed sandpiper, red-necked stint and red-capped plover) in the South Lagoon dominated by extremely hypersaline-tolerant chironomid larvae
- Diet of sharp-tailed sandpiper in the North Lagoon was more diverse, with amphipods preferred over chironomids
- Diets of waterfowl (chestnut teal and grey teal) in the Coorong dominated by *Ruppia* and included other vegetation

Food resource availability and key drivers

- Zooplankton diversity and abundance was highest in the Murray estuary, where freshwater species from River Murray flows contributed to productivity
- Zooplankton species diversity decreased with increasing salinity along the Coorong, with the South Lagoon having few species in low density
- Macroinvertebrate communities in the Murray estuary and North Lagoon were species rich, with high abundance and biomass
- Macroinvertebrate prey in the South Lagoon was limited, and dominated by chironomid larvae present in low abundance



- Fish diversity decreased from the Murray estuary to the South Lagoon, but was seasonally variable
- Fish numbers were dominated by small-bodied species; sandy sprat in the Murray estuary and smallmouth hardyhead in the South Lagoon
- Freshwater flow and salinity were the key drivers for the availability of zooplankton, macroinvertebrates and fish
- Highest densities and biomass of macroinvertebrates and fish prey were recorded at salinities <40 g/L, and decreased with salinities >50 g/L

Nutritional value and energy content of major food sources

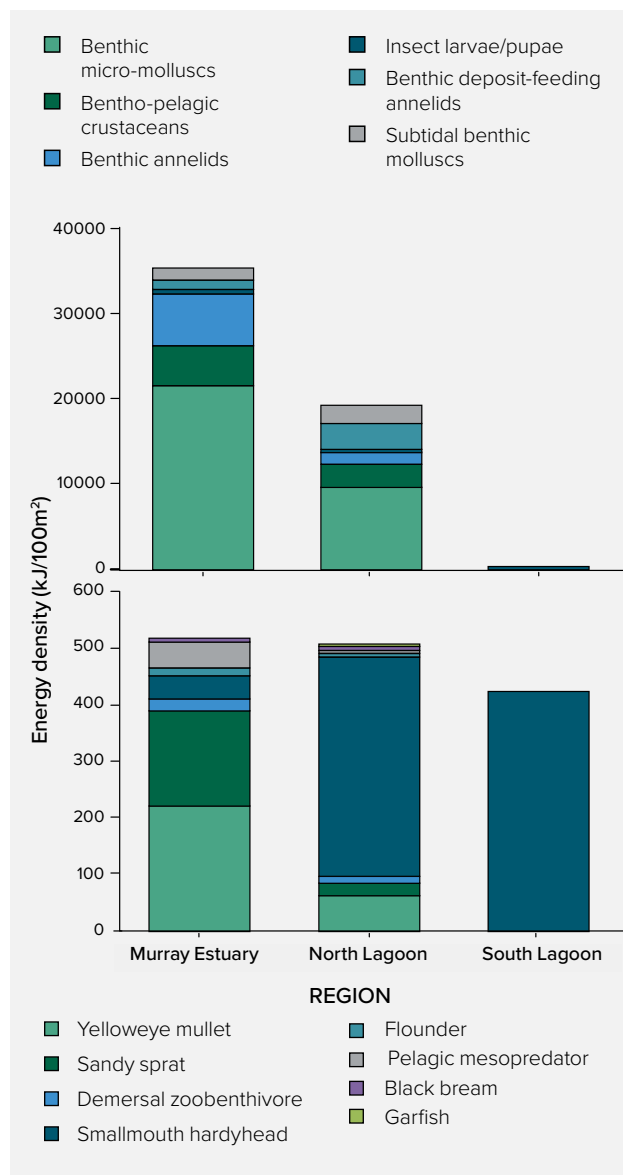
- Fish and shorebirds feeding on macroinvertebrates in the South Lagoon had low prey availability and low nutritional value (energy density)
- Macroinvertebrate prey in the Murray estuary and North Lagoon had high nutritional value, providing energy rich food
- Nutritional value of fish was seasonally variable, but slightly higher in the Murray estuary and North Lagoon, compared to the South Lagoon where most energy was sourced from the high abundance and biomass of smallmouth hardyhead
- The nutritional value of smallmouth hardyhead was reduced in the South Lagoon during summer, suggesting seasonal salinity stress

Food web modelling

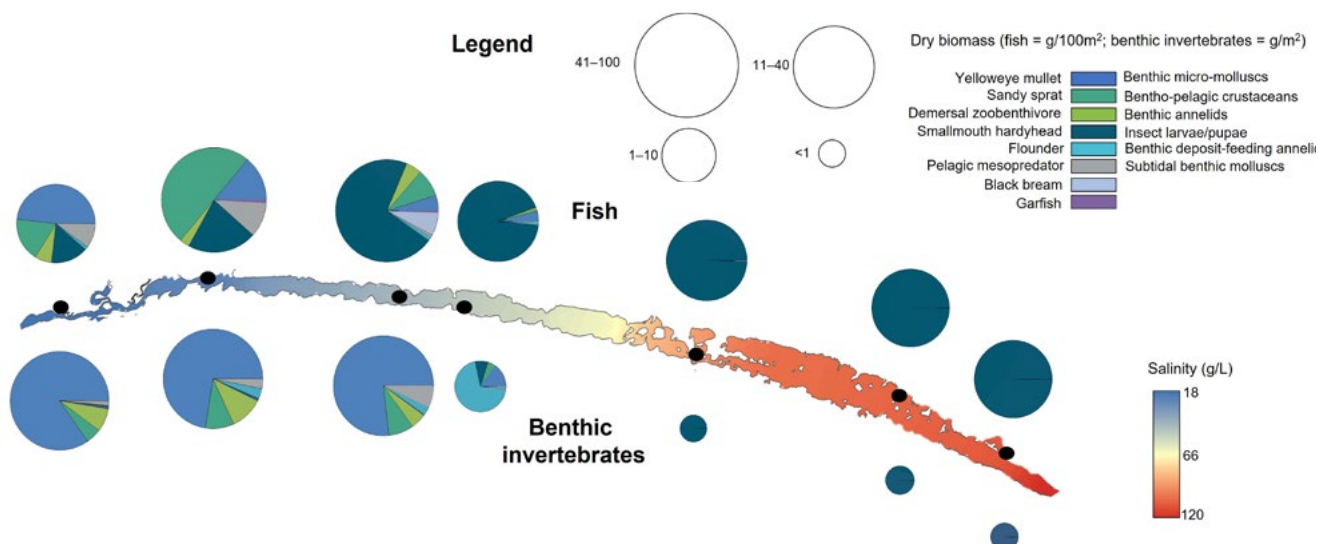
- There was a strong response relationship between barrage flow and relative biomass of waterbird groups in the North Lagoon, with most group biomasses reaching a peak with barrage outflows between 6,000 and 10,000 GL/y
- There was a strong negative response among all waterbird groups to salinity in the South Lagoon, with biomasses generally increasing as salinity reduced below 100 g/L

Ideas for improvement

- Continuous and increased freshwater inputs to the Coorong to support the recovery of Coorong food webs
- Salinities <60 g/L (or ideally <40 g/L) to increase zooplankton, macroinvertebrate and fish diversity, abundance and biomass
 - These salinity conditions will also increase food abundance and diversity for key fish and waterbird species and food web complexity and resilience
- Continuous connectivity between riverine, estuarine and marine environments



Energy density of fish and macroinvertebrates across the three Coorong regions.





fairy tern with smallmouth
hardyhead – Chris Haskett



Waterbirds

The Coorong provides critical habitat and a drought refuge for a diverse range of waterbird species. Waterfowl and piscivorous waterbirds that rely on aquatic vegetation and fish populations are negatively impacted by periods of low water level and very high salinity in the South Lagoon. Shorebird abundance is driven by the area of mudflat and shallow water accessible for foraging and roosting, and salinity-tolerant chironomid larvae provide a useful resource for this group in all but the most extreme salinities.

Priority research questions

- How do key waterbirds species use the Coorong and regional wetlands?
- How do we effectively measure habitat quality for key waterbird species?
- What are the critical habitat features that support key waterbird species in the Coorong and regional wetlands?

Key findings

Habitat requirements in the Coorong and regional wetlands

- Distributions of key species in the Coorong differ due to their unique habitat requirements
- Water level and salinity are the primary drivers of abundances of key species in the Coorong, with shorebird abundance strongly correlated with shallow water and area of exposed mudflat in both the Coorong and regional wetlands like Tolderol
- Waterfowl and piscivorous waterbirds preferred intermediate water coverage at regional wetlands
- The Coorong along with wetlands in the south-east of SA are important drought refuge habitats
 - The Coorong is particularly important for black swan, sharp-tailed sandpiper, red-necked avocet and red-necked stint
- High salinity restricts aquatic vegetation and fish populations and negatively impacts the waterfowl and piscivorous waterbirds (e.g., black swan, Australian pelican, fairy tern) that rely on these food resources
- Habitat quality for waterbirds can be measured directly by quantifying the link between habitat characteristics and waterbirds reproductive and survival rates, or indirectly through proxies
 - Reproductive success is a good measure of habitat quality for waterbirds that breed in the Coorong (e.g., Australian pelican, fairy tern)
 - Useful proxies of habitat quality include water level, area of foraging habitat, local species abundance, prey availability, environmental parameters and body condition

Investigations focussed on 10 key waterbird species from three guilds of waterbirds:

Shorebirds: curlew sandpiper, sharp-tailed sandpiper, red-necked avocet, common greenshank, red-capped plover and red-necked avocet. **Waterfowl:** chestnut teal and black swan. **Piscivores:** fairy tern and Australian pelican.



Australian pelican – Rowan Mott



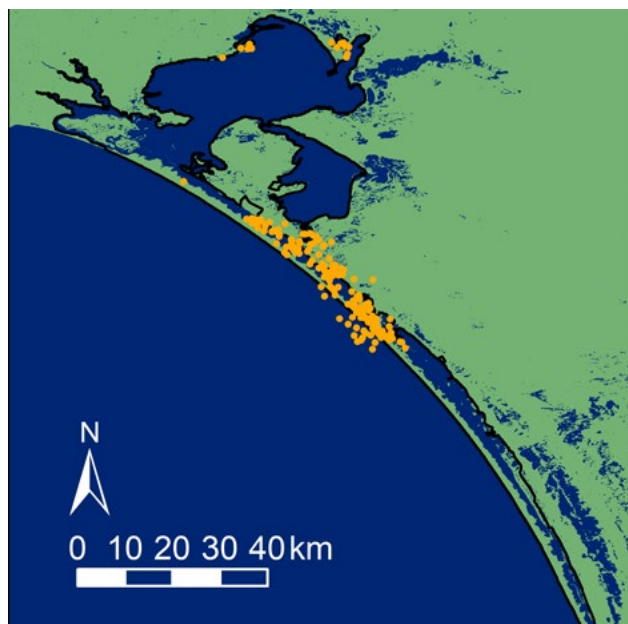
sharp-tailed sand piper – Rowan Mott

Tracking waterbird movements

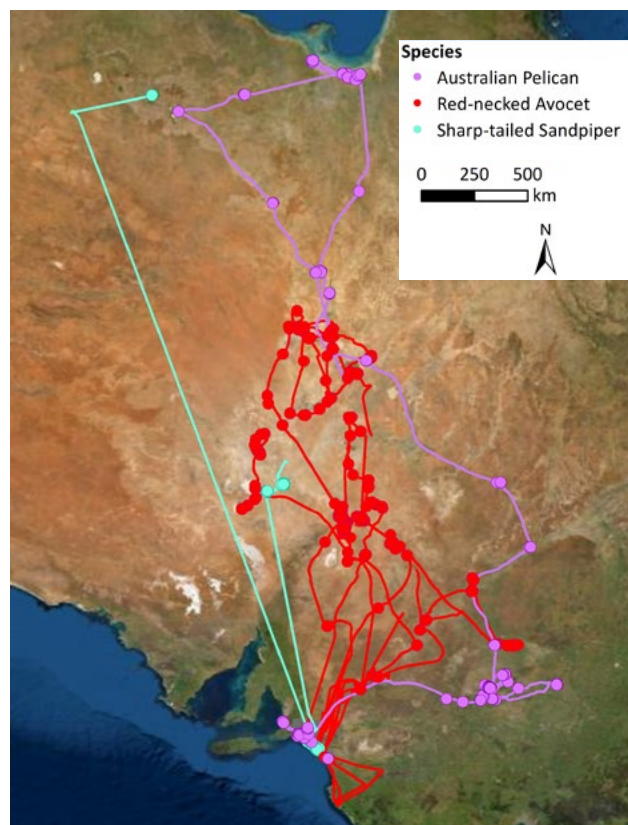
- Each species tracked had unique movement patterns and responses to environmental conditions in the Coorong
- Australian pelicans, sharp-tailed sandpipers and red-necked avocets used wetlands at local and national scales
- Sharp-tailed sandpipers used Lake Alexandrina wetlands, including Tolderol, on their northern migration
- Waterbird movement is influenced by the availability and condition of wetlands across the continent. This study captures movements at a point in time, and therefore, may change under different climatic and environmental conditions

Ideas for improvement

- Increased freshwater inflows to support a mosaic of habitats for key waterbirds in the Coorong, including varying salinities and extensive productive mudflats during key times (spring-autumn)
- Manage water levels and salinities across the Coorong to ensure healthy populations of aquatic plants (for waterfowl), fish (for Australian pelican and fairy tern) and benthic invertebrates (for resident and migratory shorebirds, provided shallow water and mudflats are available)
- Increased extent of regional wetland habitat at key times to:
 - Improve long-term resilience of waterbird populations using the Coorong
 - Provide alternative wetland habitats while restoration is underway in the Coorong
- Provision of complementary regional wetland habitat by:
 - Water level management to increase the extent of productive mudflats for migratory and resident shorebirds
 - Integrated management across the south-east to provide wetlands with a diversity of water levels and vegetation characteristics across space and time



Tracked movement of a sharp-tailed sandpiper.



Tracked movements of key waterbird species.



© South Australian Tourism Commission



Ngarrindjeri Aboriginal Corporation Ngarrindjeri Knowledge Research Project

Ngarrindjeri Philosophies and knowledge are built on generations of cultural knowledge transmission that has been passed down, which give an understanding of the region's ecology, and how it has changed and adapted over time, including climate change.

Five research components were developed and delivered by Ngarrindjeri Aboriginal Corporation (NAC) in collaboration with the Department for Environment and Water (DEW) and Flinders University, with the support of Nature Glenelg Trust and Environmental Systems Solutions (ESS).

Ngarrindjeri community member, Shirley Hartman summarised the On Country Workshops stating,

'It was a wonderful opportunity to share my knowledge and cultural understanding of the importance of the Coorong. This project has given me the opportunity to have this information recorded for my grandchildren.'

Outcomes



44 Ngarrindjeri Community Representatives contributed to the project through sharing their personal oral histories



ESS worked with NAC to deliver a Ngarrindjeri Database



3 individual research topics

- No:ri (pelicans)
- Freshwater soaks
- South Lagoon Ngartji (totems)



Further development of the Yarlurwar-Ruwe assessment tool





© Ngarrindjeri Aboriginal Corporation



The Yarluwar-Ruwe Assessment technique



The Yarluwar-Ruwe Assessment technique is directed by the Ngarrindjeri Community and is based on the recognised Ngarrindjeri cultural authority of all Laklinyer:ar (clan groups) of Ngarrindjeri. The methodology has the ability to be used for ecological restoration across Ngarrindjeri Yarluwar-Ruwe (Sea Country).



Oral Histories



No:ri



Freshwater
soaks



South Lagoon
Significance
to Ngartji
specifically
jumping mullet
(Kanmeri)

Ngarrindjeri Knowledge database



Development of a database bringing together Ngarrindjeri resources and knowledge in an accessible and culturally appropriate way to support Ngarrindjeri engagement and input into current and future environmental research/management projects.



Coorong site management



"Ultimately this will ensure that Ngarrindjeri Knowledge is considered, and cultural values are protected, contributing to the wellbeing of the Ngarrindjeri people."

– Ngarrindjeri Community Member

Our Vision

Our vision is for our people of the Ngarrindjeri Nation and our Ngartjis to be healthy, have access to and enjoy our lands and waters. We long for the Yarluwar - Ruwe (sea country) of our ancestors and will restore clean waters, healthy lands, people and all living things

Land

Ngarrindjeri speak for, care for and exercise cultural responsibility for Ruwe/Ruwar

Water

Ngarrindjeri cultural values are protected and enhanced in planning and implementation of management actions.

Water is available to support Ngarrindjeri culture and wellbeing

Ngartjis

Provide a habitat for our Ngartjis to be healthy and spiritually alive

After sharing his oral history, Ngarrindjeri community member Owen Love Jnr stated the following,

'Our community needs more projects like this, where our people are engaged to talk about our Ruwe and have our voices heard. I would love to see more projects like this done in the future, focusing on other Ngartji's and sharing our stories about Ruwe.'



Climate adaptation

Adapting the management of the Coorong will be complex as the climate continues to change; requiring dynamic adaptation on ecological, social and institutional levels, over many decades

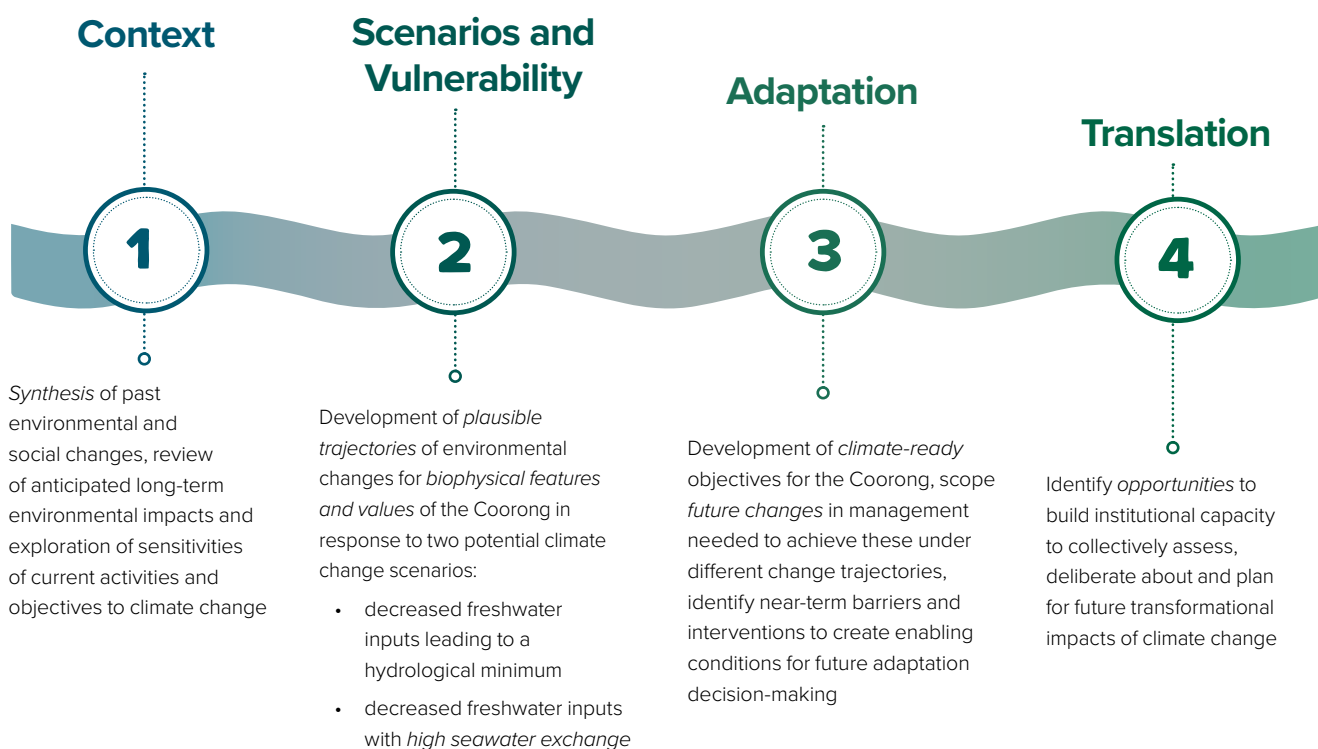
Priority research questions

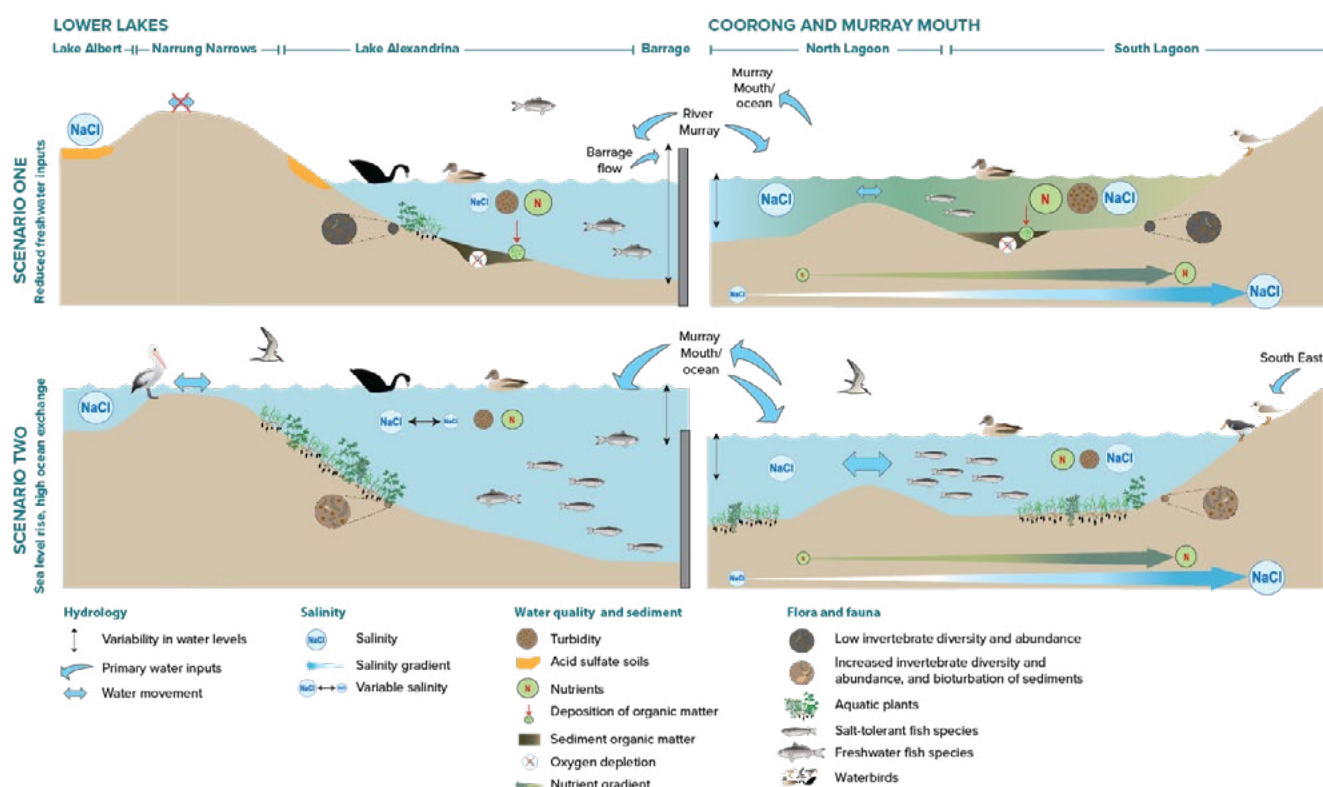
- Which of the multiple values held by people for the CLLMM could persist as the system transforms in response to climate change?
- What future changes in management might be required to maintain values in the long term?
- What institutional changes could help guide adaptation decision-making?
- What near-term actions could help communities understand on-going change, maintain valued connections to the system as it changes, and enable new options for future policy and management?

Approach

The climate adaptation project was undertaken as a sequence of activities to help managers and decision makers understand future adaptation challenges and build their capacity to identify actions and processes to navigate those challenges.

The project explored potential future changes, over the longer term (50-100 years) to explore ecological and social consequences of future changes and identify actions that could be taken to prepare more effectively for a future with uncertain but potentially significant change.





Physical, ecological, social and cultural values of the CLLMM would be most vulnerable under the scenario with decreased freshwater inputs. Many values could persist under the scenario with decreased freshwater inputs with high seawater exchange, but with changes to the numbers and locations of some habitats and species (particularly freshwater).

Key findings and future needs

The CLLMM has experienced a long history of social and ecological change. Further ongoing changes are likely in response to climate change.

Many valued features of the CLLMM could persist as the system changes. This outcome would require managing the system in a different hydrological and ecological state, along with evolved social connections, and institutions that anticipate change and accommodate uncertainty.

The project identified a series of key issues and actions to enable climate adaptation:

1. Institutions need to evolve to anticipate change, and actively decide when to accommodate it and when to resist it.

2. Don't delay preparing for future change

Delaying planning and action may risk making it much harder to adapt in the future.

3. Incremental change

Processes of reform can be incremental, but they need to be intentional, accommodate future change and involve all levels of decision making.

4. Accommodating ambiguity

Contemplating and planning for transformative change will require people to engage with and accommodate unfamiliar, uncertain ideas about the CLLMM, rather than seeking the comfort of the familiar.

5. Enabling environments

Climate adaptation in the CLLMM needs to be facilitated by open and informed consideration, within and among all stakeholder groups, engaging with future change and its implications.

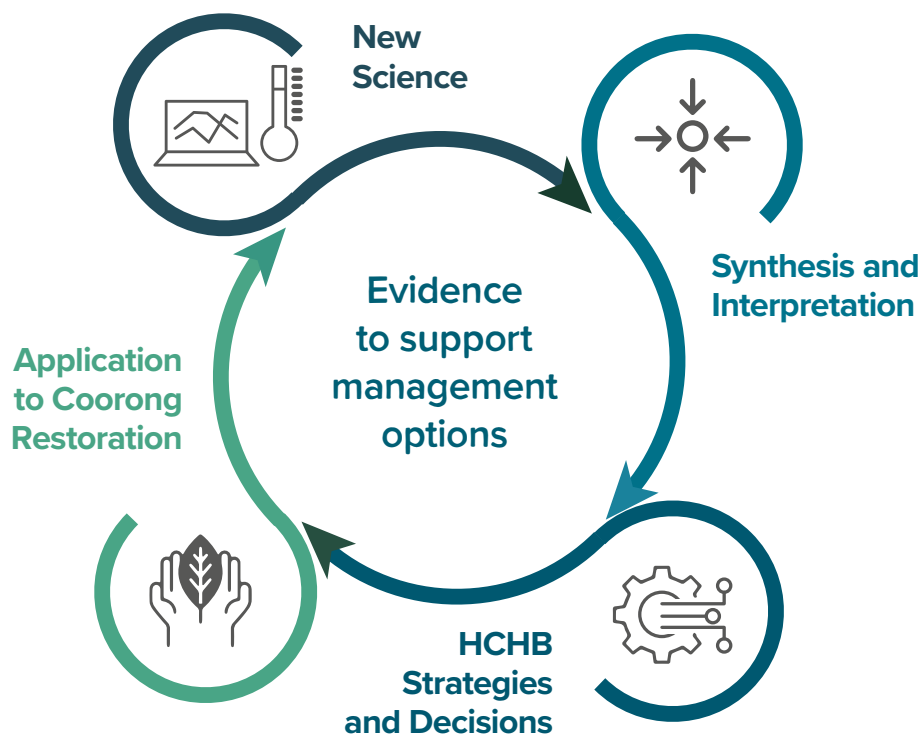


Science integration

Science Integration is a process that brings together, develops and applies the knowledge and tools that have been generated across the Trials and Investigations Project.

Science integration activities included:

- Development and improvement of hydrodynamic, biogeochemical and ecological response models
- Validation of models against observed data and application of models through development of detailed scenarios to assess management options for the Coorong
- Development of methodologies and frameworks to summarise, evaluate and communicate potential outcomes of scenarios for management options
- Interpreted and synthesised, up-to-date science that guided feasibility assessments and provided the evidence base for decision-making and prioritised Program directions





Knowledge and data management

With the significant investment in scientific research and investigations into future solutions, it became critical for ongoing effective storage, sharing and use of the newly generated knowledge and data. A knowledge and data management strategy and processes were developed for data collation, storage, and use across the Trials and Investigations Components.

The Strategy is based around a living data repository – updated as new science and knowledge emerges. As advances in technology and data management occur ongoing access to knowledge and data will be enabled such that research, tools, and models that will support decision-making to improve the long-term health of the Coorong have rapid and informed access.

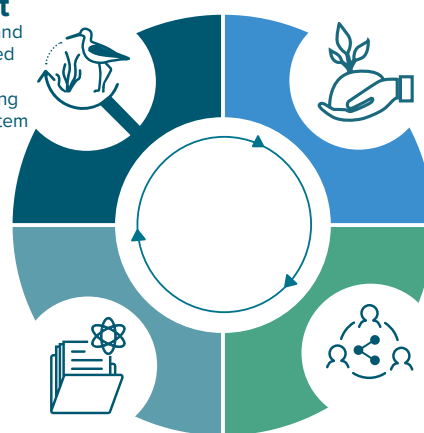
Collect

Knowledge and data acquired to build an understanding of the ecosystem



Use

Integrating knowledge and data into decision-making through science synthesis, tools and models



Store

Storage of knowledge and data for future use



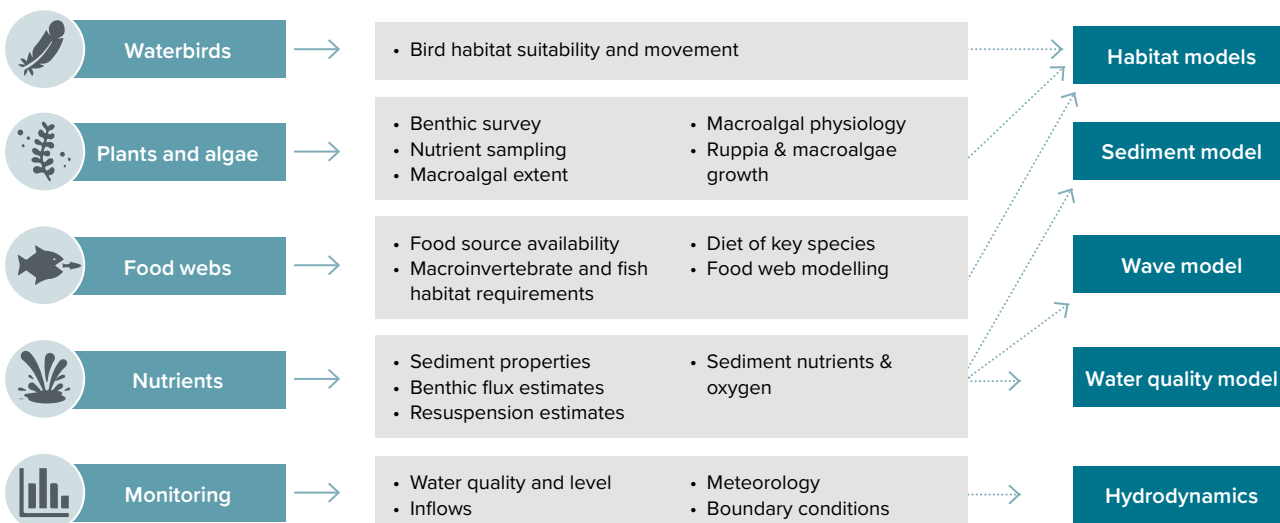
Share

Sharing knowledge and data between stakeholders



Integration of knowledge and data for model development and improvement

Scientific knowledge and data from across the Trials and Investigations Project were integrated and applied into the development and improvement of a series of models and tools.



Core developments of the Coorong Dynamics Model



Nutrient cycling and metabolism

External and internal nutrient loads, nutrient fluxes and cycling, Phytoplankton and Chlorophyll-a dynamics



Sediment biogeochemistry

Sediment loads, dynamic coupling of hydrodynamic and sediment models



Ruppia habitat & algae dynamics

Improvement of Ruppia Habitat Suitability Index and development of filamentous algae variable and Habitat Suitability Index

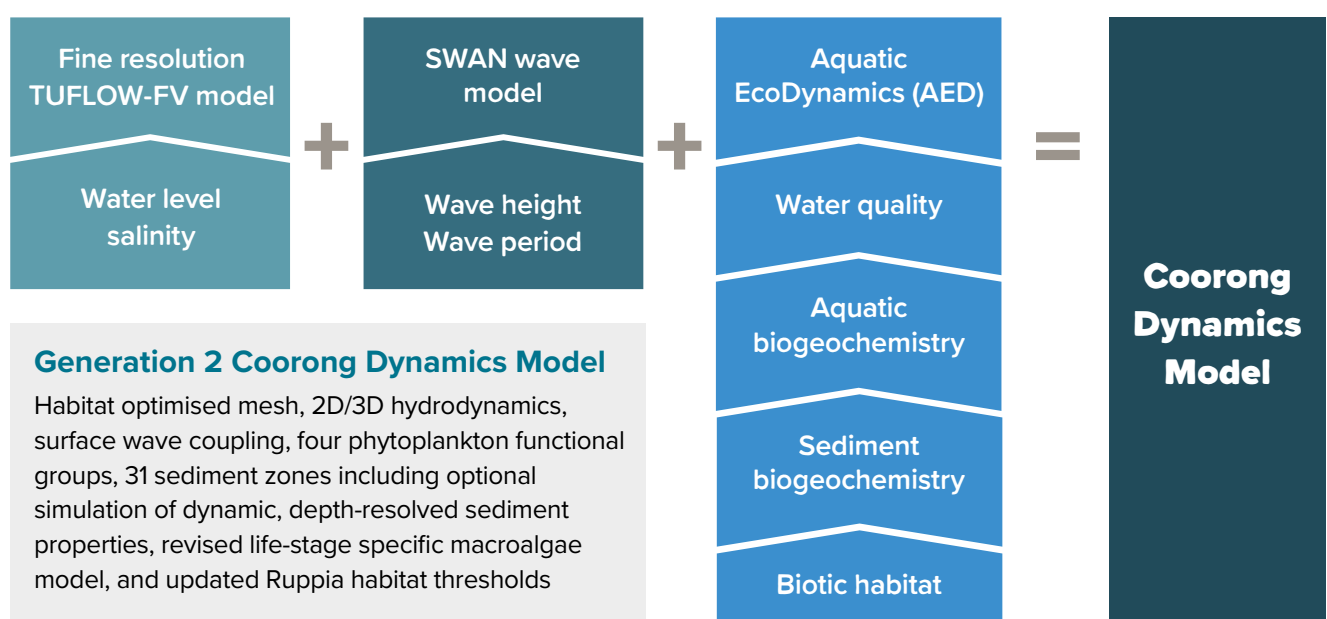


Waves and resuspension

Coupling of wave and hydrodynamic models to enable modelled sediment resuspension and impacts on water quality

Integration of science into development of the Coorong Dynamics Model

The Coorong Dynamics Model is a spatially resolved model to simulate the environmental conditions within the Coorong. It is comprised of a series of models that can be configured, coupled, and applied at varying spatial and temporal scales.



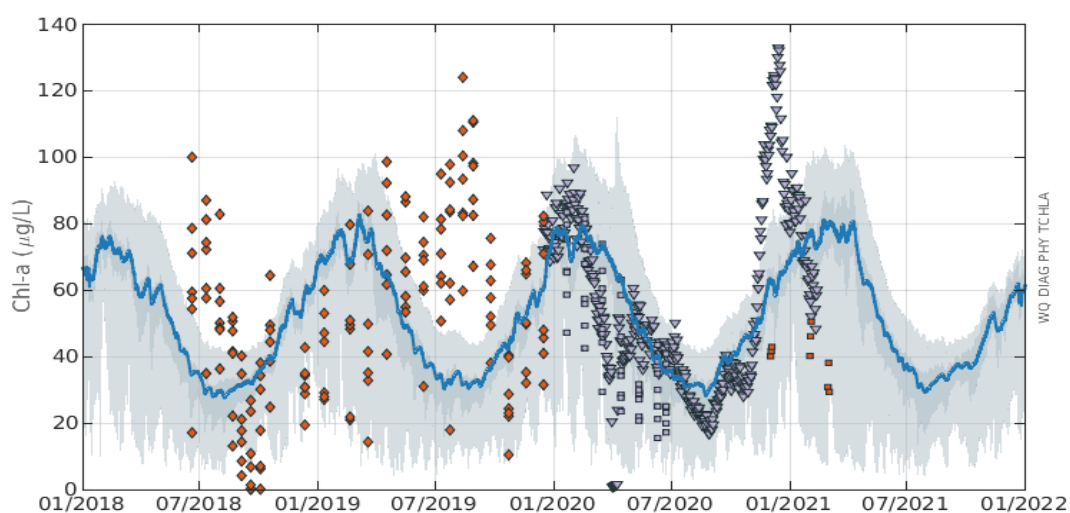
Core components of the Coorong Dynamics Model.

Validation and application of the Coorong Dynamics Model

Validation shows the ability of the model to represent observed conditions, and confidence in the modelled values. The Coorong Dynamics Model was validated using a range of data collected including water quality sampling, biotic surveys and experimental data. Model performance assessments along with an integrated assessment of the calibrated model were undertaken and demonstrated the updated model functionality and a high level of model performance. Comparison of model outputs to measured data provided confidence that the Coorong Dynamics Model could be applied to understand how the Coorong system may respond to changing conditions over time and space.

The Coorong Dynamics Model was then used to quantitatively assess the response of the system to a number of management options. It was developed to be adaptable and meet requirements at varying spatial and temporal scales, to enable scenario testing from short-term operational to long-term restoration and climate change adaptation strategies. The model will continue to be improved and applied to support on-going site management, including the identification and assessment of long-term management options for the Coorong.

Chlorophyll-a validation:



When compared against the chlorophyll-a data from continuous Coorong monitoring sites, the Coorong Dynamics Model adequately represents the phytoplankton biomass and the long-term mean gradient in biomass along the Coorong. Additionally, the model represents the seasonal and high variability in chlorophyll-a throughout the Coorong.

Scenario themes

Model application

 Operations	Extensive model calibration and validation using continuous monitoring data and a range of field and scientific data
 Infrastructure	
 Climate change	- Barrage release scenarios: volume, split and timing to align with wind and tide conditions - Changing inflow scenarios: impact of environmental water in barrage releases, impact of South East flows
 What if? science	
 Temporal scales	Hydrodynamic, biogeochemical and habitat assessment of a range of infrastructure options
 Short term (years)	Long term hydrodynamic assessment of infrastructure options under historical and potential future climate change conditions
 Long term (decades)	

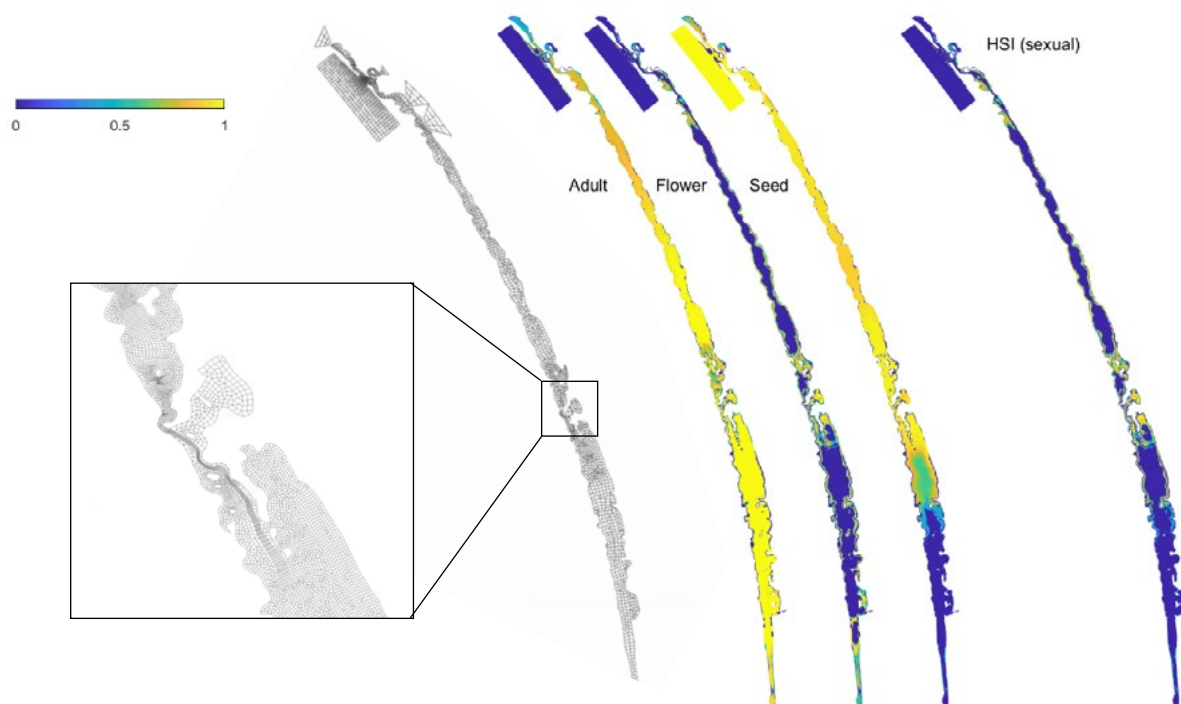


Model outputs and interpretation for management options in the Coorong

Using the Coorong Dynamics Model, a range of hydrodynamic, biogeochemical and habitat modelled outputs were produced to assess the performance of infrastructure options for a range of scenarios with varied climate and flow conditions. The interpretation of these outputs in association with integrated ecological assessment and evaluation (e.g. Coorong decision-making framework)

provided the scientific evidence base to support program decision-making.

The ecological assessment and interpretation were critical inputs to the assessment of performance of potential long-term infrastructure and other management options (i.e. on-ground works) for the Coorong.



Habitat Suitability Index (HSI) for the successful completion of the sexual life cycle of Ruppia tuberosa. A HSI of 0 (dark purple) represents unsuitable habitat conditions, while an HSI of 1 represents optimal conditions (yellow).

Habitat suitability for *Ruppia* was based on assessment of modelled environmental conditions relative to the known requirements of *Ruppia tuberosa*. A Habitat Suitability Index (HSI) was produced for each phase of the *Ruppia* lifecycle. HSI results for different life stages were then combined and integrated to obtain overall HSI results for successful completion of sexual or asexual life cycles. For each annual cycle these model results were then summarised over the length of the Coorong, to allow estimation of the total suitable area.



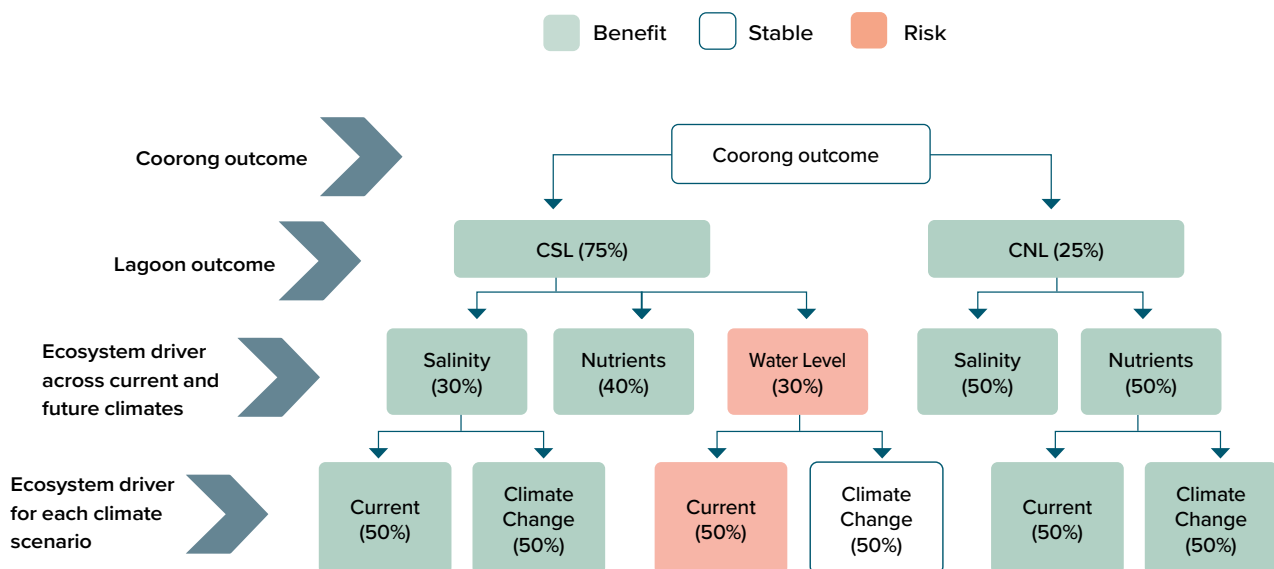
Ecological risk assessment for management options

An ecological risk assessment evaluated various modelled scenario outputs, including the level of risk posed by different levels of salinity, water depth and nutrient conditions. These scenarios reflected potential infrastructure and management options with respect to a base case.

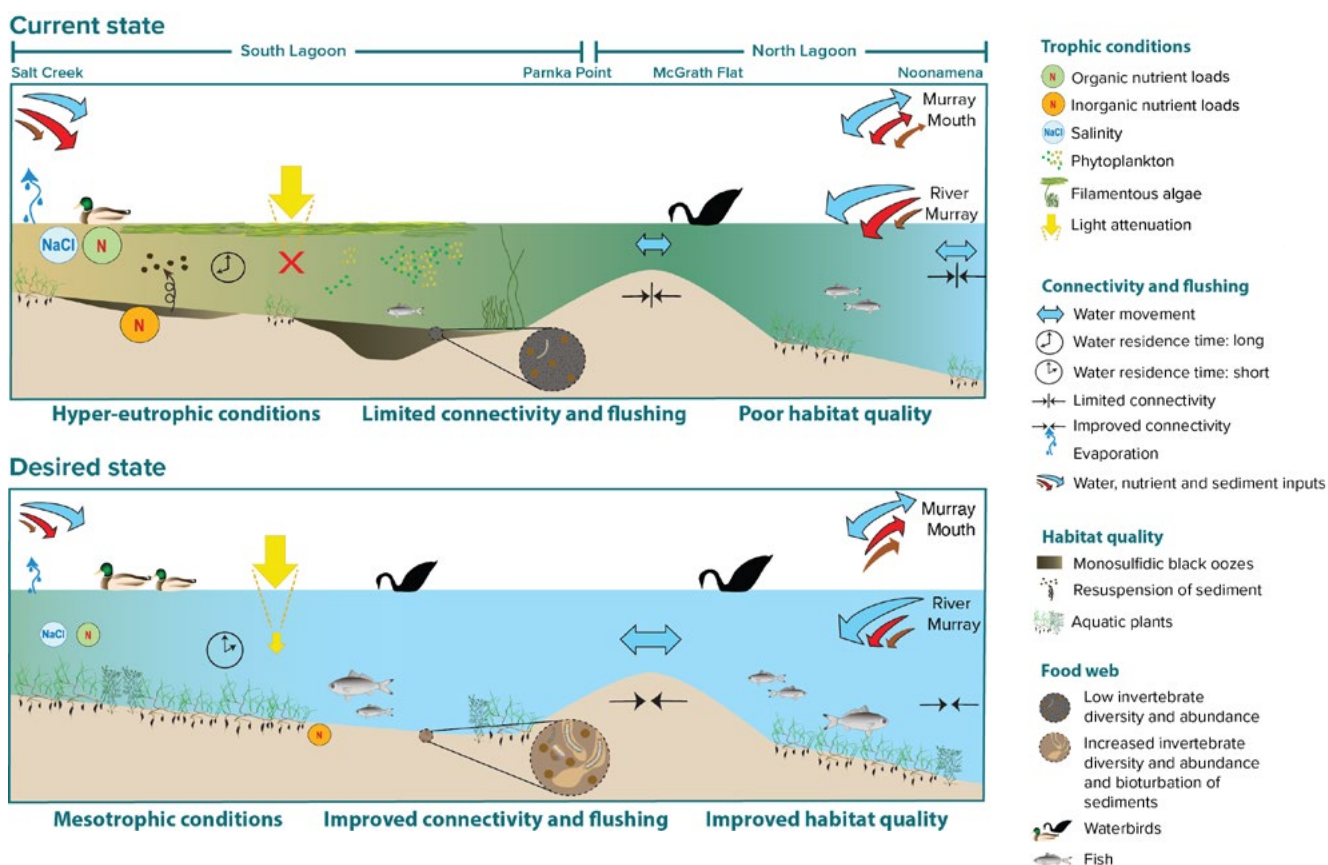
The risk-based approach enabled decision-makers to consider any uncertainty derived from model validity, future climatic and inflow conditions, and the expected outcomes resulting from infrastructure and management options.

The likelihood of risk to the ecosystem were assessed using consequence level values and expected scores were then calculated for each ecosystem driver and climate scenario (inflow scenario).

Ecological benefit was indicated where an option had a higher expected value than the base case for a given outcome (i.e. end-point). Conversely, ecological risk was indicated where an option had lower value than the base case. Stable means there was no difference in the level of risk compared to a base case.



Outcome criteria and risk assessment end-points used for ecological evaluation of infrastructure and management options



The southern Coorong is a unique and complex ecological system that is in a degraded state and requires complex management solutions to restore the system. Waterbirds, fish, plants and invertebrates of the southern Coorong have been affected by prolonged hyper-saline and hyper-eutrophic conditions. The desired state for the southern Coorong is a resilient and naturally variable system with only short periods of restricted connectivity and hyper-salinity. The desired state is characterised by moderate levels of nutrients in persistent aquatic plants with diverse invertebrates that promote healthy nutrient cycling, and therefore the southern Coorong can provide habitat for waterbirds and fish. To reach the desired state, net export of salt and nutrients is needed by increasing inflows, water levels and system-wide connectivity.

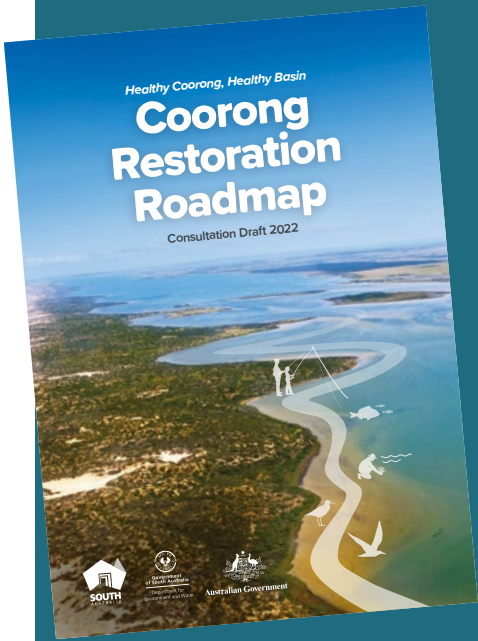


Next steps

Scientific case for action: Restoration Roadmap

The science is clear that the southern Coorong has suffered long-term decline and is currently in a degraded state. The next steps towards a healthier Coorong are outlined in the Coorong Restoration Roadmap and Coorong Infrastructure Investigations Project Feasibility and Future Directions publications.

The Coorong Restoration Roadmap is based on International Principles and Standards for the practice of ecological restoration. It will guide the development of an integrated restoration program, aiming to improve ecological function, build resilience and support the ecological character of the Coorong for many years to come.



Key principles:

Restoration of the Coorong will be underpinned by National and International Standards for the Practice of Ecological Restoration:

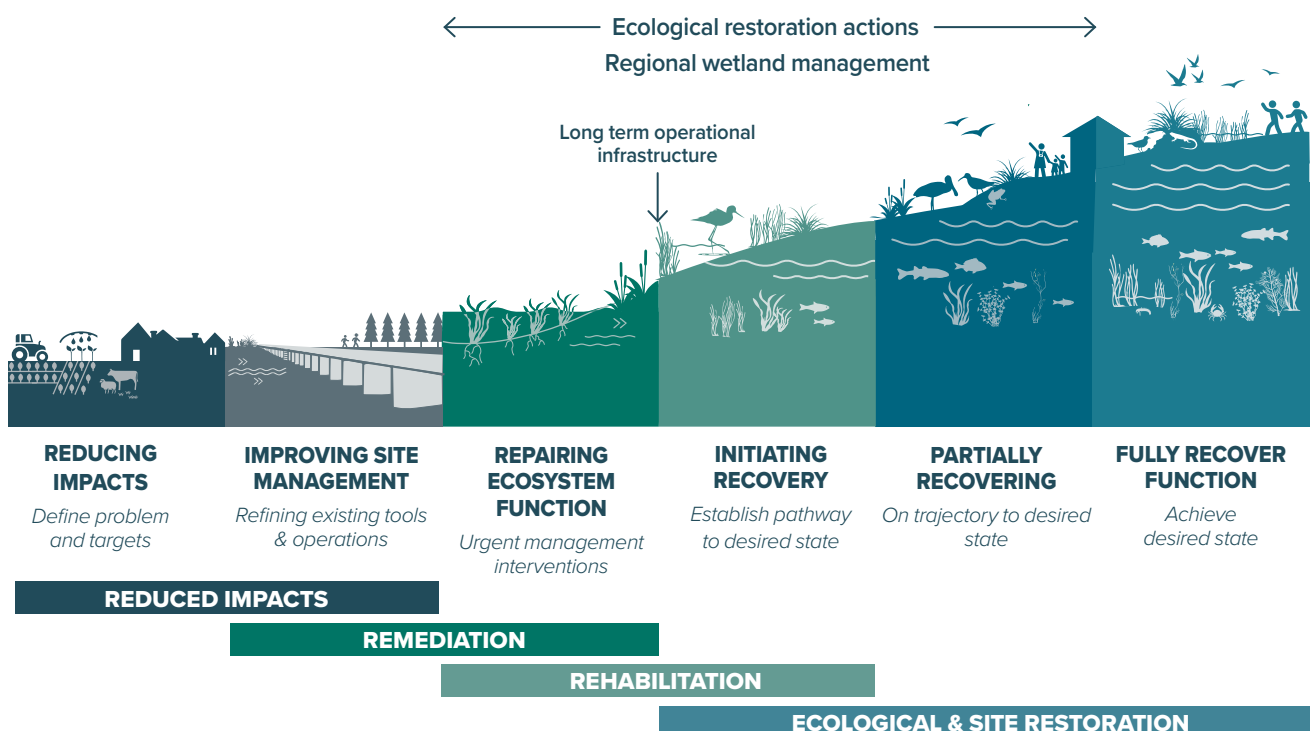
 Engage Stakeholders	 Informed by natural reference systems while considering environmental change
 Draw on many types of knowledge	 Support ecosystem recovery processes by repairing, rehabilitating and/or restoring ecological function
 Use clear targets, goals, objectives and measurable indicators	 Include activities that form part of a restorative continuum and gain cumulative value when applied at large scales
	 Include activities that seek the highest level of recovery possible

Adapted from: International Principles and Standards for the Practice of Ecological Restoration, 2nd Edition. National standards for the practice of ecological restoration in Australia.



Healthy Coorong, Healthy Basin restoration actions will include a range of management interventions that collectively contribute to the recovery of ecological function along a

Restorative Continuum. A range of restorative activities will allow us to successfully progress through the stages of the Restorative Continuum and contribute to ecological recovery.



The Restorative Continuum illustrates how the implementation of restorative activities at all levels can optimise broad scale ecological and social outcomes (adapted from SER 2019)





Glossary

Anoxic — Lacking oxygen.

Aquatic plants — A phrase used to describe the mixed, submerged aquatic plant community of the Coorong (see *Ruppia* Community).

Bacteria — A unicellular microorganism with simple internal structures.

Benthic — Of, or associated with, the sediment at the bottom of an estuarine or marine system.

Bioavailable — Amount of nutrient that is utilised

Biomass — The total mass of living organisms (plants or animals) in a sampled area, measured as a wet, dry or ash free dry mass.

Bioturbation — The reworking of sediments by animal activities, including burrowing, ingestion, and defecation of sediment grains, and by plants. It has a profound effect on sediment condition and the environment.

Charophyte — The charophytes (Streptophyta, Viridiplantae) are the extant group of green algae that are most closely related to modern land plants.

Chironomid larvae — The juvenile (larvae) form of non-biting midge that live in aquatic habitats.

Connectivity — A mechanism that allows for the movement of water, materials and animals between areas, including between the North and South lagoons of the Coorong, between the sea and the Coorong through the Murray Mouth, and from the River Murray or South East flows to the Coorong (but not typically vice versa). It is an important element of hydrodynamics, has a strong influence on water quality (through exchange of salt and nutrients) and is essential for some ecological processes, such as migration of fish at different times of year and for the transport of zooplankton from freshwater inflows to support food webs of the Coorong.

Coorong Dynamics Model — A spatially resolved model to simulate the environmental conditions within the Coorong at varying spatial and temporal resolutions. The core of the Coorong Dynamics Model is the fine resolution Coorong TULOW-FV hydrodynamic model, and Aquatic EcoDynamics (AED) comprising a library of modules and algorithms for simulation of water quality, aquatic biogeochemistry, biotic habitat, and aquatic ecosystem dynamics. These models can be optionally linked with the Simulating Waves Nearshore (SWAN) wave model.

Denitrification — The microbial process by which nitrate is converted to nitrogen gas bubbles, which are released to the atmosphere. If the sediment is anoxic, then nitrification-denitrification cannot occur and the nitrogen remains in the nutrient cycle.

Energy density — The energy (i.e. total number of calories) per volume or per mass of tissue. Here we refer to this as the nutritional value with the caveat that it refers to the energy component, not other nutritional components provided by macro nutrients (carbohydrates, fats, proteins) and micro nutrients (vitamins and minerals).

Eutrophic — A system with elevated supply of organic matter and nutrients.

Eutrophication — The process of nutrient enrichment and the increase in the supply of organic matter. Eutrophic systems typically have excessive plant and algal growth, which become internally produced organic matter loads as they decay. They grow excessively in response to nutrient enrichment such as nitrogen and phosphorus inputs. Eutrophication has cascading effects for the entire ecosystem. The hyper-eutrophic state in the southern Coorong is characterised by high concentrations of chlorophyll-a (>50 mg/L), total nitrogen (>4 mg/L) and total phosphorus (>0.2 mg/L) in the water.



Evapo-concentration — The concentration of solutes such as salt and contaminants as water evaporates. The effects of evapo-concentration increase with increasing water residence time, and at higher temperatures in summer.

Food web — A natural interconnection of food chains showing what eats what, starting with primary production based on Carbon fixation by plants.

Filamentous algae — The green filamentous algal community which occurs in the Coorong, consisting of *Ulva paradoxa*, *Rhizoclonium* sp. and *Cladophora* sp..

Habitat — The natural home or environment of a plant, animal or other organism.

Herbivore — An animal that eats plants.

Hyper-eutrophic — A high-nutrient state due to eutrophication.

Hypersaline — Salinities that are greater than that of normal seawater.

Inorganic — Not consisting of or deriving from living matter.

Invertebrates — Animals without a backbone. Benthic invertebrates live on or in the sediment, while pelagic invertebrates (e.g. zooplankton) live in the water.

Macroinvertebrate — Invertebrate fauna that are greater than 0.5 mm.

Macrophyte — An aquatic plant large enough to be seen by the naked eye, in this research specifically a flowering plant (angiosperm), but also including macroalgae.

Mesocosm — An in-field, experimental system that examines the natural environment under controlled conditions.

Mesotrophic — Intermediate levels of nutrients, common in healthy estuaries. A mesotrophic Coorong would be fairly productive (with plant and animal life), but could be at risk of having water quality problems.

Microbiome — The microorganisms associated with a particular environment.

Millennium Drought — An Australian drought which impacted the Murray-Darling Basin over the period 1996–2010, and substantially impacted the Coorong over the period 2001–2010. The period from 2007–2010 was particularly extreme with extended periods of no flow through the barrages to the Coorong.

Monosulfidic black oozes — Monosulfidic black oozes (MBOs) form when there is an excess of organic matter, and sediments become anoxic as the bacteria consume all the oxygen to decompose the organic matter. Iron (III) and sulfate are converted by bacteria to iron (II) and hydrogen sulfide, because there is no oxygen. The iron typically comes from iron oxide minerals in the sediment that are reduced, whereas sulfate comes from water (it is plentiful in seawater and saline groundwaters).

Nitrogen — A nutrient that is essential to plants and animals and forms compounds such as amino acids and proteins. Nitrogen can be found in aquatic environments in dissolved, particulate, inorganic, organic and gaseous forms. Too much nitrogen can be associated with eutrophication.

Nitrification — Nitrification is the process by which ammonium is converted to nitrite and then nitrate. It can also take place in the sediment and requires oxygen.

Nutrient cycling — The movement or exchange of nutrients, such as nitrogen, from inorganic and organic forms into organic matter, including plants and animals, and back again.

Organic — Relating to or derived from living matter.

Oxygenate — Supply or enrich with oxygen. Sediments in aquatic systems need to be oxygenated in order for healthy nutrient cycling and nutrient exchange from sediment to water and to the atmosphere to occur. Oxygenation of sediments can occur through biological processes (e.g. animal movement, pumping through plant roots), or physical processes such as water turbulence and currents moving sediments around.

Phenology — The study of cyclic and seasonal natural phenomena, especially in relation to climate and plant and animal life.

Phosphorus — A nutrient essential to life and strongly influencing water and sediment quality in the Coorong. Phosphate is the dissolved form of phosphorus, which is uptaken by plants and algae.

Phytoplankton — Small plankton algae that is essential to aquatic food webs.

Picophytoplankton — Microalgal cells < 5-6 µm in diameter that are present in nearly all aquatic systems

Ruppia — A genus of aquatic plant, referring the species *Ruppia tuberosa* that is most common across the southern Coorong.



Ruppia Community — The multi species assemblage that has become established across the southern Coorong and includes *Ruppia tuberosa*, *Althenia cylindrocarpa* along with an as yet unresolved species of *Ruppia*.

Salinity — Salinity can be defined as the concentration of dissolved mineral salts present in waters and soils on a unit volume or weight basis. Salinity is measured as Electrical Conductivity (EC), which is the presence of charged ionic species in solution that enables water to conduct electrical current. EC is converted to Total Dissolved Solids at 25°C and reported in parts per thousand (ppt) or grams per Litre (g/L) in the case of the Coorong.

Sediment — The inorganic particles of mud, sand or other sizes, plus the organic matter and other nutrients that are deposited at the bottom of aquatic systems.

Southern Coorong — The Coorong South Lagoon and the central Coorong from the Needles southward.

Sulfide — A binary compound of sulphur with another element or group.

Translocation — The movement of something from one place to another.

Turion — Reproductive structure of *Ruppia tuberosa* (Type I and Type II) and *R. polycarpa* (Type I), produced on rhizomes underground that are capable of forming into a new plant.

Water quality — The condition of water or some water-related resource as measured by biological surveys, habitat-quality assessments, chemical-specific analyses of pollutants in water bodies, and toxicity tests.

Water residence time — the average amount of time water spends at a particular stage/location in the hydrologic cycle. The residence time is calculated by dividing the total amount of water at that stage or location by the rate at which water is added and removed from that stage or location.

Zooplankton — Animals (often microscopic) that either move by water currents or are weak swimmers in the water column.

List of shortened forms

AHD — Australian Height Datum. The vertical height of 0.0 m (sea level) in Australia as defined by taking the mean sea level of 30 tide gauges around the Australian coastline from 1966 to 1968.

CLLMM — Coorong, Lower Lakes and Murray Mouth

g DW/m² — grams dry weight per square metre

HCHB — Healthy Coorong, Healthy Basin

MBO — Monosulfidic black ooze

ppt — parts per thousand

PSU — Practical salinity units

T&I — Trials and Investigations, a project of the Healthy Coorong, Healthy Basin Program

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