GLAAM RESEARCH CENTRE | GOYDER INSTITUTE FOR WATER RESEARCH

Identification of waterbird research priorities for the Coorong, Lower Lakes and Murray Mouth

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Thomas A. A. Prowse, Ruth Cope, Johanna G. Kuhne, Steven Delean, Rebecca Boulton, Phill Cassey and Justin Brookes

The CLLMM Research Centre has the objective of developing and delivering locally driven, innovative, and impactful research that reflects community and First Nations priorities to provide an evidence base to address critical needs of the CLLMM region. The CLLMM Research Centre will also bring together our First Nations, local community and scientists to create and share knowledge, and support our well-informed and engaged community and empower our future generations to be part of the solution. Where available, we have used the First Nations name for waterbird species to reflect cultural significance. We have predominately used Ngarrindjeri naming based on the Ngarrindjeri Dictionary (MIPAAC 2020).

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Enquires should be addressed to: CLLMM Research Centre
Level 1, 92 Barrage Road
Goolwa, SA 5214
e-mail: info@cllmmresearchcentre.org

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Executive Summary

The diverse and abundant waterbird community of the Coorong, Lower Lakes and Murray Mouth (CLLMM) played a central role in the region's listing as a Wetland of International Importance under the Ramsar Convention. The CLLMM region is located at the end of the Murray-Darling Basin (MDB) in southern Australia. The CLLMM is an important site for migratory shorebirds of the East Asian–Australasian Flyway, many species of which have suffered population declines. The CLLMM also provides foraging and breeding habitat for non-migratory waterbirds and acts as a habitat refuge for many species during drought conditions. Significant opportunity exists to consult with diverse stakeholders to develop future waterbird research streams, and to engage community scientists in the delivery of this research.

This project identified and prioritised scientific research to inform management of the CLLMM region to support the viability of migratory and non-migratory waterbird populations under climate change. Firstly, we reviewed the global scientific literature to identify key threats posed to waterbirds by a changing climate along with documenting examples of direct relevance to the CLLMM region. Secondly, with the long history of CLLMM-focused waterbird research in mind, we engaged with a range of stakeholders to identify key knowledge gaps and information needs pertaining to waterbirds in the region. Through this process, we refined a set of proposed waterbird research projects and identified and developed new research projects to address these gaps and needs. Finally, we evaluated these projects based on: (1) the importance of the research for informing future management of the CLLMM, particularly under a changing climate; (2) the ability of the research to lead to improvements in the viability of threatened waterbird species; and (3) the significance of the project to stakeholders, and the project's ability to engage community actively or passively in the research.

The literature review identified seven overarching and interacting climate-related threats to waterbirds: (1) reduced water availability; (2) reduced habitat suitability; (3) asynchrony between waterbird needs and key resources (e.g. food, shelter, nesting sites); (4) increased energetic costs; (5) increased disease risk; (6) increased frequency and intensity of extreme weather events; and (7) rising sea levels. Most of the research quantifying the magnitude of these threats has been conducted in the northern hemisphere. Key knowledge gaps highlighted in the literature included: (1) the scarcity of data on how waterbirds move across habitat mosaics and what drives habitat selection as environmental conditions change; (2) the need to understand how suitable habitat will shift under future climate conditions to inform pre-emptive conservation actions (e.g. acquiring wetlands for conservation and restoration, or creating new wetlands); and (3) a poor current understanding of how climate-driven land-use changes (e.g. altered flood irrigation practices and crop types) will affect waterbirds.

Through a series of targeted workshops, feedback on waterbird research priorities for the CLLMM region was obtained from numerous stakeholders representing First Nations and community, 'Friends' groups, environmental non-governmental organisations (eNGOs), South Australian and Commonwealth government agencies, and university and government scientists. First Nations groups stressed the importance of waterbirds as a link to

country, culture and language, highlighted the negative impacts of upstream water extraction and diversion on waterbirds, and supported research designed to help maintain key waterbirds within the CLLMM region under climate change. Vehicle access to beaches and protected areas, and its impact on migratory and beach-nesting shorebirds, was a key focus of community and 'Friends' groups. Scientists, eNGOs and government agencies emphasised the importance of understanding waterbird movements between the CLLMM and the broader wetland network as environmental conditions change, and highlighted research to demonstrate the benefits of past and current wetland restoration efforts. Water managers focused on research to inform strategies for delivering environmental water allocations to the CLLMM, particularly under drought conditions, and to demonstrate the multi-scale responses of waterbirds to environmental watering throughout the MDB.

Eight key research projects were developed and/or refined through the consultation process: (1) waterbird telemetry (i.e. GPS tracking) to document waterbird habitat selection and movement at a range of scales; (2) DNA-based monitoring of waterbird food resources, diets, and pathogen load; (3) waterbird condition monitoring through community science; (4) targeted conservation modelling for key waterbird species to inform climate preparedness and restoration actions; (5) identifying water management scenarios to support colonial nesting waterbirds in the Lower Lakes; (6) quantifying human disturbance of beach-nesting and migratory shorebirds; (7) identifying sites of shorebird congregation immediately prior to the northerly migration; and (8) control-impact studies to understand the benefits of wetland restoration for waterbirds. Based on evaluation against the three prioritisation criteria, all projects were supported to some degree, with particularly high rankings for waterbird telemetry and targeted conservation modelling projects for key threatened, migratory or culturally important waterbird species.

Acknowledgement

We acknowledge the cultural connections to the land and connected waters, as well as the cultural significance of waterbirds that exist between people of the Ngarrindjeri and Boandik Nations across the Coorong, Lower Lakes, and Murray Mouth region. We recognise that First Nations 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. We are committed to fostering and nurturing ongoing relationships with First Nations community in the CLLMM region, as we continue to work together towards a diverse and thriving waterbird community.

This project was funded by the Goyder Institute for Water Research's CLLMM Research Centre, which is funded by the Australian Government. We thank Nick Whiterod (CLLMM Research Centre) and CLLMM Research Centre for project initiation, support and management. We thank the Goyder Institute for Water Research, Research Advisory Committee and two anonymous reviewers for constructive feedback on the report.

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1. Introduction

The diverse and abundant waterbird community of the Coorong, Lower Lakes and Murray Mouth (CLLMM) has played a central role in the region's listing as a Wetland of International Importance under the Ramsar Convention (O'Connor et al. 2012). The CLLMM is an important site for migratory shorebirds of the East Asian–Australasian Flyway, many species of which have suffered global population declines. The region also provides foraging and breeding habitat for non-migratory waterbirds and acts as a refuge for many species during summer and drought conditions (O'Connor et al. 2012; Prowse et al. 2022; Sánchez-Gómez et al. 2022). The Coorong and surrounds have long sustained First Nations societies, and waterbirds have immense cultural significance to First Nations peoples (Clarke 2019). An important driver of waterbird abundance and diversity in the CLLMM (Fig. 1) is the range of wetland habitats present, including the freshwater habitats of Lakes Alexandrina and Albert, the tidal mudflats of the Murray estuary, and the extensive mudflats of the Coorong lagoons, especially the South Lagoon (Phillips and Muller 2006).

Figure 1. The Coorong, Lower Lakes and Murray Mouth (CLLMM) region, located at the end of the Murray-Darling Basin (MDB) in southern Australia.

The CLLMM has experienced a long-term decline in its ecological condition, primarily due to a reduction in inflows. Anthropogenic modification of the Coorong's natural flow regime now sees water levels declining in the South Lagoon rapidly during spring and summer along with periods of extreme salinity and/or excessive phytoplankton and filamentous algal growth. These changes have impacted the structure and function of Coorong food webs (Ye et al. 2020) and influenced the availability of resources and foraging habitat for waterbirds (Paton et al. 2020). Furthermore, the Millennium Drought (2001–2009), together with extraction of water for human uses, resulted in very low freshwater input to the CLLMM for an extended period (Montazeri et al. 2011, Aldridge et al. 2017). This negatively impacted the ecological condition of the whole CLLMM system and produced 'winners' and 'losers' amongst the waterbird assemblage (Gosbell and Grear 2005, Ecological Associates 2010, Paton et al. 2020).

Nevertheless, the Ramsar site regularly supports 100,000 to 300,000 waterbirds and in some years accounts for a substantial proportion of waterbird abundance across all six of The Living Murray icon sites within the MDB (Kingsford and Porter 2008; Kingsford and Porter 2009; Porter et al. 2019). The wetland also meets all five Ramsar Criteria pertaining to bird abundance and distribution (O'Connor et al. 2012). The CLLMM provides important habitat for threatened waterbird species formally listed under national and/or state legislation (e.g. the fairy tern/Talamarari *Sterna nereis nereis*); and supports the key waterbird life-history stages of reproduction (15 species, particularly colonial- and beach-nesting birds) and moulting (56 species) (O'Connor et al. 2012; Paton 2010).

Intensive annual monitoring in the Coorong and Murray Mouth since 2000 and in the Lower Lakes since 2007 (Paton et al. 2020) provides comprehensive spatial data on the abundance and distribution of waterbirds over time. The waterbird assemblage of the Coorong, and particularly the Coorong South Lagoon, is distinct from those found in other parts of the CLLMM (Paton et al. 2009; Rogers and Paton 2009) and contributes substantially to the overall abundance and diversity of waterbirds across the entire Ramsar site. In summer, the Coorong typically supports approximately twice as many waterbirds as the Lower Lakes (Paton et al. 2020). Comparisons between data collected for the Coorong South Lagoon in 1985 and 2000–2007 showed that 23 of the 27 most common species declined over this period by at least 30% (Paton et al. 2009), and long-term trend analyses indicate drastic declines in shorebird populations in the Coorong between ~1981 and 2017 (Clemens et al. 2019). Importantly, however, the Coorong and Murray Mouth continue to provide critical foraging habitat for migratory shorebirds of the East Asian–Australasian Flyway (EAAF) (Clemens et al. 2016; Clemens et al. 2019), and regularly support > 1% of the total flyway population size for three shorebird species (O'Connor et al. 2012).

Recent research through the *Healthy Coorong, Healthy Basin* (HCHB) Phase One Trials & Investigations Project (Component 4 – Maintaining viable waterbird populations), led by The University of Adelaide, focused on how water management in the CLLMM impacts waterbirds from different functional groups. Specifically, the project: (1) modelled the distribution of key waterbird species in the Coorong under different environmental conditions (Prowse et al. 2022); (2) investigated measures of habitat suitability for different species (Jackson et al. 2022); (3) GPS-tracked three waterbird species (Mott et al. 2022); (4) developed a machine-learning approach to automated body-condition scoring for shorebirds (Jackson et al. 2022); and (5) conducted regional waterbird surveys and

modelled the distribution of waterbirds in wetlands throughout south-east South Australia using community-science datasets (Sánchez-Gómez et al. 2022).

Key learnings from past waterbird research in the CLLMM region include: (1) the critical importance of creating shallow mudflat habitat (which is regionally rare during summer) to support foraging by migratory shorebirds (Hunt et al. 2019; Jackson et al. 2022; Prowse et al. 2022; Sánchez-Gómez et al. 2022); (2) strong evidence that typical summer conditions in the Coorong South Lagoon do not support the foraging requirements of piscivorous waterbirds (O'Connor et al. 2013; Paton et al. 2020; Mott et al. 2022; Prowse et al. 2022); (3) documentation of long-distance dispersal events (and for some species, likely breeding attempts) during periods of high inland water availability, along with evidence of site fidelity to the CLLMM by individual waterbirds (Mott et al. 2022); and (4) improved understanding of trade-offs inherent in water-level management strategies designed to support different waterbird functional groups (Rogers and Paton 2009; O'Connor et al. 2013; Prowse et al. 2022). However, significant questions remain regarding the capacity of the CLLMM (and wetlands in the broader landscape) to support migratory shorebirds over their non-breeding period, and the viability of waterbird populations under rapidly advancing climate change. Given the diversity of migratory and non-migratory waterbirds, the variety of management options available (from targeted interventions for threatened species through to broad-scale management of environmental flows), and the range of stakeholders with interests in the CLLMM region, there are many future waterbird research possibilities that need to be prioritised. Articulation and prioritisation of research topics relating to waterbirds will inform development of the Science Program of the CLLMM Research Centre, which is delivering research that reflects community and First Nations priorities as well as management and decision-making needs for the CLLMM region in the face of climate change.

1.1 Aims

This foundational project of the CLLMM Research Centre aimed to identify and prioritise scientific research to inform management of the CLLMM region to support waterbird populations under climate change. Specifically, we aimed to establish priority research projects that: (1) could inform management of the CLLMM under a changing climate; (2) potentially lead to improvements in the viability of threatened waterbird species; and (3) were significant to a range of stakeholders (including First Nations groups) and afforded opportunities for community engagement in research.

1.2 Project overview

The project aims were achieved through the following three stages (Fig. 2):

- **Literature review.** We conducted a global literature review to evaluate climate-related threats to waterbirds and identify key knowledge gaps.
- **Collaborative research project development.** With this review in mind, we drafted four example waterbird research projects focussing on the CLLMM and surrounding region and shared these proposals with a range of stakeholder groups with interests in waterbird conservation and management. These included First Nations communities with traditional knowledge and cultural connections to the land and waterways; government agencies with responsibilities for management and policy in the CLLMM region; and environmental NGOs and scientists largely focused on

conservation activities and specific-species protection in the region. The stakeholder groups were invited to participate in workshops to provide feedback on the draft proposals and contribute new project ideas. Stakeholders feedback was used to revise the draft proposals to ensure relevance and alignment with community needs and priorities, and to develop further research project proposals. This stakeholder consultation process was carried out over four months.

- **Research project ranking.** Each research project or sub-project was scored (high, medium, or low) against three criteria aligning with the goals of the CLLMM Research Centre: (a) the importance of the research for informing future management of the CLLMM, particularly under a changing climate; (b) the ability of the research to lead to improvements in the viability of threatened waterbird species; and (c) the significance of the project for community, and the project's ability to engage community actively or passively in the research. Draft rankings were initially developed by The University of Adelaide project team. These were circulated to stakeholders for feedback which was used to revise rankings as necessary.

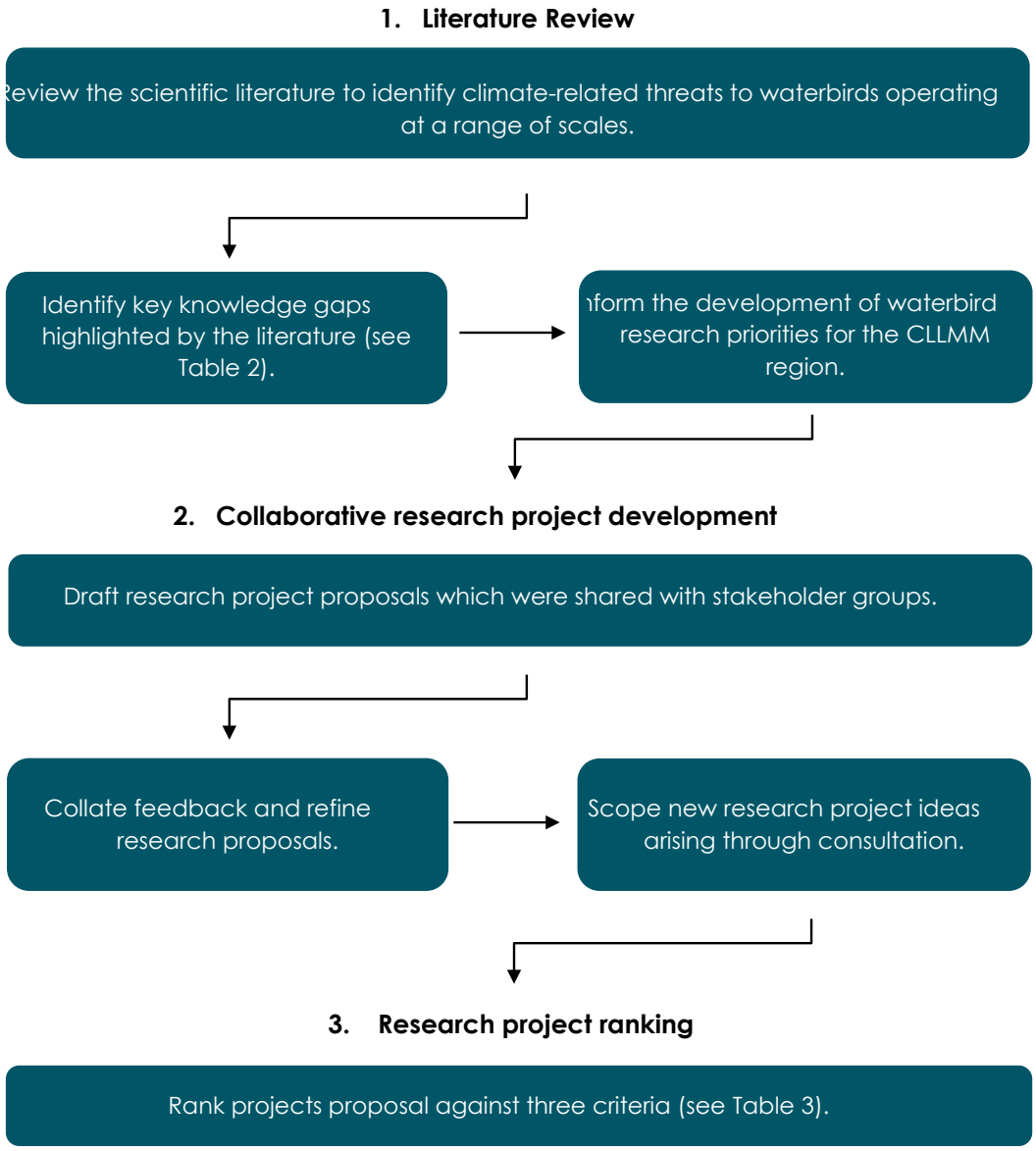

Figure 2. Flow chart illustrating the methodology used to develop and prioritise research to support the viability of waterbird populations in the CLLMM region under climate change.

2. Review of climate-change threats to waterbird populations

2.1 Methods

An initial search of published literature was conducted to find relevant review articles covering threats posed to waterbirds by climate change. We searched Web of Science and Google Scholar using combinations of the following search terms: "climate" AND ("chang*" OR "warming" OR "heat*") AND ("water bird*" OR "waterbird*" OR "shore bird*" OR "shorebird*" OR "wader*") AND ("threat*"OR "impact*" OR "risk"). To permit assessment of these search results within the project timeframe, results were limited to papers published in the last 20 years. Within these results, we located review articles and large multi-species studies (Table 1) from which we identified overarching climate-related threats. Having identified seven overarching climate threats, we conducted further searches to fully characterise each threat and to locate relevant examples.

Table 1. Review papers and large multi-species studies with a focus on waterbirds and climate change, which were used to identify overarching climate threats and their likely impact on waterbirds.

TYPE	REFERENCE
Review paper - global	Desta, H, Lemma, B, Fetene, AJJoAS (2012) Aspects of climate change and its associated impacts on wetland ecosystem functions: A review. *Journal of American Science* **8**, 582-596.
Review – covering European ducks (Anatidae) only	Guillemain, M, Pöysä, H, Fox, AD, Arzel, C, Dessborn, L, Ekroos, J, Gunnarsson, G, Holm, TE, Christensen, TK, Lehikoinen, A, Mitchell, C, Rintala, J, Møller, AP (2013) Effects of climate change on European ducks: what do we know and what do we need to know? *Wildlife Biology* **19**, 404-419.
Review paper - global	Norris, K, Atkinson, PW, Gill, JA (2004) Climate change and coastal waterbird populations–past declines and future impacts. *Ibis* **146**, 82-89.
Review paper - Tunisia	Sahbani, S, Béjaoui, B, Benabdallah, S, Toujani, R, Fathalli, A, Zaaboub, N, Aouissi, J, Kassouk, Z, Hamdi, N, Mbarek, NB (2022) Systematic review of a RAMSAR wetland and UNESCO biosphere reserve in a climate change hotspot (Ichkeul Lake, Tunisia). *Journal of Sea Research* 102288.
Review paper - global	Seri, NA, Rahman, AA (2021) Impact of Climate Change on Migratory Birds in Asia. *Pertanika Journal of Science & Technology* **29.**
Review paper- global	Sutherland, WJ, Alves, JA, Amano, T, Chang, CH, Davidson, NC, et al. (2012) A horizon scanning assessment of current and potential future threats to migratory shorebirds. *Ibis* **154**, 663-679.
Broad study of 390 species at 6,822 sites between 55° S and 64° N latitude.	Amano, T, Székely, T, Wauchope, HS, Sandel, B, Nagy, S, Mundkur, T, Langendoen, T, Blanco, D, Michel, NL, Sutherland, WJ (2020) Responses of global waterbird populations to climate change vary with latitude. *Nature Climate Change* **10**, 959-964.
Broad study of 69 waterbird species using wetlands across south-western Spain.	Ramírez, F, Rodríguez, C, Seoane, J, Figuerola, J, Bustamante, J (2018) How will climate change affect endangered Mediterranean waterbirds? *PLOS ONE* **13**, e0192702.

Broad study of 151 species across 21 Mediterranean countries.	Verniest, F, Le Viol, I, Julliard, R, Dami, L, Guelmami, A, Suet, M, Abdou, W, Azafzaf, H, Bendjedda, N, Bino, T (2023) Anticipating the effects of climate warming and natural habitat conversion on waterbird communities to address protection gaps. *Biological Conservation* **279**, 109939.

This included backward and forward citation searches from the review papers. In addition, we reviewed recent reports by government and relevant stakeholder groups concerning waterbirds in the CLLMM. Where possible, we prioritised studies from the southern hemisphere and particularly Australia. Papers focussed exclusively on artic or tropical species or habitats were excluded.

2.2 Results

Seven overarching climate-related threats to waterbirds were identified from the key studies identified (see Table 1): (1) reduced water availability; (2) reduced habitat suitability; (3) asynchrony between waterbird needs and key resources; (4) increased energetic costs; (5) increased disease risk; (6) increased frequency and intensity of extreme weather events; and (7) rising sea levels. Here we elaborate on each of these threats, provide relevant examples from the scientific literature, and highlight some key knowledge gaps (the latter are also summarised in Table 2).

2.2.1 Reduced water availability

Increasing temperatures and evaporation rates, together with increased anthropogenic water use, will result in an overall loss of waterbird habitat.

Altered habitat extent and connectivity

Numerous studies have modelled the effect of future drying and heating scenarios on waterbird habitat. For example, vast reductions in suitable habitat are predicted throughout the Africa-Eurasian flyway (Breiner *et al.* 2022) while reduced habitat extent and connectivity is predicted to increase waterbird extinction risk in Italy (Bellisario *et al.* 2014). In Australia, waterbird populations are declining across the Murray Darling Basin (MDB), and waterbird habitat has been degraded by water resource development and will likely be negatively impacted further by climate change (Bino *et al.* 2021).

Anthropogenic water use

While inflows to wetland habitats will be reduced by heating and drying, this problem will be exacerbated by increasing anthropogenic water use. Higher demand for water in the upstream areas of a system reduces waterbird habitat extent and quality downstream (Brandis *et al.* 2018; Maleki *et al.* 2021).

Local-scale movements and habitat selection

Waterbirds use different components of habitat mosaics and conditions in one part of a landscape may affect the relative value of other areas. For example, wintering waterbirds in Europe select sites with characteristics that reduce winter harshness (e.g. greater protection and higher flows) (Musilová et al. 2018). In Australia, waterbirds rely on coastal sites as refugia during drought while using inland habitat during wet years. Conditions at these inland wetlands can affect waterbird survival rates, as shown for sharp-tailed sandpiper/Nemineri (*Calidris acuminata*) (Clemens *et al.* 2021) and Australian white ibis/Tloperi (*Threskiornis moluccus*) (Wen *et al.* 2016). Localised weather is a strong predictor of waterbird abundances in Australia (Padgham 2011) so understanding species-level

habitat selection and movement triggers is critical to inform climate-change adaptation strategies. Globally, movement and habitat selection patterns are better studied for migratory than non-migratory waterbird species, yet overall we have a poor understanding of how waterbirds move across habitat mosaics and what drives habitat selection as environmental conditions change.

2.2.2 Reduced habitat suitability

The negative impacts of heating and drying, together with changes in rainfall and flow volumes and timing, will include higher water temperatures and reduced inundation depth and timing. This will impact habitat suitability for waterbirds, potentially causing range shifts, changes to the availability of key biotic resources (e.g. invertebrate communities), reduced suitable breeding or wintering windows, and increasing adverse conditions (e.g. disease outbreaks or algal blooms). There is a general need to understand how suitable habitat will shift under future climate conditions to inform pre-emptive conservation actions (e.g. acquiring wetlands for conservation and restoration, or creating new wetlands), and to understand how climate-driven land-use changes (e.g. altered flood irrigation practices and crop types) will affect waterbirds.

Reduced inundation depth and altered timing

As well as reduced habitat extent, inundation depths and periods will also decrease for many wetlands. This will lead to reduced breeding success for species that rely on these habitats for nesting and food resources (Maleki *et al.* 2016). For island-nesting species, low water levels can allow predators access to nests (Carneiro *et al.* 2016). For example, egg predation is a leading cause of breeding failure in the fairy tern/Talamarari in Australia (Greenwell and Dunlop 2023). Increasing capacity to store environmental water allocations and to time water releases to support breeding waterbirds could prove a useful mitigation strategy during drought (Kingsford and Auld 2005; Bino *et al.* 2014).

Resource shifts

Complex food web changes are likely under climate change and will have cascading effects that impact waterbirds. For example, warming temperatures in a New Zealand intertidal habitat favoured a parasitic trematode species, which proliferated and decreased the abundance of its host amphipod, which in turn was a key prey item for some waterbirds (Poulin and Mouritsen 2006).

Waterbird distribution shifts

Numerous studies have demonstrated or predicted a shift in waterbird distributions towards cooler areas as the climate warms and habitat suitability changes spatially. These studies are largely focused on the northern hemisphere and suggest a northerly shift for many species because warming arctic regions will provide additional habitat (e.g. Guillemain et al. 2013; Han et al. 2018; Amano et al. 2020). Distributional shifts will result in some species moving away from conservation reserves to new areas that are not currently under protection (Pavón-Jordán et al. 2020). Acquiring areas identified as likely future wetland refuges and implementing conservation strategies now may lessen the negative impact of range shifts.

2.2.3 Asynchrony between waterbird needs and key resources

Changes in waterbird phenology, and in the duration and extent of resource pulses, may cause asynchrony between the availability/abundance of key resources (e.g. food, shelter, nesting sites) and waterbird requirements. Although asynchrony between resource pulses and waterbird phenology is a commonly cited impact of climate change, supporting evidence largely comes from terrestrial bird species and studies based in the northern hemisphere (Samplonius et al. 2021).

Migration and breeding times will shift

Climate-induced shifts in temperature, wind conditions and food resources are likely to alter the timing of waterbird breeding events (Alves et al. 2019) and migration (Chambers et al. 2014; Zaifman et al. 2017; La Sorte et al. 2019). For example, common greenshank/Terilteril (*Tringa nebularia*) in central Europe display a long-term pattern of advancing spring and delaying autumn migrations (Anthes 2004). The timing of these life history events could then become asynchronous with suitable resources.

Phenological effects will be species-specific

Waterbird species might experience positive, negative, or neutral outcomes from phenological and resource changes. Waterbirds can use temperature triggers to stimulate migration and flow thresholds to stimulate breeding. For example, high flow events act as a trigger for breeding events in many colonial species like the royal spoonbill/Kraurarli (*Platalea regia*) (Arthur et al. 2012). However, species likely vary in their capacity for plastic phenological adaptations to climate change (Gill et al. 2014; Keogan et al. 2018; Meltofte et al. 2018). Understanding the triggers for important life history and movement/dispersal events, and how they differ between species, will be critical to inform management actions under a changing climate.

2.2.4 Increased energetic costs

The energetic costs of thermal regulation will increase with warmer temperatures, and altered habitat extent and connectivity may necessitate greater flight distances to access resources. For migratory waterbirds, changes to wind patterns will affect energy use during migration.

Energetic costs to stay cool

Birds demonstrate adaptive strategies to mitigate temperature effects but, as temperatures rise, the frequency and costs of employing such strategies will also increase. For example, nesting great skuas (*Stercorarius skua*) bathe more frequently at higher temperatures, presumably for thermal regulation. This behaviour has an energetic cost and also leaves nests undefended from predators more often (Oswald et al. 2008).

Increased movement to access resources

Many waterbirds rely on multiple habitat types; for example, pied oystercatchers/Prukal (*Haematopus longirostris*) preferentially nest on sandy beaches but prefer to forage on intertidal mudflats (Lauro and Nol 1995). Where one or more habitats are impacted by climate change, waterbirds may need to travel further to access their preferred resources which will incur an energetic cost (Haig *et al.* 2019). The energetic demands of increased movement will be particularly critical during vulnerable periods such as the breeding period and times of low food availability.

Changes in wind patterns increase the energetic costs of migration

Changes in the strength of advantageous and unfavourable winds, together with new temperatures regimes, could alter the optimal flight heights of migratory species and might impact survival rates by increasing the energetic cost of migration (Sutherland *et al.* 2012; Guillemain *et al.* 2013). Understanding species-level habitat selection and migration patterns will be critical for predicting climate-change effects on migratory species. For example, red-necked stint (*Calidris ruficollis*) appear less vulnerable than curlew sandpiper (*Calidris ferruginea*) to changed migration conditions, possibly because they use more stop-over sites and are therefore less susceptible to changes in the suitability of any one site (Lisovski *et al.* 2021).

2.2.5 Increased disease risk

Warmer temperatures and reduced habitat quality may increase the abundance and transmission of pathogens causing waterbird disease. Where habitat is reduced by overall drying, waterbirds may congregate in specific areas, which in turn could increase the frequency and scale of disease outbreaks. Habitat changes are also likely to change bird movement patterns and create novel pathways for pathogen transmission (Gilbert *et al.* 2008; Petherbridge *et al.* 2022). Waterbirds act as a reservoir for several economically significant pathogens (Wille *et al.* 2018) and climate-induced changes to host-pathogen dynamics could increase disease occurrence or spread. Significant pathogens carried and transmitted by waterbirds include avian influenza virus (Gaidet *et al.* 2007), Japanese encephalitis (Walsh *et al.* 2023), West Nile virus (Deichmeister and Telang 2011; Fereidouni *et al.* 2011) and avian cholera (Samuel *et al*. 2007).

2.2.6 Increased frequency and intensity of extreme weather events

Droughts, floods, storms and extreme heat events are projected to increase in frequency and intensity under climate change, thereby impacting waterbirds directly and indirectly. Temperature extremes may result in mass mortality events. Extreme weather will also impact waterbird habitats in many ways, including by altering the chemical composition of waterbodies, modifying fish and invertebrate communities, reducing protection from predators in nesting and foraging areas, and altering habitat connectivity.

Habitat destruction

Extreme flooding can erode and flatten vegetation while drought can cause habitat degradation/ loss and mass waterbird fatalities. An increase in the frequency and intensity of bushfires is also likely to alter wetland habitats. For example, the "Black Summer" bushfires in Australia affected 206 hectares of saltmarsh and mangrove habitat used by waterbirds, with effects still evident two years after the fire (Glasby *et al.* 2023).

Extremes weather events during vulnerable periods

More frequent and intense extreme heat events and cold snaps will directly increase waterbird mortality rates (Newton 2007; Glencross *et al.* 2021). For example, the 2014–2016 marine heat wave in the northeast Pacific Ocean resulted in mass mortality and reproductive failure of the common murre (*Uria aalge*) (Piatt *et al.* 2020). However, the threat posed by extreme weather events varies substantially between species, with small-bodied birds likely more vulnerable to climatic extremes (Clark 2009). For breeding birds, extreme weather events can result in mass nest abandonment and/or high offspring mortality rates. Suboptimal incubation temperatures can alter the developmental rates of

eggs, while high temperatures can render developing chicks more vulnerable to chemical contaminants (Lunny *et al.* 2020). Exposure of nesting sites means birds and eggs are more susceptible to high temperatures (Hart *et al.* 2016) so conserving protected nest sites with adequate shelter might be beneficial in warming conditions (D'Alba *et al.* 2009).

Chemical changes to waterbodies

Extreme weather events including drought, flood and wildfire alter the chemical composition of wetland systems. During severe drought, for example, shrinking wetlands can expose acid-sulphate soils. When water returns once more, the resulting changes in water chemistry can result in mass fish mortality events, reducing food resources for piscivorous waterbirds (McCarthy et al. 2006). Acid sulphate soils were exposed by the Millenium drought along the Murray River and, five years following the end of the drought, recovery was incomplete in the soils of the lower Murray (Mosely *et al.* 2017).

Increased vulnerability to predators

Reduction in water levels due to drought allows predators access to near-shore islands where waterbirds roost and breed. During breeding, frequent disturbance by predators can cause nest abandonment. In South Australia, for example, predation of Australian pelican (*Pelecanus conspicillatus*) eggs by foxes caused direct mortality and abandonment of nests, with impacts likely exacerbated by drought conditions (Johnston 2016).

2.2.7 Rising sea levels

Rising sea levels will flood coastal freshwater wetlands which could result in tidal and storm surge damage to beach-nesting or colonial nesting waterbirds.

Saltwater inundation changes freshwater systems

Although saltwater incursion may create new wetlands (Guillemain et al. 2013), where freshwater wetlands are inundated the shift in salinity will likely reduce habitat suitability for many waterbird species (Clausen and Clausen 2014; Wikramanayake et al. 2020). A Danish study of three coastal wetlands found saline incursion decreased bird diversity and caused shifts in flora and fauna communities (Holm and Clausen 2006). The reduction of coastal wetland habitat by saltwater inundation will affect population movement for migratory species. A study of ten species of the East Asian-Eurasian flyway found 23–40% of intertidal habitat used by these species will be inundated by rising sea levels (Iwamura et al. 2013). Identifying sites that are vulnerable to sea level rise, and on which a large proportion of migratory populations rely, will help identify conservation priorities.

Threats to beach-nesting shorebirds

For beach-nesting species, storm surges during the nesting season could inundate nests (Craik *et al.* 2015) and are already a leading cause of breeding failure in some species such as the fairy tern/Talamarari (Greenwell and Dunlop 2023). Understanding species nesting preferences will allow for the conservation prioritisation (or creation of) suitable nesting locations that can withstand climate-induced water level changes. For example, small, narrow, elongated islands away from water levies were identified as conservation priorities for nesting American avocet (*Recurvirostra americana*), black-necked stilts (*Himantopus mexicanus*) and Forster's tern (*Sterna forsteri*) in an American wetland (Hartman *et al.* 2016).

2.2.8 Caveats

Although our literature review focused on Australian and southern hemisphere research where possible, most of the relevant studies documented were conducted in the northern hemisphere. Given the large difference in environmental conditions and variability between the best studied regions (e.g., the Palearctic) and southern Australia, further research is clearly required to understand how the threats detailed above are likely to affect waterbirds in the CLLMM. Of course, the distributions of all waterbird species that use the CLLMM extend well beyond this local system, so the species-level impacts of climate change will depend on climate effects acting across these ranges. Further, interactions between these climate-change threats complicates prediction of their combined impacts on waterbirds. For example, decreasing average rainfall together with more frequent extreme rainfall events are likely to affect upper and lower areas of a catchment differently. Likewise, climate-induced changes to habitat structure and food resource availability might benefit some waterbird species while being detrimental to others. Climate-change impacts are also acting on ecological systems in conjunction with other anthropogenic threats (e.g., pollution and land clearing) which should also be considered (Saunders *et al.* 2021).

Table 2. Key knowledge gaps identified by the literature review that relate to climate-change threats to waterbird populations.

KNOWLEDGE GAP	ADDRESSING THESE KNOWLEDGE GAPS IN THE CLLMM REGION
Waterbird movement and food resource availability. There is a scarcity of data showing how waterbirds move across habitat mosaics and what drives habitat selection as environmental conditions change.	Waterbird telemetry can provide crucial spatial information on movement and habitat selection by waterbirds at a range of scales under different environmental conditions, and help identify high-use locations to focus management and conservation activities. One key driver of habitat selection is food availability, which can be addressed within the CLLMM region by studying the drivers of variation in food resources for waterbirds of different functional groups. DNA-based monitoring of macroinvertebrate/plant/fish assemblages in the CLLMM and surrounding wetlands could be tested as a cost-efficent approach to quantifying multiple food resources simultaneously.
Habitat suitability under a changing climate. It is critical to understand how suitable habitat for waterbirds will shift under future climate conditions to inform pre-emptive conservation actions (e.g. acquiring wetlands for conservation and restoration or creation of new wetlands).	Through development of population viability analysis (PVA) models and/or habitat suitability models for target waterbird species, the predicted impact of different climate scenarios can be explored, to inform management/restoration decisions within the CLLMM and the broader wetland network. Body condition is a direct and effective proxy of habitat quality for shorebird species. Engaging community scientists to monitor shorebird body condition using photography (together with a machine-learning approach to body-condition scoring) could provide crucial data on current and changing habitat suitability,

	the ability of migratory species to gain body condition over their non-breeding period, and the capacity of resident shorebirds to maintain condition over their breeding period.
Impacts of climate-driven land-use changes. Currently, we have a poor understanding of how climate-driven land-use changes (e.g. altered flood irrigation practices and crop types) will affect waterbirds.	Waterbird telemetry data can provide useful information on the habitats used by different species and hence the likely impact of changing agricultural practices. Through consevation modelling for target waterbird species, the predicted impact of different flow availabilities could be simulated, to understand the downstram impact of changed irrigation practices on waterbirds in the CLLMM region.

3. Waterbird research priorities

3.1 Methods

A combination of face-to-face and online workshops were conducted with different stakeholder groups from November 2023 to February 2024. The aim of these workshops (usually 2-hours in length) was to identify waterbird research projects to inform management that supports waterbird populations in the CLLMM, particularly under climate change. Example research projects developed by The University of Adelaide team were discussed with workshop participants who provided feedback as introduced new project ideas. The following organisations participated directly in a workshop, or provided feedback out of session:

- The Ngarrindjeri Aboriginal Corporation and broader Ngarrindjeri community
- The South East Aboriginal Focus Group and the First Nations of the South East community
- Friends of Shorebirds South East
- Friends of the Coorong
- Birdlife Australia
- Nature Glenelg Trust
- South Australian Shorebirds Foundation
- BioR
- Department for Environment and Water (including The Living Murray program)
- Limestone Coast Landscape Board
- Murraylands and Riverland Landscape Board
- Murray Darling Basin Authority
- Department of Climate Change, Energy, the Environment and Water
- Commonwealth Scientific and Industrial Research Organisation

Please refer to the Appendix for a comprehensive list of stakeholders consulted (Tables A1-A9), along with the key take-away messages from each organisation or individual.

3.2 Proposed waterbirds research projects in the CLLMM region

The following projects were initially developed by The University of Adelaide project team and were subsequently refined through the consultation process.

3.2.1 Waterbird telemetry

Background: Telemetry studies can provide crucial information on how waterbird species use the CLLMM, and the location and nature of habitats required for nesting, roosting and foraging. The HCHB waterbirds project produced spatial tracking data for three waterbird species (Australian pelican/Nori, red-necked avocet/Nitinyi, and sharp-tailed sandpiper/Nemineri). Key learnings included: regular foraging trips made by Australian pelicans from the South Lagoon breeding colony to the North Lagoon (Fig. 3), roosting by shorebirds on islands within the Coorong lagoons, and predictable relationships between water depth and red-necked avocet and sharp-tailed sandpiper/Nemineri occupancy. However, the CLLMM does not exist in isolation but is one component of a broader network

of wetlands that supports populations of resident and migratory waterbirds with different requirements. Telemetry can help to contextualise the relationship between the CLLMM and surrounding (including restored) wetlands by documenting waterbird movements between them. For example, the previous HCHB waterbirds project: (1) identified wetlands (e.g. Tolderol Game Reserve, Berri Basin, Lake Eyre-Kati Thanda, Lake Brewster) used by individuals tagged within the CLLMM; and (2) documented site fidelity of red-necked avocets that dispersed to inland wetlands for likely breeding attempts but returned to the Coorong once more. Expansion of waterbird telemetry to track additional species (e.g. fairy tern/Talamarari, large-bodied migratory and resident shorebirds, and dabbling ducks) would produce valuable data for conservation planning.

Aims: For a representative set of waterbird species, to use telemetry to understand: (1) use of habitats within the CLLMM region (including Ocean Beach) and foraging ranges; and (2) connectivity between the CLLMM and the broader wetland network, including to document the contribution from restored wetlands.

Where: Waterbird tagging locations would be focused in the CLLMM but also target important wetlands in the broader landscape. Depending on the study species and water availability, telemetry data would likely document wetland use at a range of scales, from local (e.g. the CLLMM, Ocean Beach) and regional (e.g. Lake Hawdon, coastal lakes of the South East) to national (e.g. Kati Thanda-Lake Eyre Basin, MDB).

How: Following methods employed by Mott et al. (2022), GPS telemetry devices would be selected to suit target species. Suitable waterbird trapping locations would be identified using long-term survey data and expert knowledge, and experienced ecologists would fit tracking devices on-site. Priority functional groups/species could include:

- Piscivores, particularly **fairy tern/Talamarari** to consider foraging distributions around nesting sites, and dispersal, or **Caspian tern/Tenatjeri** (*Hydroprogne caspia*) might possibly be used as representative of the diving piscivores.
- Shorebirds, particularly migratory **common greenshank/Terilteril** (which can carry a high-quality GPS unit and has been abundant at Lake Hawdon recently) and **sharp-tailed sandpiper/Nemineri** (for which better GPS technology is now available), and the resident **pied oystercatcher/Prukal** (which uses Ocean Beach and the CLLMM).
- Herbivorous waterfowl, particularly **chestnut teal/Ngra:ki** *(Anas castanea*) (a relatively sedentary species favouring coastal areas) and **black swan/Kungari** (*Cygnus atratus*) (which forages in water depths of ~20–100 cm). Other possibilities include **Australian shelduck/Wa:nyi** (*Tadorna tadornoides*), a resident breeder along the limestone coast, and the endangered ***magpie goose*/Pangkuli** (*Anseranas semipalmata*), which has First Nations significance.
- Colonial nesting waterbirds that breed in the Lower Lakes, such as **royal spoonbill** (*Platalea regia*) and **straw-necked ibis** (*Threskiornis spinicollis*).
- Herons, particularly the endangered **Australasian bittern/Talkuri** (*Botaurus poiciloptilus*).

Expected Outcomes: Long-term telemetry studies would improve our understanding of how species move between wetlands and respond to changing climatic conditions. By identifying key foraging, roosting and/or breeding habitat, the project would guide tailored management of the CLLMM and other regional wetlands to support a variety of waterbird functional groups. Climate-induced shifts in habitat suitability and connectivity (see sections

2.2.1 and 2.2.2.) will likely impact species across the CLLMM, and improved understanding of habitat preferences could help parameterise habitat suitability models for tracked species and inform e-water delivery planning. This project could also link with parallel research streams, including investigation of pathogen loads in migratory species (through serology and/or cloacal swabs from trapped birds) and characterisation of waterbird flight paths/heights which is relevant to the risks posed by windfarm construction. Finally, telemetry studies provide excellent opportunities for community engagement and science communication, from involvement of volunteer and other organisations in waterbird trapping, to an online live steam of waterbird locations and/or media illustrating a 'birds-eye' view of waterbird flight paths.

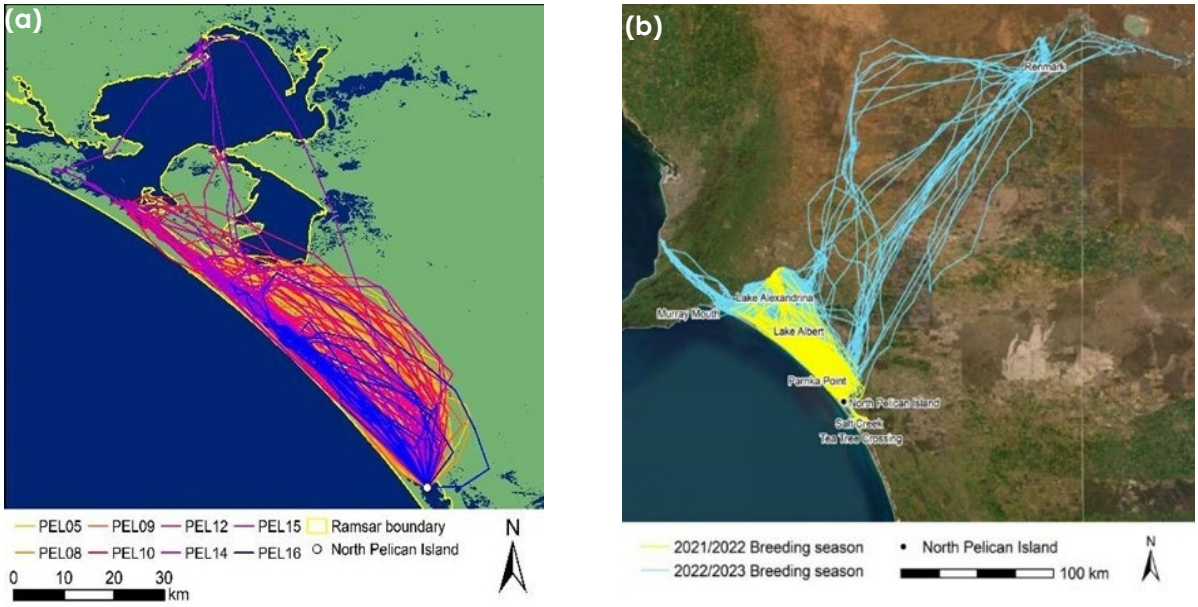

Figure 3. Australian pelican telemetry: (a) regular foraging trips from the north pelican island breeding colony (south lagoon) to the north lagoon in the 2021–2022 breeding season; (b) foraging by pelicans breeding on north pelican island extended to the berri basin in the 2022–2023 season (Mott et al. 2022).

3.2.2 DNA-based investigation of prey availability, shorebird dietary preferences and pathogen load

Background: The availability of food resources is one proxy of habitat quality that is widely used in the shorebird literature. However, traditional monitoring of macroinvertebrate abundance/diversity using sediment cores is time-consuming, produces low-precision estimates of density, and does not provide information on prey selection by shorebirds. Monitoring species assemblages using environmental DNA (eDNA) is becoming increasingly cost-effective and this approach could be applied in the CLLMM and other wetlands to quantify variation in shorebird food resources over space and time. Simultaneously, DNA-based analysis of shorebird scats could yield specific information on the species being consumed and dietary preferences (i.e. consumption relative to availability), and provide additional information on the aquatic plant species consumed. Understanding shorebird preferences for prey species, if they exist, is critical to inform management of the CLLMM system. For example, prior DNA-based work on the diet of waterbird species in the Coorong provided some evidence that shorebirds preferentially targeted amphipods over chironomid prey. Further analysis of scat and background environmental samples would

help to understand prey availability and selection, and potentially the foraging locations, of key species (e.g. migratory shorebirds) over the seasonal cycle. As global change processes are modifying the pathogen exposure of migratory shorebirds, analysis of shorebird scats could be expanded to investigate the pathogen load of these waterbird species.

Aims: The primary aims are: (1) to validate eDNA-based monitoring of macroinvertebrate assemblages in the CLLMM; (2) to quantify how macroinvertebrate prey respond to intra- and inter-annual variation in environmental conditions (e.g. water level, salinity); (3) to identify prey and aquatic plant preferences of key shorebird species; and (4) to characterise the viral and bacterial pathogen load of migratory shorebirds.

Where: The CLLMM and nearby wetland sites (e.g. Tolderol Game Reserve, Morella Basin, Lake Hawdon South and North, Teringie wetland complex).

How: Scat sample and background environmental (e.g. sediment and/or water) samples would be collected using a site × time sampling design. DNA-based approaches would be used to consider spatial and temporal variation in available and consumed species, and pathogen load. In parallel, traditional sampling of macroinvertebrate assemblages via visual counts from sediment cores would be used to validate the DNA-based approach to macroinvertebrate monitoring. Where wetland restoration activities occurred during the project timeline (e.g. Lake Hawdon North), before-after control-impact surveys could be planned to quantify the impact of management on shorebird food resources. Two DNA-based analysis methods could be used in this project: (1) specific DNA quantification for target species using quantitative PCR (qPCR) with species-specific amplification primers; and (2) community composition analyses, using a DNA metabarcoding approach based on 'universal' amplification primers designed for high-level taxonomic groups (e.g. Insecta), thereby producing data on the relative abundance of DNA sequence reads from different species or genera.

Expected Outcomes: This project would deliver an improved understanding of plant and prey selection by waterbird species, a validated method for monitoring baseline data on seasonal changes in benthic prey species, and (potentially) a direct evaluation of the impact of targeted wetland restoration on shorebird food resources. Understanding current resource usage by shorebirds and their dietary preferences is critical given climate-induced shifts in food availability are likely (see section 2.2.2) and timings (section 2.2.3). Importantly, results for the Coorong would contribute to the current uncertainty around the relative importance of macroinvertebrate abundance or diversity to shorebirds. Further, a key output from this project would also be to assess food availability for shorebirds in the drier months prior to their migration north. Investigating the pathogen load of migratory shorebirds (e.g. avian influenza, West Nile virus, antimicrobial-resistant bacteria) over the course of their non-breeding season would produce information of conservation and biosecurity/OneHealth relevance at a time when the risk of emerging infectious diseases is increasing due to climate warming (see section 2.2.5). The project could also be extended to test capacity for eDNA-based monitoring of other aspects of the system, such as *Ruppia* seagrasses and fish species, with potential for validation against traditional monitoring data collected from other research themes.

3.2.3 Shorebird body condition monitoring through community science

Background: Shorebird body condition is an effective proxy of habitat quality, as the physical condition of birds reflects prey availability and accessibility. During the HCHB waterbirds project, a machine-learning algorithm was developed to classify the body condition of shorebirds from still images (Fig. 4). However, significant questions remain regarding the capacity of the CLLMM (and wetlands in the broader landscape) to allow migratory shorebirds to improve their body condition before their northward migration in autumn. This function is potentially becoming more important under climate change which will likely affect the food resources available to shorebirds before and during their migration (see section 2.2.3). Furthermore, it is unknown whether current ecological conditions in the CLLMM are sufficient to allow resident shorebirds to maintain body condition during their reproductive period when they must remain close to their nests. To address these questions, a web portal (or other application) could be developed to facilitate submission of shorebird photographs from the CLLMM and other south-east wetlands by community scientists.

Aims: To work with community to create a spatiotemporal database of shorebird images, with which to: (1) continue to improve an automated condition scoring system for different shorebird species; (2) compare body condition trajectories over the non-breeding period for migratory shorebirds (e.g. sharp-tailed sandpiper, red-necked stint) in different wetlands; and (3) evaluate body condition of resident beach-nesting shorebirds (e.g. pied oystercatchers, hooded plovers) over their reproductive periods.

Where: Photographs taken by scientists and community scientists, and captured using remote monitoring devices (i.e. camera traps), would be collated from the CLLMM and other wetlands.

How: Community events held in the CLLMM region (e.g. Goolwa), as well as information posted online (e.g. Facebook groups), would raise awareness of this community science initiative, highlighting the importance of submitting georeferenced shorebird images to a designated website/app (to be developed). In parallel, research to validate condition scoring for additional species would be conducted; for example, using >20,000 camera-trap images produced by the HCHB waterbirds project. Body condition scores would be assigned by experts for a sample of photographs for each shorebird species to improve the machine-learning classifier of physical condition. The classifiers would then be used to score all submitted images, allowing body-condition changes over time and differences in shorebird condition between sites to be evaluated.

Expected Outcomes: A larger collection of shorebird photos from community scientists would allow improvement of the machine-learning algorithm, reducing classification errors, and enhancing our ability to draw meaningful conclusions regarding habitat quality in the CLLMM region. The community scientist initiative would actively engage community in shorebird science and conservation. Differences between sites in the capacity of migratory shorebirds to gain condition, or the capacity of resident shorebirds to maintain condition while breeding, could provide useful data on habitat quality variation and inform future management. In combination with parallel telemetry and associated observations on captured individuals, this project could provide data on the timing of fat deposition relative to moulting and also the foraging area indexed by body condition scores for individuals captured in the CLLMM and other wetlands.

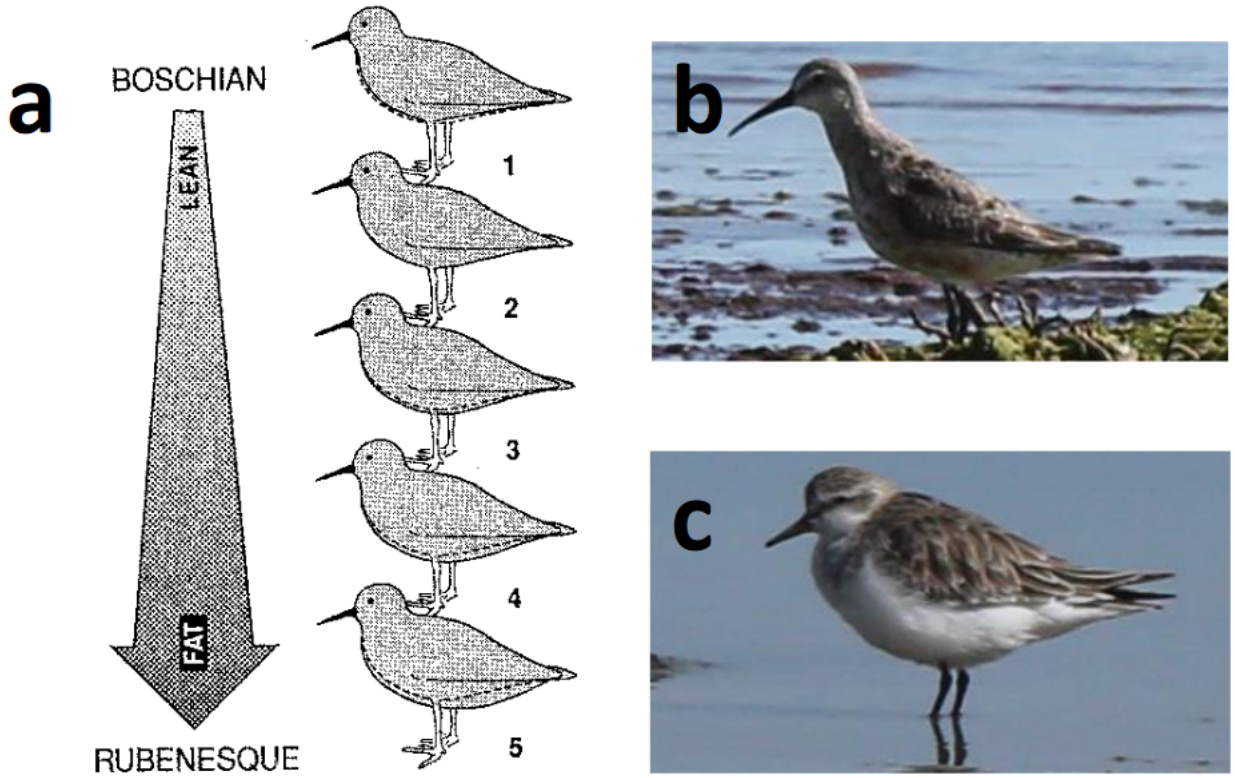

Figure 4. (a) index for scoring shorebird body condition, reproduced from Wiersma and Piersma (1995). (b) example image of a curlew sandpiper/Nemineri (*Calidris ferruginea*) assigned a score of 2. (c) example image of a red-necked stint (*Calidris ruficollis*) assigned a score of 4.

3.2.4 Conservation modelling for key waterbird species to inform climate preparedness and restoration actions

Background: Wetland availability and water quality in the CLLMM and beyond are impacted during drought and will also be affected by systemic climate change. The effects of drought have already been seen in waterbird assemblages of the Coorong, with more 'loser' than 'winner' species during the Millennium Drought. The HCHB waterbirds project developed statistical response models for the Coorong lagoons only, quantifying how the distribution and abundance of ten key waterbird species is impacted by environmental and biological conditions. However, the viability of waterbird populations under a range of current threats and rapidly advancing climate change is uncertain. For example, as sea level rises, ingress of salt-water will impact water levels in the Coorong lagoons and modify the salinity of the Lower Lakes. The development of population viability analysis (PVA) models or habitat suitability models could inform hydrological management and restoration decisions in the CLLMM and (depending on the species and scale chosen) the broader wetland network. Specific research subcomponents to quantify the magnitude of species-specific threatening processes would be required to inform model development. This project would be informed by the proposed telemetry project which would provide information on dispersal between wetlands and other habitats.

Aims: To inform climate preparedness and restoration for representative species, by: (1) targeted field and desktop research to quantify the demographic impact of current threatening processes; (2) evaluation of possible restoration and threat-abatement opportunities; and (3) development of PVA or habitat suitability models that are

mechanistically linked to hydroecological models/projections, to allow simulation-based evaluation of population viability under climate change and different restoration alternatives.

Where: Depending on the species, this research could vary from local (i.e. the CLLMM) to the landscape scale.

How: The project focuses on species-specific threats and population viability. Priority species might include:

- **Fairy terns/Talamarari.** The CLLMM fairy tern/Talamarari population is the best studied in south-eastern Australia, with long-term monitoring of survival rates (through a capture-mark-recapture program), a 20-year dataset of breeding success, and an annual census. The availability of suitable fairy tern/Talamarari nesting habitat declines in the Coorong when water levels are very low (because feral predators can reach islands used for nesting) or high (because islands are inundated). By combining historical data on island nesting habitat area, water level/salinity and long-term fish density monitoring (conducted by SARDI), this project would quantify drivers of nest-site selection, breeding success and mortality for the Coorong population. Further, field research could estimate predator and vehicle impacts (e.g. through camera traps installed at key locations, such as the Murray Mouth) and specific restoration options could be evaluated (e.g. creation of artificial nesting habitat). This knowledge would be integrated within a spatial PVA model, allowing prediction of fairy tern/Talamarari population trajectories under different hydroecological scenarios and targeted management interventions (e.g. predator control, vehicle restriction, low-cost options for artificial habitat creation through placement of dredge spoil).
- **Sharp-tailed sandpiper/Nemineri.** Previously, the HCHB waterbirds project demonstrated a clear positive relationship between the abundance of sharp-tailed sandpiper/Nemineri and the extent of shallow foraging habitat, documenting the deficiency in the availability of this habitat throughout south-east South Australia in summer, and showing the importance of Coorong islands for roosting. A landscape-scale model of habitat suitability could be developed for this species, integrating abundance monitoring data for the Coorong lagoons/Lower Lakes, community science datasets for other wetlands, and macroinvertebrate prey monitoring, to test the impact of climate change scenarios and specific wetland restoration activities.
- **Black swan/Kungari**. The HCHB waterbirds project demonstrated a decline in black swan/Kungari abundance in the Coorong South Lagoon as water level fell and salinity rose during the Millenium drought. A PVA model for black swan/Kungari could consider the impact of climate-change and management scenarios on the subpopulation of this species in the CLLMM. Further, through First-Nations-led assessments of traditional harvesting practices, the minimum hydroecological targets required to sustain those practices could be estimated.

Expected Outcomes: By focusing on threat assessment and abatement opportunities for a representative set of key waterbird species, this project could provide recommendations regarding future management/restoration within the CLLMM (and beyond) that explicitly account for climate change. Restoration activities could also provide opportunities for community conservation; for example, creation of artificial nesting habitats for fairy

terns/Talamarari could encourage community involvement (e.g. through painting of decoy incubating fairy terns/Talamarari). By integrating different datasets within quantitative models, this project would also provide a clearer picture of the carrying capacity of the entire CLLMM, and its ability to sustain populations of waterbirds with different requirements under climate change and a range of management/infrastructure and hydroecological scenarios.

3.3 Additional projects arising through consultation

3.3.1 Colonial nesting species within the Lower Lakes

The impact of flow decisions on the breeding success of colonial nesters in the Lower Lakes is poorly understood. The main colonial breeding species are pied cormorant/Ngalgurindi (*Phalacrocorax varius*), white ibis and royal spoonbill (the latter might stimulate most community and management interest). Colonial nesting could be studied in a variety of ways (e.g. modelling long-term monitoring data in relation to hydrological conditions, drone-based surveys coupled with machine learning approaches for automated enumeration of nests). This research could be used to understand what conditions benefit colonial breeders, and potentially to justify e-water delivery to the Lower Lakes. Given the increasing frequency of extreme weather events due to climate change, understanding breeding triggers for these species is critical. For example, high-flow events act as a trigger for reproduction in many colonial nesting species such as the royal spoonbill/Kraurarli (Arthur et al. 2012) (see section 2.2.6).

3.3.2 Human disturbance of beach-nesting and migratory shorebirds

From the Murray Mouth to far south-east South Australia, humans disturb beaches and wetlands in a range of ways, including through substantial vehicle access, legal and illegal camping, and game duck hunting. As the climate changes, the effects of human disturbance on beach-nesting species may be exacerbated by rising sea levels causing a reduction in the area of suitable nesting habitat and increasing the risk of storm surge damage to nests (see section 2.2.7). GPS-based telemetry could be used in tandem with monitoring of disturbance processes to understand how disturbance impacts the roosting and foraging behaviour and location of waterbirds (e.g. sharp-tailed sandpiper). Vehicle disturbance is particularly strong over the summer holiday period and could be measured using laser-based vehicle counters installed at entry points.

3.3.3 Monitoring migratory shorebird congregations prior to migration

Climate warming is influencing the timing of shorebird migrations (see section 2.2.3) and may affect access to resources on which shorebirds rely before and during migration. This project could generate spatially and temporally replicated shorebird counts to identify sites where migratory shorebirds congregate prior to their migration north, with a particular focus on the 6–8 weeks before departure. Identifying sites where shorebirds (including sanderling) congregate prior to migration could lead to improved management of these areas year-round to help conserve shorebird populations. Additionally, shorebirds use environmental triggers to stimulate migration, and structured monitoring to understand these triggers and how they differ between species could inform wetland management actions under a changing climate.

3.3.4 Benefits of restoring terrestrialised habitats to wetlands

A dedicated project could consider the benefits of restoring terrestrialised habitats to wetlands, and methods to achieve the best waterbird outcomes. For example, as restoration continues in Tilley Swamp and Lake Hawdon, there in uncertainty regarding the impacts of mulching vegetation to create open wetlands. This biomass might prevent the formation of muddy substrates (favoured by shorebirds) for many years. Tilley swamp could provide a comparison between mulched and unmulched areas, and a study on prey availability/shorebird abundance here could help understand how the decomposition of vegetation is progressing and influencing habitat quality for shorebirds. Further, targeted waterbird monitoring at wetland sites with scheduled rehabilitation actions could help demonstrate the short- and long-term benefits of restoration.

3.4 Project prioritisation

Each research project identified through the consultation phase was evaluated (high, medium or low) on the basis of:

- the importance of the research for informing future management of the CLLMM, particularly under a changing climate;
- the ability of the research to lead to improvements in the viability of threatened waterbird species; and
- the significance of the project for community, and the project's ability to engage community actively or passively in the research.

For Criteria 1 and 2, the following scoring guide was applied: (1) 'high' rankings were reserved for projects that could lead to specific climate-ready management or conservation recommendations for threatened waterbirds or species with a heavy reliance on CLLMM wetlands; (2) 'medium' rankings were applied when the link between the research and future management or threatened species conservation under climate change was clear but less direct, potentially relied on resources that might be limiting in the future (e.g., abundant freshwater input), or did not involve species that rely heavily on the CLLMM wetlands; and (3) 'low' rankings reflected projects focused on common species and/or species primarily occurring outside CLLMM wetlands, or projects with little relevance to climate preparedness. For Criterion 3, rankings were based on stakeholder feedback received through the workshop series as well as the capacity of the project to engage community scientists actively and/or accommodate passive engagement (e.g., through weblogs or other media). Initial project rankings were drafted by The University of Adelaide team, and these were circulated to stakeholders for feedback. This feedback was then incorporated within the final project rankings (Table 3).

Table 3. waterbird research projects identified during the consultation process and their rankings (high, medium, low) against three criteria (ability of the project to inform management under climate change, to contribute to threatened species conservation, and to address community priorities and stimulate community engagement).

PROJECT	SUB-PROJECT	CLLMM MANAGEMENT UNDER CLIMATE CHANGE	THREATENED SPECIES CONSERVATION	COMMUNITY SIGNFICANCE AND ENGAGEMENT
Water telemetry Tracking waterbirds provides detailed information on local habitat use and improves our understanding of how birds move dynamically through the CLLMM system and beyond as environmental conditions change. Telemetry data can inform water management decisions under climate change for different waterbird functional groups. Community could be engaged through visual monitoring of banded birds and online interaction with GPS-based tracking locations.	<u>Fairy tern/Talamarari</u> Few diving piscivorous waterbirds have been tracked before. Fairy terns/Talamarari are listed as Endangered in South Australia, and lightweight (c. 2g) GPS units could be used for this species. Telemetry could shed light on the foraging distributions and dispersal distances of fairy terns/Talamarari, and potentially link to water management decisions.	High	High	Medium
	<u>Caspian tern/Tenatjeri</u> If fairy tern/Talamarari tracking was deemed too unsafe due to their threatened status, Caspian tern/Tenatjeri provide a suitable alternative to represent diving piscivorous waterbirds. There is no federal or South Australian conservation listing for Caspian tern/Tenatjeri, and its large size allows for a high-quality c. 20 g GPS device.	Medium	Low	Medium
	<u>Sharp-tailed sandpiper/Nemineri</u> This small-medium sized migratory shorebird spends its non-breeding season in Australia and New Zealand and is nationally listed as Vulnerable. Like many migratory shorebirds, the sharp-tailed sandpiper/Nemineri is experiencing a global population decline.	High	Medium	Medium
	<u>Common greenshank/Terilteril</u> A medium-sized migratory shorebird that is nationally listed as Endangered, the common greenshank/Terilteril is large enough to bear a c. 5 g tracker capable of collecting high-frequency location data. Understanding movement of this species locally in the CLLMM and at landscape scales could have conservation implications.	High	High	Medium
	<u>Pied oystercatcher/Prukal</u> This species is representative of resident beach-nesting shorebirds and telemetry could improve our understanding of localised movements between the Coorong and Ocean Beach. The Coorong population of pied oystercatcher/Prukal is significant relative to the global population. The species distinctive appearance (black-and-white plumage and vibrant orange bill), and ease of visually	Medium	Low	High

PROJECT	SUB-PROJECT	CLLMM MANAGEMENT UNDER CLIMATE CHANGE	THREATENED SPECIES CONSERVATION	COMMUNITY SIGNFICANCE AND ENGAGEMENT
	monitoring breeding pairs, could captivate community interest.			
	Chestnut teal/Ngra:ki This species is a dabbling duck, and one of the few duck species favouring high-salinity conditions. There is no federal or South Australian conservation listing for chestnut teal/Ngra:ki, but its population size is substantially smaller than similar species (e.g. grey teal). Telemetry for chestnut teal/Ngra:ki could improve our understanding of the impacts of wetland restoration on herbivorous waterfowl.	Medium	Medium	Medium
	Australian shelduck/Wa:nyi A herbivorous waterfowl that feeds by grazing on vegetation on the periphery of wetlands, Australian shelduck/Wa:nyi use the CLLMM region and are also resident breeders along the limestone coast. Tracking this species could showcase how restoration efforts in the South East contribute to maintaining a broader wetland network.	Medium	Low	Medium
	Black swan/Kungari An iconic and culturally important species in the CLLMM that holds substantial significance for First nations peoples and garners significant community interest. There is no federal or South Australian conservation listing for black swan/Kungari, but telemetry could be used to understand connectivity between the CLLMM population and other areas, and specifics of how swans move between the coastal lakes (and SE drainage network) and the CLLMM as conditions change.	Medium	Low	High
		Low	High	Medium
	Australasian bittern/Talkuri Endangered in South Australia and nationally, telemetry provide data on Australasian bittern/Talkuri movements to inform local habitat management	Medium	High	Medium

PROJECT	SUB-PROJECT	CLLMM MANAGEMENT UNDER CLIMATE CHANGE	THREATENED SPECIES CONSERVATION	COMMUNITY SIGNFICANCE AND ENGAGEMENT
	and protection and on gather information of broader movements (such as between the Lower Lakes and the Riverina). However, tracking a representative sample size may be difficult due to the species' cryptic nature.			
DNA-based investigation of waterbird food resources Knowledge of the key food resources and dietary preferences of waterbirds is critical to improve actions to support healthy waterbird populations. DNA-based methods offer a viable, non-destructive method for assessing waterbird food resources and diet.	<u>A DNA-based method for monitoring waterbird prey species</u> The availability of macroinvertebrate prey in the CLLMM is an important component of habitat quality for shorebirds, and this varies over the seasonal cycle and with environmental conditions. Environmental DNA (eDNA) monitoring could be tested as a cost-effective means to monitor multiple prey species simultaneously, and be validated against traditional visual monitoring methods using sediment cores. This DNA-based approach could help document the availability of key food resources for migratory shorebirds prior to their northerly migration in autumn.	Medium	Medium	Low
	<u>DNA analysis of waterbird scats to assess dietary preferences</u> DNA-based analysis of shorebird scats from target species would yield information on the key macroinvertebrate prey species consumed and dietary preferences (i.e. consumption relative to availability). Data on the aquatic plants consumed could also be produced.	Medium	Medium	Low
	<u>DNA analysis of shorebird pathogen load</u> The pathogen load of migratory shorebirds inhabiting the CLLMM is poorly understood. As global change processes modify the pathogen exposure of migratory species, characterising the viral/bacterial load of shorebirds through DNA analysis could provide valuable information of conservation and biosecurity/OneHealth relevance, and potentially lead to conservation actions (e.g., vaccination).	Medium	High	Low
Shorebird body condition monitoring through community science	The physical condition of shorebirds serves as a direct measure of prey availability and accessibility and is one indicator of the capacity of the CLLMM (and other wetlands) to support healthy shorebird populations. Waterbird body condition can be	Medium	Medium	High

PROJECT	SUB-PROJECT	CLLMM MANAGEMENT UNDER CLIMATE CHANGE	THREATENED SPECIES CONSERVATION	COMMUNITY SIGNFICANCE AND ENGAGEMENT
	assessed through still images, and there is strong community interest in contributing photos to support this project.			
Conservation modelling for key waterbird species Population viability analysis (PVA) models and habitat suitability models can be developed for key waterbird species, to inform water management and restoration in the CLLMM and broader wetland network.	<u>Fairy tern/Talamarari</u> The CLLMM fairy tern/Talamarari population is probably the best studied in south-eastern Australia. Long-term data on survival and breeding success can be used to inform PVA models and allow the impact of different conservation actions (e.g. water management, predator control, artificial nesting habitat) on fairy tern/Talamarari to be simulated.	High	High	Medium
	<u>Sharp-tailed sandpiper/Nemineri</u> This migratory species requires shallow foraging habitat. Long-term survey and community science datasets could be used to understand how management of the wetland network could increase foraging habitat availability for this species and inform wetland restoration efforts.	High	Medium	Medium
	<u>Black swan/Kungari</u> Conservation modelling could predict the impact of different climate change and water management scenarios on the CLLMM population of this species, whilst accounting for the traditional harvest of black swan/Kungari eggs which supports First Nations culture, connection to language, and kinship.	High	Low	High
Colonial nesting species within the Lower Lakes Understanding the conditions that benefit colonial breeders could provide justification for e-water delivery to the Lower Lakes.	The impact of flow decisions on the breeding success of colonial nesters in the Lower Lakes can be investigated through existing datasets and additional research (e.g. drone-based surveys, camera-trap based nest monitoring). The main colonial breeding species are pied cormorant, straw-necked and white ibis, and royal spoonbill, with the spoonbill likely to foster the most community and management interest.	High	Low	Medium
Human disturbance of shorebirds From the Murray Mouth to far south-east South Australia, humans disturb beaches and wetlands in a range of ways, including through substantial	<u>Vehicle disturbance</u> Vehicles on beaches disturb beach-nesting birds by interfering with their foraging activity and destroying their nests. Implementing monitoring measures (e.g. laser-based vehicle counters) on key access routes could help quantify the impact of vehicle disturbance on these species. Findings from this research could inform vehicle	Low	Medium	High

PROJECT	SUB-PROJECT	CLLMM MANAGEMENT UNDER CLIMATE CHANGE	THREATENED SPECIES CONSERVATION	COMMUNITY SIGNFICANCE AND ENGAGEMENT
vehicle access and game duck hunting, and research to quantify those impacts is needed. NOTE: This project has strong community interest but is not specifically related to management of CLLMM wetlands.	management decisions, and foster collaboration across First Nations and community groups who have strong interest in this issue. <u>Game duck hunting</u> The hunting frequency and effort at individual lakes in the state's South East are poorly understood, particularly due to the lack of enforced bag returns. Implementing measures to quantify hunting effort in space and time, in concert with fine-scale GPS-based telemetry for key species, might provide insights into how hunting activities disrupt the roosting, nesting and/or foraging of waterbirds.	Low	Medium	High
Monitoring migratory shorebird congregations prior to migration	Locating where shorebirds choose to congregate 6-8 weeks before their northward migration could identify sites requiring management/conservation and inform efforts to recreate these favourable conditions in other areas, while also providing information on migration cues.	Medium	Medium	Medium
Benefits of restoring terrestrialised habitats to wetlands	Increasing the availability and quality of foraging habitat for shorebirds is an important management goal. Several wetlands in the CLLMM provide opportunities for evaluating the success of different restoration activities.	Medium	Medium	Low

4. Discussion

Within this project, we: (1) reviewed the global scientific literature to identify key threats posed to waterbirds by a changing climate and to identify relevant examples; (2) consulted with a diverse range of stakeholders to record their interest in and suggestions for waterbird research in the CLLMM region; (3) developed and refined eight key research projects; and (4) evaluated these projects based on three criteria. All projects were supported to some degree, with particularly high rankings for waterbird telemetry and data-driven conservation modelling projects for key threatened, migratory or culturally important waterbird species.

First Nations groups stressed the importance of waterbirds as a link to country, culture and language, highlighted the negative impacts of upstream water extraction and diversion on waterbirds, and supported research designed to help maintain key waterbirds within the CLLMM region under climate change. Vehicle access to beaches and protected areas, and its impact on migratory and beach-nesting shorebirds, was a key focus of community members and 'Friends' groups. Scientists, eNGOs and government environmental agencies emphasised the importance of understanding waterbird movements between the CLLMM and the broader wetland network as environmental conditions change, and highlighted research to demonstrate the benefits of past and current wetland restoration efforts. Water managers focused on research to inform strategies for delivering environmental water allocations to the CLLMM, particularly under drought conditions, and to demonstrate the impact of environmental watering on waterbirds throughout the MDB.

Here we summarise important and/or common feedback received on the eight proposed research projects, consider possible project extensions, and highlight how specific research components could inform management of the CLLMM region to support viable waterbird populations under climate change.

4.1 Waterbird telemetry

There is a clear need, highlighted by our literature review and stakeholder consultation, to understand how waterbirds of different functional groups select habitats for roosting, breeding and foraging, and how management interventions and climate change might impact those habitats. Similarly, there is substantial applied interest in how birds choose to move between habitats or sites as environmental conditions change. Telemetry (tracking) studies can capture the scale of waterbird movement and help to: (1) identify environmental triggers for waterbird breeding and movement, (2) inform management seeking to replicate favourable conditions for different species/guilds under climate change; (3) demonstrate the impact of environmental water delivery on waterbirds; and (4) demonstrate the utility of past of current wetland restoration activities. Habitat selection by waterbird species within the CLLMM can usefully be studied over 1–2 years. However, to identify high-use wetlands beyond the CLLMM and the triggers for long-distance movement, telemetry studies need to be long-term, with GPS-tagging conducted for many individual birds over multiple years to capture variation in environmental conditions.

Although our consultation considered a broad range of species suitable for telemetry research, most stakeholders agreed with a focus on threatened, migratory or culturally

significant species that use the CLLMM. As an important extension, stakeholder feedback stressed that shorebirds could be trapped and GPS-tagged in wetlands of the South East, early in the migration season, to understand movements later in the season (e.g. a shorebird using Lake Hawdon will need to relocate when that lake dries). Such research could demonstrate whether regional wetlands help reduce overall dependence on the Coorong and thereby contribute to overall population viability. Further, stakeholders agreed on the importance of understanding the impacts of climate change and restoration on herbivorous waterbirds such as chestnut teal/Ngra:ki and the culturally important black swan/Kungari, both of which use natural wetlands and the South East drainage network.

Feedback from waterbird researchers studying colonial nesting waterbirds (e.g. spoonbill, ibis and egret) indicated that extending telemetry studies to cover these species in the CLLMM would usefully complement research conducted elsewhere in the MDB. Similarly, documenting the relocation of migratory shorebirds tagged near the coast to inland wetlands could be useful for identifying high-use sites and reviewing their current management.

4.2 DNA-based investigation of prey availability, shorebird dietary preferences, and pathogen load

This project could increase understanding of how conditions likely under climate change (e.g. reduced water availability, higher water temperatures) are likely to impact shorebird food resources and the timing of peak food abundance relative to key phases (e.g. the period immediately preceding migration). First Nations and community groups strongly supported this research proposal because it aims to inform management that maintains waterbird food resources in the CLLMM region, and thereby to encourage continued waterbird use of these areas. Government stakeholders noted the DNA-based monitoring component could potentially be extended to cover a range of important biotic components of the CLLMM ecosystem (e.g. aquatic plants, fish), and that dietary studies could also cover herbivores (e.g. teal duck, black swan) to investigate their preference for different aquatic plants (including different species of *Ruppia* seagrass).

Stakeholders with interests beyond the CLLMM stressed the expansion of a DNA-based investigation of prey availability to the broader wetland network. For example, differences in macroinvertebrate diversity and abundance have been observed between Lake Hawdon South and North (Jackson et al. 2022). Including nearby wetland sites in this research component could help demonstrate the impact of management and/or restoration on shorebird food resources. In particular, the planned restoration of Lake Hawdon North, which has the primary objective of increasing habitat availability/quality for shorebirds, could be used as a case study in macroinvertebrate recovery following restoration, with Lake Hawdon South being used as a control site. Other possible locations for food resource monitoring include Lake Bonney SE, Tolderol Game Reserve, and the Teringie wetlands before and after planned restoration activities.

Through consultation, we noted two difficulties with inferring waterbird dietary preferences from traditional or DNA-based monitoring data. Firstly, interpretation of prey selection is complicated by the differing availability of prey species. For example, where macroalgae have proliferated, chironomid larvae are located below the algae (and are therefore less available) while species like amphipods are present on top of the algal mats (and will be

more accessible to shorebirds). Secondly, due to limited understanding of the foraging ranges of different species, linking shorebird diets to local conditions is not necessarily straightforward. For example, the dietary components in the scats of very mobile species (e.g. sharp-tailed sandpiper) might come from a range of habitats across a large spatial extent. Nevertheless, it was agreed the latter issue can be mitigated by collecting scats deposited by birds observed foraging for a significant duration at a single site, and by calculating 'background' prey availability (which is required to consider prey preference) at a range of spatial scales.

Given the observed and projected climate-related shifts in pathogen exposure for migratory shorebirds, monitoring of infectious pathogens carried by these species would provide useful baseline data and potentially an early warning system for the detection of novel pathogens. Waterbird ecologists working throughout the MDB suggested that investigating waterbird pathogens in the CLLMM region would contribute usefully to disease surveillance activities elsewhere in the basin.

4.3 Shorebird condition monitoring through community science

First Nations, community groups and eNGOs showed substantial interest in shorebird body condition monitoring. This project could support substantial community involvement throughout the CLLMM region and, through the consultation process, the details of volunteers willing to provide historical images and/or capture additional targeted images were obtained. Many stakeholders agreed that body condition provides a useful direct measure of how well the CLLMM system is supporting shorebirds. There was substantial interest in using camera traps to produce regular waterbird images, and in the potential for First Nations and community involvement in camera-trap deployment and maintenance. However, the HCHB waterbirds project used high-quality waterbird images for condition scoring, and the suitability of camera-trap images for this purpose has not yet been tested. As a possible extension of this project, a body condition scoring system could be trialled for colonial nesting waterbirds, in collaboration with researchers working at sites throughout the MDB.

As detailed above (see section 4.2), we noted that linking body condition to prevailing, local conditions is not necessarily straightforward for highly mobile waterbirds. In contrast, the body condition of resident shorebirds (e.g. pied oystercatcher, hooded plover) fluctuates during the breeding season, and condition monitoring would provide clear information on local habitat quality for these territorial species. Nevertheless, waterbird telemetry could provide detailed information on foraging distributions for mobile species and inform interpretation of the body condition data. Further, it is likely that tracking body-condition trajectories over space and time can reliably be used to make habitat quality comparisons over large spatial scales and between years with different environmental conditions, which could inform management under climate change.

4.4 Conservation modelling for key waterbird species to inform climate preparedness and restoration actions

There was broad support for the three key species proposed as the focus of targeted conservation modelling: fairy tern/Talamarari, sharp-tailed sandpiper/Nemineri and black swan/Kungari. Stakeholders noted that these species are all present in key management

areas (the Coorong, Lower Lakes, Murray Mouth and South East), their food resources are impacted by how we manage water, and they are representative of different functional groups for which management should seek to build resilience against climate change. Ideally, feedback suggested species-specific conservation modelling involving water management scenarios should consider how much water is likely to be available under various climate change scenarios (i.e. the feasibility of different water management scenarios is important). The latter would involve considering upstream storage systems under climate scenarios, which could be informed by the CLLMM Research Centre flagship project focusing on climate adaptation.

Detailed spatial PVA modelling for the Coorong fairy tern/Talamarari population was generally deemed a logical priority, and stakeholders highlighted the importance of linking water management to the suitability of breeding islands and the availability of small-bodied fish prey. A review of possible complementary measures (e.g. predator control techniques, creation of artificial nesting habitat, decoy tern "colonies", guardian animals) was also considered valuable, noting there will be examples from the global literature on the implementation of such innovative strategies.

Targeted habitat suitability modelling for sharp-tailed sandpiper/Nemineri (as a representative shorebird) was supported, provided models were developed at a landscape-scale and covered the coastal lakes of the South East, restored wetlands (e.g. Tolderol Game Reserve, Pick Swamp), and wetlands that will be rehabilitated in the future (e.g. Lake Hawdon North, the Teringie wetlands). Further, the sharp-tailed sandpiper/Nemineri is a focal "touchstone species" for the MDBA so there is federal interest in this species. We also noted that, although Water Observations from Space (WOfS) data can show surface water extent, fine-resolution Digital Elevation Models (DEMs) are not available for all water bodies, which limits calculation of the extent of shallow foraging habitat in some areas.

For Ngarrindjeri, the black swan/Kungari is a totemic species, and the traditional harvesting of swan eggs is an important practice that links people to country and culture. Maintaining suitable habitat for black swan/Kungari in the CLLMM as climate changes is a high priority for Ngarrindjeri, who strongly supported targeted population modelling for this species. The potential to use models to compare traditional harvesting rules to theoretically optimal strategies was also discussed and supported. Population modelling for black swan/Kungari would be usefully informed by parallel telemetry studies for this species.

4.5 Additional projects arising through consultation

Government stakeholders involved in environmental water management were interested in understanding how flow decisions impact the abundance and breeding success of colonial nesting waterbirds in the Lower Lakes. Understanding the flow-related triggers for colonial breeding here could be used to inform water management under a changing climate, and feed into the development of a "Drought Operating Plan" for the CLLMM system.

Vehicle access to beaches and protected areas, and its impact on migratory and beach-nesting shorebirds, was regularly raised during workshop sessions. Field research could estimate vehicle traffic and impacts (e.g. through camera traps installed at key locations, such as the Murray Mouth), which would help assess the potential benefits of car exclusion

zones, particularly for beach-nesting species. Understanding disturbance more generally, through simultaneous monitoring of human activities (vehicles, camping, game duck hunting) and waterbird abundance and behaviour would help understand the implications of disturbance on waterbirds, and possibly identify management options for reducing disturbance processes. This research was deemed particularly important by community members with intimate first-hand knowledge of the CLLMM, Ocean Beach, and other wetland habitats and beaches.

Friends of Shorebirds South East and Friends of the Coorong suggested dedicated spatiotemporal monitoring of shorebirds in the CLLMM region in February/March might identify pre-migration congregations and provide useful environmental data on the triggers for migration. Such a project could be supported by substantial community involvement, through traditional visual surveys and/or camera-trap deployment.

A key focus for eNGOs and Landscape Boards was monitoring to ascertain whether waterbirds are using restored wetlands, and to contrast the impact of different restoration decisions. For example, future monitoring could investigate whether migratory shorebirds (which on-the-ground works at Lake Hawdon North, Tolderol Game Reserve, and Teringie wetlands are designed to benefit) use these habitats once restoration is complete. Further, research might consider lags between restoration actions and full recovery (e.g. by comparing macroinvertebrate diversity at restored and natural wetlands over time), and the impact of vegetation management (e.g. mulching) on the abundance/behaviour of shorebirds and their prey. Such research was deemed important by stakeholders involved in restoration activities or planning, in part because future funding for wetland restoration might depend upon the success of current initiatives.

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6. Appendix

Stakeholder consultations

Workshop 1: Environmental non-governmental organisations (29 November 2023)

Attendees: Sonia Sanchez, Kerri Bartely, Ben Taylor, Bryan Haywood, Keith Jones, Rebecca Boulton, Thomas Prowse, Steve Delean, Justin Brookes, Phill Cassey, Ruth Cope.

Other invitees: Chris Purnell (BirdLife), Laura Rhodes (BirdLife), Colin Rogers (Tolderol Working Group), Peter Koch (Tolderol Working Group).

Table A1. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 29 November 2023.

ORGANISATION	KEY POINTS
BirdLife Australia (*Sonia Sanchez, Kerri Bartley, Rebecca Boulton*)	• The CLLMM fairy tern/Talamarari population is unique due to the availability of long-term monitoring datasets (a capture-mark recapture program, a 20-year dataset of breeding success, and an annual census) which are not available for populations in the east. • Expansion of waterbird telemetry to track additional species (e.g. fairy tern/Talamarari) would produce valuable data for conservation planning, and address questions of foraging distributions around nesting sites, and dispersal. • Population viability analyses are important to assess the likely impact of climate change on fairy terns/Talamarari and to integrate the impact on their primary prey species (e.g. safeguarding fairy nesting habitat might not make sense if suitable prey will not be available in the future). • Fairy tern/Talamarari research offers collaborative research opportunities with Birdlife Australia, given ongoing monitoring of populations around the Murray Mouth and Bird Island (Outer Harbor). • The proposed projects on shorebird diet and body condition might face difficulties due to our limited understanding of the foraging ranges of different species (which in turn affects our ability to characterize background prey availability and the quality of 'available' habitat). This is less of a problem for more territorial shorebirds (e.g. pied oystercatcher, hooded plover); however, fine-scale spatial comparisons of body condition for more mobile species (e.g. sharp-tailed sandpiper) might not make sense. The proposed telemetry project could provide useful data on foraging ranges for a subset of shorebird species. • Field research could estimate vehicle traffic and impacts (e.g. through camera traps installed at key locations, such as the Murray Mouth), which would help assess the potential benefits of car exclusion zones, particularly for beach-nesting species.
Nature Glenelg Trust (*Ben Taylor, Bryan Haywood*)	• Telemetry can help to contextualise the relationship between the CLLMM and surrounding (including restored) wetlands by documenting waterbird movements between them. Trapping and GPS-tagging should not be focused solely on the Coorong, but should also take place at other wetlands, to improve our understanding of population connectivity across the broader landscape. Shorebirds should be trapped and GPS-tagged in

	wetlands in the South East, early in the season, to understand movements later in the season when these wetlands dry up. A shorebird present in the Coorong early in the season might well stay there all summer, but a shorebird using Lake Hawdon will need to relocate when the lake dries. It is important to understand if these regional wetlands help reduce overall dependence on the Coorong and thereby contribute to overall population maintenance. • If including a large-bodied migratory shorebird as a target species for telemetry, the common greenshank/Terilteril has been seen in high numbers at Lake Hawdon recently. • There is potential to expand the DNA-based investigation of prey availability to the broader wetland network. For example, differences in macroinvertebrate diversity and abundance between wetlands (e.g. between Lake Hawdon South and North) have been observed previously. Including nearby wetland sites in this research could help demonstrate the impact of management and/or restoration on shorebird food resources. • The proposed restoration of Lake Hawdon North, which has the primary objective of increasing habitat availability/quality for shorebirds, presents an opportunity for research into a range of shorebird-related questions. Lake Hawdon South could act as a pseudo-control in a landscape-scale BACI design.
SA Shorebirds Foundation *(Keith Jones)*	• Pied oystercatchers/Prukal are a useful representative species of resident beach-nesting birds in the CLLMM region. • The population size of pied oystercatchers/Prukal in the Coorong is significant relative to their global population and regular monitoring is needed. The population size of this species has decreased in the CLLMM, and one possible cause is human disturbances of nesting areas (e.g. off-road vehicles). • Expanding the waterbird telemetry project to include pied oystercatchers/Prukal would help understand localized movements between the Coorong Lagoon and Ocean Beach. Trapping this species on the Ocean Beach may be challenging, although chartering commercial pipi fishing vehicles could assist in this. It is possible that pied oystercatcher/Prukal ranges are smaller where pipi density is higher. There are large datasets available that document the harvest of pipis in the region (e.g. SARDI pipi density surveys, recreational fishing surveys, fishery-independent surveys). • Monitoring of shorebird body condition need not be restricted to migratory species. The body condition of resident shorebirds (e.g. pied oystercatchers and hooded plovers) will fluctuate during the breeding season, and body condition monitoring would provide information on local habitat quality because these species are territorial.

Workshop 2: BioR (10 December 2023)

Attendees: David Paton, Fiona Paton, Thomas Prowse, Steve Delean.

Table A2. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 10 December 2023.

ORGANISATION	KEY POINTS
BioR	• The Coorong South Lagoon is currently in extremely poor condition, with indications of very low *Ruppia* density/recruitment in late 2023. This indicates that current water management/delivery is not appropriate to maintain

(*David Paton, Fiona Paton*)

extensive dense *Ruppia* beds, or to promote the recovery of this key species, which is a prerequisite for improving conditions for waterbirds.

- The current salinity in the Coorong South Lagoon is too low to suppress filamentous algal growth. Damaging algal blooms should be expected to continue and to limit any re-establishment of *Ruppia tuberosa* in the short term until much higher salinities are re-established and maintained.
- The failure to maintain appropriate water levels through spring is also a driving factor in dampening the resilience of *Ruppia tuberosa* in the long-term.
- The presence of polychaetes throughout the southern Coorong is a new phenomenon which is also related to the low salinities that have established.
- An important, often overlooked part of the debate over a desired state for the macroinvertebrate assemblage of the Coorong South Lagoon is that the adult phase of the chironomid life history provides an important food resource for terrestrial species including bush birds and spiders (in contrast to entirely aquatic species like polychaetes and amphipods). The salt-tolerant chironomid (*Tanytarsus barbitarsis*) is severely disadvantaged during periods of low salinity in part because filamentous algal blooms prevent adults from emerging.
- Dietary studies for shorebirds are useful, but interpreting prey selection is difficult due to the differing accessibility of prey species (irrespective of abundance). For example, where macroalgae have proliferated, chironomid larvae will be present below the algae where they are difficult for birds to harvest (and therefore are less available to birds than the actual abundances suggest) while species like amphipods can be present in the upper layers of algal mats and so remain accessible to shorebirds.
- Using eDNA to assess waterbird diets provides information about the species consumed, but as detailed above, using eDNA for infer dietary preferences is more difficult due to variation in food item availability over time and space.
- The wetlands of the CLLMM are permanent and offer a diversity of wetland systems to waterbirds. The diversity of wetlands is determined largely by the range of salinities and the maintenance of the full range of salinities is important.
- The importance of the Coorong varies for different groups of waterbirds, with the migratory and non-migratory shorebirds primarily using the Coorong as a summer-autumn refuge, as do selected herbivorous waterfowl. Many of these shorebirds and waterfowl moult during December and January. Use of the CLLMM wetlands by various piscivorous species (terns, pelicans, cormorants) may also include breeding during spring and summer. Use of the Coorong in February to April coincides with the period when migratory shorebirds may need to fatten prior to migrating back to the northern hemisphere.
- Managing waterbird outcomes in the CLLMM (and southern Coorong in particular) requires knowledge of the food resources and the quantities needed to support the abundances and activities of the birds. There can be periods when the resources are inadequate to support the birds (resources either limited in abundance and/or accessibility). Knowledge of the scales over which the different bird species move within and beyond the Coorong is important to determine the likely consequences of food shortages for the birds. The timing and extent of waterbird movements is also likely to vary from one year to the next depending on conditions along the Coorong and conditions of wetlands beyond the Coorong. Identifying periods of food shortages may be possible by assessing consumption rates (pecks/min) and speeds of foraging (metres travelled by minute of foraging and by the extent

to which birds have to forage (% time allocated to foraging). Fine-scale historical waterbird monitoring data for individual Coorong bays ('Baywatches') could be interrogated to understand how the proportion of waterbirds foraging varies over different timescales and (potentially) with changes in food abundance. These could be repeated to determine if there have been significant changes in recent years.

- Assessing shorebird body condition from still images is complicated by the ability of birds to 'fluff up' their feathers for insulation during cold conditions, and it is also possible that pre-migration fattening occurs elsewhere (e.g. northern Australia) rather than in the CLLMM.
- An alternative assessment could include measuring the extent that food resources are being suppressed, by excluding birds from foraging in small plots and comparing changes in food resources through time with similar nearby plots where birds have not been excluded. Some data on the extent of waterfowl grazing of *Ruppia* shoots has been collected annually in recent years and that data could be interrogated.
- In a similar vein, research to understand the changes in macroinvertebrate prey over the course of spring, summer and autumn is critical, and hence a long-term project on shorebird resources in the Coorong over multiple years (and different environmental conditions) is high priority. Further, Tolderol Game Reserve offers a potential experimental system for exploring fine-scale management options for ensuring food resources for modest numbers of migratory species are available throughout the entire non-breeding season.
- Given the likely variability in conditions from one year to the next, telemetry studies of waterbirds need to be long-term, involve tagging 40 or more individuals of a species and be conducted over multiple years to properly document movements.
- The movements of one species are unlikely to provide a basis for the movements of other similar species, and so extrapolating the movements of a species based on the movements of another similar species should not occur. For example, Sharp-tailed sandpipers/Nemineri favour fresher wetlands than other migratory shorebirds, while red-necked stints are more salinity-tolerant, so the movements of those two species are likely to differ. Red-necked Stints could be a focal species for tracking studies but more challenging to track over the long term because of their smaller size.
- As an alternative to GPS tracking, feather dyes (and leg flags) could be used to mark the breasts of captured birds, and the community engaged to report sightings of marked birds across the CLLMM and the broader landscape.
- A focus on catching and tagging shorebirds at Tolderol may aid in establishing connectivity between this area and the Coorong.
- Pied oystercatchers likely move between the Coorong wetlands and the ocean beach and birds if caught could carry a leg flag and/or transmitter, to determine the frequency and extent of these local movements, and hence establish the extent to which this species depends on the Coorong wetlands.
- Of the predominantly herbivorous waterfowl, chestnut teal/Ngra:ki show a predilection for the brackish and more saline wetlands of the CLLMM. This species is likely to be disadvantaged by deteriorating conditions in the Coorong (e.g. imminent loss of *Ruppia* beds in the southern Coorong). Hence this species should be a priority for telemetry studies.
- While most piscivorous waterbird species are faring reasonably well in the CLLMM, the fairy tern/Talamarari is an obvious exception. Long-term datasets for the Coorong fairy tern/Talamarari population are available and

currently being used to estimate demographic rates as a function of environmental conditions, and hence population viability. A high proportion of pullus that are banded at breeding colonies are not sighted again as adults, which could be due to high juvenile mortality and/or permanent emigration to other areas. Birds that were banded as pullus outside the Coorong have been detected breeding in the Coorong, and adult birds caught and tagged while breeding in the Coorong have been detected outside the Coorong. A key knowledge gap is assessing whether all or part of the fairy tern/Talamarari population disperses away from the Coorong during the non-breeding season, and whether the proportion that vacate the Coorong varies from one year to next. Understanding why the birds vacate the Coorong in the first place (assuming that most do for part of the year) will help with managing this species. Hence, fairy tern/Talamarari dispersal patterns are a key knowledge gap. As well as GPS-based studies, banding of fairy terns/Talamarari in the CLLMM and elsewhere (e.g. Bird Island, Outer Harbour) would provide additional information about dispersal and the level of connectivity between populations.

- Caspian terns/Tenatjeri are another piscivorous species that could be examined with telemetry.
- Fairy terns/Talamarari that breed earlier in the season might have greater reproductive success, because nest predators (e.g. ravens) are more likely to find and predate nesting sites over time. Summer storms (with associated heavy rain) seem to have a large negative impact on breeding success. These issues could be explored by strategically deploying camera traps at the major fairy tern/Talamarari breeding sites each year.
- Restoration of wetlands adjacent to the Lower Lakes (e.g. Waltowa) could provide conservation benefit and also support traditional harvesting of black swan/Kungari eggs.
- Landscape-scale PVA modelling for sharp-tailed sandpiper/Nemineri could test strategic management scenarios that wet and dry different wetlands (e.g. Tolderol, Waltowa, Teringie, Lake Hawdon).

Workshop 3: South Australian governmental organisations (13 December 2023)

Attendees: Adrienne Rumbelow, Jody O'Connor, Gareth Oerman, Mark de Jong, Claire Harding, Sam Hardy, Thomas Prowse, Steve Delean, Justin Brookes, Ruth Cope.

Other invitees: Daniel Rogers (DEW), Kate Mason (Murraylands and Riverland Landscape Board), Simon Oster (Head Ranger of Coorong NP).

Table A3. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 13 December 2023.

ORGANISATION	KEY POINTS
DEW- The Living Murray (*Adrienne Rumbelow*)	• The inclusion of fairy tern/Talamarari and sharp-tailed sandpiper/Nemineri in the waterbird telemetry project would increase our understanding of where these species preferentially locate and feed during high/low flow years, and when/why they choose to forage beyond the CLLMM (e.g. Morella Basin). This information could potentially link to e-water decisions and the Flow-MER program. • The analysis of shorebird scats could be expanded to investigate consumption of aquatic plants, and the diet of herbivorous waterfowl could also be quantified. It would help to develop a clearer picture of the dietary

	composition of shorebirds and waterfowl, and whether these species have preferences for feeding on specific species of *Ruppia* seagrass. • Fairy terns/Talamarari and black swans/Kungari are good target species to include in population modelling to build resilience against climate change. The species are present in key management areas (Murray Mouth, Coorong Lakes and SE) and their food resources are impacted by how we manage water. • A new project could be developed focusing on colonial nesting within the Lower Lakes. The impact of flow decisions on the breeding success of colonial nesters in the Lower Lakes is poorly understood. The main colonial breeding species are cormorant, white ibis, and spoonbill (and spoonbill might stimulate most community and management interest) • Colonial nesting in the Lower Lakes could be studied in a variety of ways (e.g. GPS-based telemetry, analysis of long-term monitoring data, drone-based surveys coupled with machine learning approaches for automated enumeration). This research could be used to understand what conditions benefit colonial breeders, and potentially to justify e-water delivery to the Lower Lakes.
DEW- Coorong Restoration (*Jody O'Connor, Gareth Oerman*)	• Waterbird telemetry is an important link in the story of how birds dynamically move through the system. Telemetry data has the potential to capture the scale of waterbird movement and the environmental conditions/habitat characteristics driving habitat selection and dispersal. This information can be used to inform water management decisions that seek to replicate favourable conditions for different species and guilds. The proposed target species represent the different guilds/habitats well, and the project can provide useful data over a range of scales (local, regional and national). • For the DNA-based investigation of shorebird diet, the planned spatial sampling of scat collection is essential (and should ideally include the Murray Mouth region) to understand how the diet of these species changes across the CLLMM. Including plants in the investigation would also be useful, and potentially illuminate the shorebirds' role as vectors for aquatic plant dispersal (noting a new species of *Ruppia* may have been recently introduced to the Coorong). The DNA-based project should clarify the specific methods to be used (e.g. quantitative PCR for target prey species versus metabarcoding for relative abundance data covering a broad range of prey species). • Shorebird body condition provides a direct measure of how well the CLLMM system is supporting these species and therefore this project has strong implications for shorebird management. The project also has the potential to support substantial community involvement throughout the CLLMM. If a camera-trap monitoring component was included in this project, community could also be involved in camera-trap maintenance across the region. • The inclusion of black swan/Kungari in the population viability analyses project has strong cultural knowledge implications. It is important to maintain ongoing relationships with First Nations people to understand how traditional harvesting practices influence swan recruitment year to year. Given the CLLMM forms just one component of black swan/Kungari habitat in the region, it would be important to think carefully about the region/subpopulation used for PVA modelling.
Limestone Coast Landscape Board	• Trapping and GPS-tagging outside of the Coorong is encouraged and permission for trapping on public and private land is likely to be acquired easily. By tracking species like sharp-tailed sandpiper/Nemineri, we can

(*Mark de Jong*)	identify key refugia and provide evidence of habitat usage that is not focused solely on the Coorong (e.g. Pick Swamp, Bool Lagoon). • The waterbird telemetry project could also be expanded to include Australasian bittern/Talkuri. Tracking this endangered species would not only provide information of their local movements, identifying areas for management and protection, but also document movement at larger scales as they move between the Lower Lakes and the Riverina. Bittern telemetry could potentially link to the Karst Spring Restoration Project. • It is important to understand the impacts of climate change and restoration on herbivores, making chestnut teal/Ngra:ki a suitable species for telemetry and population viability analyses. Additionally, Australian shelducks/Wa:nyi are resident breeders along the limestone coast and could be included as an additional species (or replace chestnut teal). • A dedicated project on the restoration of terrestrialised habitats to wetlands might be possible. For example, as restoration continues in Tilley Swamp and Lake Hawdon, there are questions regarding the methodology of mulching vegetation to create open wetlands. This biomass will likely prevent the formation of muddy substrates (favoured by shorebirds) for many years. Tilley swamp could provide a comparison between mulched and unmulched areas, and a study on prey availability/shorebird abundance here could help understand how the decomposition of vegetation is progressing and influencing habitat quality for shorebirds.
National Parks and Wildlife Service SA (*Claire Harding*)	• As an alternative to trapping and GPS-tagging Australasian bitterns/Talkuri (due to their rareness and inconspicuous nature), magpie geese/Pangkuli could be targeted as they optimize similar habitat. The tracking of magpie geese/Pangkuli would illuminate their movements across the landscape (e.g. Pink Salt Lake). • In regard to catching and GPS-tagging shorebirds, the research question governs the time of year used for trapping (i.e. depending on whether local or migratory movements are the focus). Also, shorebird weights might be lowest early in the non-breeding season, which can impact tracker deployment, particularly for smaller species.
Murraylands and Riverland Landscape Board (*Sam Hardy*)	• A new pumping system is being installed in Tolderol Game Reserve so that the water level can be manipulated independently in each bay. This work will limit the number of available waterbird catching sites and, until it is completed (~ 18-24 months), there should be no trapping and GPS-tagging of waterbirds conducted at Tolderol. • The black swan/Kungari is a suitable species for population viability analyses, and the conservation of this species is a common point of discussion within the Tolderol Working Group. • The new water pumping system at the Tolderol Game Reserve will present an opportunity to experimentally manipulate water levels in the ponds and investigate outcomes for vegetation growth, macroinvertebrate abundance and use by shorebirds. For example, it might be possible to fine-tune a method that optimizes water-level management across multiple ponds and ensures productive mudflats are available for shorebirds across the whole non-breeding season.

Workshop 4: Friends of Shorebirds South East (16 January 2024)

Attendees: Maureen Christie, Jeff Campbell, Ross Anderson, Thomas Prowse, Ruth Cope.

Table A4. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 16 January 2024.

ORGANISATION	KEY POINTS
Friends of Shorebirds SE (FoSSE) (Maureen Christie, Jeff Campbell)	• There is concern for the continuation of Birdlife Australia's annual summer and winter waterbird counts in the Coorong, as funding may not continue. These long-term counts are vital to monitor shorebird abundance variation in response to habitat changes in the Coorong. • A new project could be developed focusing on a series of bird counts aimed at identifying sites where migratory shorebirds congregate prior to their migration north, with a particular focus on the 6-8 weeks before departure. Knowledge of where shorebirds (including sanderling) congregate prior to migration would allow for better management of these areas year-round to help conserve shorebird populations. • There are major concerns in the South East regarding the continued invasion of sea wheat-grass (*Thinopyrum junceiforme*) which is causing loss of suitable shorebird habitat for feeding migrants and nesting residents. Sea wheat-grass is an introduced terrestrial grass species that is outcompeting native grasses (e.g. spinifex) and changing the profile of the ocean beach. The grass grows between the foredune and the high-tide mark. The dense root system of sea wheat-grass allows for the accumulation of sand/debris, resulting in steep dunes and fewer blow-outs (the latter are particularly used by hooded plover). This type of dune formation is sub-optimal shorebird habitat. An experimental study in the South East has explored the impact of sea wheat-grass control. Attempts to monitor sea wheat-grass extent from satellite imagery have been largely unsuccessful, since identifying this species amongst the vegetation assemblage is challenging. • The Coastal Protection Board might have information/data on changes in beach topography over time. • FoSSE and DEW worked together to develop a 'Coastal Weed Control Plan'; a research project could potentially be built on this. • FoSSE is particularly interested in quantifying the impacts of human disturbance on shorebird numbers and distribution. For example, do hunting shots disturb the shorebirds to the point that they vacate the area? Additionally, legal and illegal camping along the coast has seen incidents of destroyed shorebird eggs and nests. Understanding the relationship between beach camping and shorebirds could be a component of the overall assessment of human disturbance and its impact on shorebirds in the CLLMM and broader region. • There are several members of FoSSE that have expressed a strong interest in contributing photos of migratory and resident shorebirds, which is an integral component of the proposed shorebird condition monitoring project. Some members already have shorebird photos taken over multiple years that could potentially be used to improve the machine-learning algorithm. • Previous research by FoSSE and the Victorian Wader Study Group in the South East shows that the body condition of shorebirds does improve prior to migration. Repeat trapping of ruddy turnstone (c. 6 weeks apart) near the end of the season showed that the birds gained weight while feeding in the South East. FoSSE have a current sanderling GPS tracking project.
DEW, District Ranger – Lower Limestone Coast (Ross Anderson)	• A dedicated project on the impacts of human disturbance of beach-nesting and migratory shorebirds would be beneficial. There are two primary aspects of disturbance: vehicles and hunting. (Uncontrolled camping is probably an issue, but can be considered a subset of vehicles on beaches.) • Vehicle disturbance is particularly strong over the summer holiday period and could be measured using laser-based vehicle counters (~$3000) installed at entry points. For example, Little Dip CP uses vehicle counters to

count vehicles as they enter, and the number of vehicle accessing the park has doubled in the last 4 years (figures supplied in meeting). Also, Discovery Bay could be a potential location to compare the impacts of disturbance, as the Victorian side has no vehicle access on beaches while the SA side permits vehicles. There is a proposed PhD project that might use this site, but currently no funding.

- The hunting frequency and effort for individual lakes in the South East is poorly understood. Currently, only 10-20% of hunters submit bag returns. Lake George (where hunting areas are spread out, and red-necked stint are common) and Lake Bonney SE (which has particular hunting areas, and higher numbers of sharp-tailed sandpiper) are two lakes where frequent hunting does occur during the season. GPS-based telemetry could be used in tandem with hunting-activity monitoring to understand how hunting impacts the roosting and foraging of waterbirds. Potentially other technology like camera traps could be used to monitor shorebirds and hunters, or audiomoths could be set up to capture gunshot and vehicle frequency.
- Despite black swans/Kungari breeding in their thousands at various sites in the South East (e.g. Lake Hawdon South), their movements after breeding are poorly understood. The inclusion of black swan/Kungari in the waterbird telemetry project would increase our understanding of how swans move between the coastal lakes and the CLLMM during the summer.
- Additionally, the inter-annual variation in the abundance of magpie geese/Pangkuli in the South East is high; for example, there can be several thousand magpie geese/Pangkuli at Bool lagoon, and 1,500 at Pink Ponds, but when they depart these areas it is unknown where they go. Conducting telemetry for this species would provide information on the local movements of this species, identifying areas for management and protection.
- In regard to the proposed waterbird diet analysis project, there is long-term data on invertebrate and shorebird numbers in Lake Bonney SE. Lake Bonney SE is similar to the Coorong South Lagoon as the wind can impact water levels dramatically, exposing and covering mudflat over short time scales. The lake was once badly polluted with organochlorine pesticides, but as that pollution eases, shorebirds are now returning in internationally significant numbers (e.g. sharp-tailed sandpiper, common greenshank, red-necked stint, and double-banded plover).
- Lake Bonney could be considered as a site for macroinvertebrate monitoring. Also, there is an outlet in the lake that could be manipulated to suit shorebirds by mitigating vegetation encroachment and maintaining mudflats. Currently, opening the outlet is triggered when lake water levels reach 2 m above sea level, but often this trigger is not reached. It might be useful to allow water levels to rise higher than 2 m, to prevent vegetation encroachment at the lake edges.
- Population viability analysis (PVA) modelling may be difficult to execute if the populations modelled are not discrete. The use of PVA-type approaches for some species (e.g. sharp-tailed sandpiper and black swan) might be most useful as a conservation modelling tool to test particular water management and harvesting scenarios through simulation. In contrast, PVA for fairy terns/Talamarari can be justified as the Coorong population is probably reasonably discrete (although noting that fairy terns/Talamarari banded in the Coorong are seen in the far South East reasonably regularly).

Workshop 5: Ngarrindjeri Goolwa (23 January 2024)

Attendees: Trevor Sumner, Christina Kartinyeri, Laurie Agius, Anton Kartinyeri-Sumner, Ian Sumner, Allan Weetra, Alac Thornton, Les Weetra, Kenneth Sumner, Cedric Varcoe, Nathan Hartman, Thomas Prowse.

Table A5. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 23 January 2024.

ORGANISATION	KEY POINTS
Ngarrindjeri–Goolwa workshop (Trevor Sumner, Christina Kartinyeri, Laurie Agius, Anton Kartinyeri-Sumner, Ian Sumner, Allan Weetra, Alac Thornton, Les Weetra, Kenneth Sumner, Cedric Varcoe)	*General comments* • Farming and water extraction has altered the natural flow regime of the Murray Darlin Basin, and impacted people, culture and wildlife in the CLLMM. • Traditional harvesting provides a strong link to country, cultural identity and language. • Language provides connection to country and identity. Using Ngarrindjeri names for waterbirds would be supported (although English names should probably be used as well). There is a list of waterbird names available. • As some background on different First Nations groups: the Miwi-inyeri Pelepi-ambi Aboriginal Corporation (MIPAAC) deals primarily with language and culture, while the NAC (Ngarrindjeri Aboriginal Corporation) handles issues related to Native Title and cultural heritage. • A wildlife rescue facility in the vicinity of Goolwa would be useful. *Control of feral and overabundant animals* • Feral predators (foxes, cats) are a serious problem for waterbirds in the CLLMM and along the length of Young Husband Peninsula. • Other invasive herbivores (rabbits, deer) are also a problem in the region. Ngarrindjeri once harvested a significant number of wild rabbits, but that practice has essentially ceased. • Although traditional harvesting of silver gull eggs once occurred, and perhaps this might help control gull populations and reduce predation by gulls on fairy tern/Talamarari nests, there is little practical interest in re-instating this harvest. *Vehicle access at the Murray Mouth and Ocean Beach* • Disturbance of waterbirds by vehicles is a problem, particularly from Goolwa Beach southwards (including at the Murray Mouth). Vehicles disturb and destroy the nests of beach-nesting birds and interfere with foraging by shorebirds. Closing Ocean Beach to vehicles would likely have conservation benefits. • Erosion due to legal and illegal vehicle access is exposing Ngarrindjeri burial grounds, which then need to be reburied. • It might be difficult to close Ocean Beach to all vehicles. As an alternative, other measures could be taken, including: (1) limiting vehicles to certain routes; (2) dedicated enforcement officers with the authority to issue on-the-spot fines for vehicles accessing prohibited areas (two officers were in place during busy periods between 2002 and 2010); and (3) increased signage to discourage vehicle access and to highlight the impact of vehicles on beach-nesting shorebirds. • Vehicles impact species other than waterbirds; for example, seal pups have been observed lying in tyre tracks on Ocean Beach, so they are clearly at risk of collision. • Monitoring vehicle access to beaches and dunes (e.g. through strategically positioned laser counters) has merit, but this idea should be checked first with the Ngarrindjeri Aboriginal Corporation.

Prey availability and diet

- Water is not flowing down the River Murray like it should, and this is impacting water availability in the CLLMM and negatively impacting food resources for waterbirds.
- There is great concern for how waterbird food resources (seagrass, macroinvertebrates, fish) can be maintained in the CLLMM under a changing climate. Maintaining these food resources requires enough water coming down the system, and it is not clear sufficient water can be delivered during drought.
- Traditional Ngarrindjeri teachings indicate that the Coorong South Lagoon was once much fresher than it is today, with much greater volumes of freshwater flowing into it, including from the south-east region (before establishment of the south-east drainage network).

Conservation modelling

- The NAC should be consulted regarding the proposed fairy tern/Talamarari modelling project.
- Traditional harvesting of black swan/Kungari eggs is an important practice that links Ngarrindjeri to country. Today, the harvest usually occurs once per year during the swan breeding season and is done from a boat in the Lower Lakes in the vicinity of Raukkan. There are rules on how many eggs can be taken; for example, if a nest contains 4 eggs, only 1 or 2 eggs would be taken. Nests can be marked so that they are not harvested more than once, and a buoyancy test is also done (i.e. eggs that float are too well developed to harvest). Traditionally, the areas harvested by elders and young people were kept separate. It is important to maintain conditions in the Lower Lakes so the harvest can continue, and support culture, connection to language and kinship.

Possible collaboration

- The abundance and diversity of birds around the Murray Mouth has changed since the early 2000's and might be impacted by dredging at the Murray Mouth. Ngarrindjeri already assist Birdlife Australia with waterbird surveys in that region but would also be interested in participating in camera-trap-based monitoring if suitable sites for deploying cameras could be identified.

Workshop 6: Murray Darling Basin Authority and Department of Climate Change, Energy, the Environment and Water (23 January 2024)

Attendees: Brittany Betteridge, Pam Beattie, Cristina Vicente, Adam Cotterill, Kyle McGrath, Thomas Prowse, Justin Brookes.

TABLE A6. SUMMARY OF THE KEY TAKE-AWAY MESSAGES FROM THE CLLMM WATERBIRD WORKSHOP CONDUCTED ON 23 JANUARY 2024.

ORGANISATION	KEY POINTS
Murray Darling Basin Authority (*Brittany Betteridge, Pam*	*Waterbird telemetry* • Waterbird telemetry is a top priority. Although additional tracking of any species would be welcome, the species proposed are complementary and would value-add to other tracking work being done throughout the MDB. The relationship between surface water conditions and movement patterns is of particular interest.

Beattie, Cristina Vicente)

Department of Climate Change, Energy, the Environment and Water

(*Adam Cotterill, Kyle McGrath*)

- Related telemetry work is also happening through the Victorian Wetland Monitoring Assessment Program (WetMAP) and the Commonwealth Environmental Water Holder's FLOW-MER Monitoring Evaluation and Research Program. The WetMAP program is targeting freckled duck, shoveler, pied stilt, red-necked avocet, whiskered tern and brolga, and identifying where these species choose to breed is a priority. The FLOW-MER program focuses on the large-waders (white ibis, straw-necked ibis, royal spoonbill and intermediate egret), with CSIRO's Heather McGinness leading this work.
- It is good to see telemetry proposed for smaller species and ducks.
- Movement information is particularly important under climate change.
- Telemetry for fairy terns/Talamarari would be valuable as few diving piscivores have been tracked. Fairy terms/Talamarari are vulnerable during both high flows (when nest abandonment occurs) and low flows (when predators can access nesting islands). It would be interesting if tracking could inform innovative complementary measures to protect populations (e.g. by relating GPS locations to small-bodied fish stocks). Understanding if the 80% loss of marked pullus (as per Dave Paton's banding studies) reflects mortality only or dispersal also. However, we should assess how disruptive trapping and GPS tracking would be to the fairy tern/Talamarari population of the Coorong.
- Caspian terns/Tenatjeri would also be a useful piscivore to track, and this species might be used to test the viability of tracking fairy terns/Talamarari.

DNA-based investigation of prey availability, shorebird dietary preferences and pathogen load

- DNA methods can be useful for detecting prey presence. There is some uncertainty about whether DNA-based methods will accurately quantify prey abundance, but this could be tested by using other measures (e.g. cores) for validation.
- The project would be more useful if it was expanded to consider the feasibility of DNA-based monitoring of the CLLMM system (and cover more than just macroinvertebrates). For example, *Ruppia* species might also be monitored this way (but noting it may be difficult to separate the different *Ruppia* species), and changes to *Ruppia* distribution under climate change is of particular interest. In summary, it would be useful to consider *Ruppia*, macroinvertebrate, and fish assemblages, and how these vary with the salinity gradient and environmental variation.

Shorebird condition monitoring through community science

- This project has a strong community focus, and there are plenty of avenues to increase the number of shorebird images available. Geotagged image uploads should work well. It might be possible to use drones to generate more images suitable for body condition scoring but ethics considerations regarding flying drones very close to shorebird flocks might limit this approach.
- The project would be stronger if there was a clearer link to informing management. On that note, it is important to understand how shorebird food resources change through time (i.e. seasonally and as a function of wet and dry environmental conditions).
- The project could be expanded beyond the CLLMM to cover a larger portion of the MDB (i.e. broadened to a landscape scale). It would be useful to understand if variation in the condition of different shorebird species behaves similarly over space and time, and to compare body condition trajectories in the Coorong to other regions.
- There are current camera-trapping programs being run at locations throughout the MDB, and staff would likely be open to targeting species

requested for this project. The 'Selected Area' teams and FlowMER project team would be useful contacts. Some thought should be given to which locations are best to target and given likely drying of the basin in the next few years, it might be best to target managed sites where e-water will be allocated.

Conservation modelling for key waterbird species

- Detailed modelling of the Coorong fairy tern/Talamarari population is a logical priority. Making the association between water management and the availability of small-bodied fish prey is very important. Consideration should be given to innovative complementary measures, such as predator control techniques, creation of artificial nesting habitat, decoy fairy tern/Talamarari "colonies", and guardian animals. A review of possible complementary measures would be valuable, and there should be examples from the global literature on the implementation of innovative strategies.
- Targeted modelling for sharp-tailed sandpiper/Nemineri makes sense as this is a good indicator species and a focus 'touchstone species' the MDBA reports on. However, estimating the area of shallow foraging habitat is likely to be more difficult outside the CLLMM – although Water Observations from Space (WOfS) data can show surface water extent, fine-resolution Digital Elevation Models (DEMs) are not available for many water bodies/wetlands.
- Black swan/Kungari is a culturally important species, and a focus on totemic species and collaboration with First Nations is supported. It would be interesting to consider future hydrology scenarios and how this would affect swan populations and the traditional harvest. Collaboration with DEW would be useful for this species.
- Modelling should consider how much water is likely to be available under various climate change scenarios (i.e. feasibility of water management scenarios is important). This would involve considering upstream storage systems under climate scenarios.

Colonial nesting species with the Lower Lakes

- There is already much research from other parts of the MDB on colonial nesting species and water levels. However, there is value in a specific investigation for the Lower Lakes. Demonstrating that ewater allocation in the lakes promotes successful breeding, would be helpful. Drone-based species/nest counts could be implemented.

Human disturbance of beach-nesting and migratory shorebirds.

- This project is largely out of scope for the MDBA and DCCEEW. However, the impacts of disturbance more broadly are important.

Restoring terrestrialised habitats to wetlands

- If it is already clear that shorebirds prefer unmulched substrate, that might be enough information to inform management.
- This project is not a priority but could be an interesting supplementary project. Two important questions are: (1) are there artificial wetland measures that will help the Coorong adapt under a changing climate?; and (2) are there areas in this region that are on the cusp of being useful to waterbirds that can be adapted for usage in the future?

Further discussion

- MBDA staff completed an internal brainstorm prior to the meeting and were happy to send through more detail on these ideas. There is a strong need for

research to inform how to manage the CCLLMM during periods of drought. It would be useful to clarify which species use the CLLMM as a drought refuge, and it is important for management to support that function. Even during drought periods when the CLLMM is in poor condition, some waterbirds will use the system because habitat is so limiting elsewhere (e.g. ducks will use the Lower lakes even when salinity is high).

- Identified that the impact of climate change on the CLLMM is not yet well understood, but also noted that additional work to generate hydrological projections under climate change is being undertaken.
- A Drought Operating Plan should be developed for the CLLMM. It would be important to consider whether there are components of the system that can be best supported by occasional 'flushes' of water rather than 'drip feeding'. Our ability to provide such pulses would be related to our capacity to hold back large volumes of water for long periods (years), to ensure the water was available when needed. A science-driven drought action plan is needed by on-ground river managers and would be extremely valuable. The fact that a climate adaptation project might pick up some of these themes was noted.
- Telemetry for waterbirds covering autumn in dry/moderate years would be particularly valuable, to understand how species use the landscape during this drier period of the year.

Workshop 7: Friends of the Coorong (6 February 2024)

Attendees: Joanne Flavel, Maureen Christie, Thomas Prowse, Ruth Cope.

TABLE A7. SUMMARY OF THE KEY TAKE-AWAY MESSAGES FROM THE CLLMM WATERBIRD WORKSHOP CONDUCTED ON 6 FEBRUARY 2024.

ORGANISATION	KEY POINTS
Friends of the Coorong (Joanne Flavel, Maureen Christie)	*General comments* • The proposed waterbird projects align with interests of the Friends of the Coorong group. • Friends of the Coorong is a volunteer group with approximately 20 active members, including several with a keen bird interest. *Waterbird telemetry* • Over the last 10-15 years, Friends of the Coorong have actively engaged in monitoring of fairy terns/Talamarari. Recognising the potential benefits of tracking this species; if disturbance to the species is justified and fieldwork receives support/involvement from David and Fi Paton, the project gains their endorsement. • Tracking fairy terns/Talamarari would provide valuable insights into the conditions within the Coorong that contribute to increased sightings and nesting in the lower South East region. *DNA-based investigation of prey availability, shorebird dietary preferences and pathogen load* • Members in the Friends of the Coorong group, and the wider community have sighted dead waterfowl (20-30 birds daily) between Mark Point and the Murray Mouth since late January 2024. A biosecurity team within PIRSA are leading the investigation and have begun testing, there are reports that it may be avian cholera (though conclusive results are pending). This

highlights the urgency for a more comprehensive understanding of the pathogen load potential among shorebirds in the CLLMM.

Shorebird condition monitoring through community science

- Unlike other foraging studies, this proposed project is a direct measure of food availability and body condition. There is desire from Friends of the Coorong members to take targeted photos of individual shorebirds.
- Maureen actively participates in the 'Sanderling Tracking Project,' where team members capture substantial amounts of sanderling photographs. The project holds an annual summer photography competition, fostering community involvement and expanding the collection of sanderling photos. With the abundance of available photos, there is a possibility for sanderlings to be considered as a species in the individual body condition project.
- If photos from this project were to be used, Danny Rodgers (Chair of the AWSG Scientific Committee) would be contacted for permission, as well as Annie Broadway (PhD candidate for the Sanderling Tracking Project) and Marcel Klaassen (Supervisor).

Conservation modelling for key waterbird species

- It would be interesting to know more of the drivers of habitat selection for different shorebirds (e.g. red knot). Understanding why different species prefer specific areas is crucial. As Maureen mentioned in the FoSE workshop, identifying the areas where shorebirds congregate 6-8 weeks before their northward departure would be valuable for effective management and conservation efforts. Identifying and safeguarding these sites, as well as replicating the favourable conditions in other areas, can contribute to habitat protection. For example, sanderlings congregate at Danger Point and Green Point.

Further comments

- The additional proposed projects: colonial nesting, human disturbance (e.g. vehicles on beaches), and restoring terrestrialised habitats to wetlands, are considered to be worthwhile projects.

Workshop 8: Ngarrindjeri Murray Bridge (15 February 2024)

Attendees: Lyn Kartinyeri, Suzi Koolmatrie, Lorraine Kartinyeri, Vicki Hartman, Warren Kartinyeri, Dorothy Wilson, Jenni Grace, Nathan Hartman, Thomas Prowse.

Table A8. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 15 February 2024.

ORGANISATION	KEY POINTS
South-East Aboriginal Focus Group (SEAFG): Bruce Hammond, Doug Nicholls, Wendy Casey, Sonya Smith, Sharyn Ghezzi, Amanda Clarke,	*General comments* • Some waterbird species have particular importance to Ngarrindjeri – the Ngartjis ("special friends"). If these Ngartjis are lost from the CLLMM system, an important part of Ngarrindjeri culture, history and connection with country would also be lost. • Waterbirds and bush birds are an important part of Ngarrindjeri culture and tradition. Certain bird species are known to provide important services to Ngarrindjeri, such as an early warning of snakes or visitors approaching (through their calls). Waterbirds, including ducks and black swan/Kungari, provided an important food resource, and culturally it was important to use as much of the animal as possible (to minimise wastage).

and Peter Clarke.

Other South-East community members: Des Hartman, Suzie Smith, Sasha Smith, and Sarah Smith.

Limestone Coast Landscape Board: David New and Mark de Jong.

- For threatened waterbird species, understanding how they use habitats within the CLLMM, along with their broader movements at regional and national scales, is considered very important. Therefore, GPS tracking is encouraged for these species.
- The Millennium drought produced conditions in the CLLMM that were clearly not suitable for many waterbird species (although the preference of stilt for high-salinity conditions favouring proliferation of brine shrimp was noted as an exception). Yabby abundance has increased again near Raukkan which could be evidence of ecological bounce-back after the drought.
- Before construction of the South East drainage network, the entire South East landscape was dominated by wetlands, and more freshwater flowed into the Coorong South Lagoon through that route.
- Seals near the barrages are very aggressive towards waterbirds in the area and might be causing problems for some species.

Waterbird telemetry (tracking)

- GPS tracking of species that use the CCLMM is supported, both to understand how these species use local habitats, but also to understand connectivity of populations between the CLLMM, the Riverland, and other areas.
- GPS tracking of fairy tern/Talamarari is supported to help understand whether juvenile birds permanently emigrate to other areas (e.g. offshore islands or coastal areas of the South East), which can inform the proposed population modelling for the Coorong population. However, if fairy tern/Talamarari tracking is to go ahead, any negative impacts of catching/tagging on the birds must be minimised.
- A focus on telemetry for sharp-tailed sandpiper/Nemineri (representative of migratory shorebirds) and chestnut teal/Ngra:ki (representative of dabbling ducks) is also supported.
- Recently there have been plenty of teal ducks in the vicinity of Raukkan, so this might be a suitable location for trapping chestnut teal/Ngra:ki for GPS tracking.

Black swan/Kungari egg harvesting

- The traditional harvest of black swan/Kungari eggs was always seasonal, coinciding with the breeding season of the species. When swans are foraging on grass/pasture it can mean they will be breeding in the area soon. The number of eggs harvested per nest was in proportion to the number present (e.g. if there were 5 eggs in a nest, 2 might be taken). Warren Kartinyeri remembers harvesters near the Wellington ferry breaking some reeds near nests they had visited to show those nests should not be harvested again. To test the egg developmental stage, eggs would be placed on the palm and held underwater – new eggs would lie flat, eggs with developing birds inside would tilt upwards, and rotten eggs would float. Two eggs were enough to feed a family for a night, so there was no need to harvest many eggs all at once.
- Due to private land ownership, there are far fewer locations where eggs can be harvested today in comparison to pre-European times. Also, once productive swan nesting areas in the Meningie area do not seem to support the same numbers of breeding animals as in the past. Today, the traditional harvest is largely limited to a single day of harvesting in the Lower lakes near Raukkan, which is organised as a community event. Eggs are usually blown out and fried, although traditionally eggs were cooked by open fire (either in the coals or buried below the fire to cook slowly).
- Two community members (Jenni Grace and Warren Kartinyeri) are interested in collaborating on a proposed project to simulate the

performance of the traditional harvest relative to a 'western' harvesting method.

Shorebird body condition analyses

- The need for high quality images of shorebirds for body-condition scoring might mean that only community members with good camera equipment could usefully participate in this project.

Developing collaborations with Ngarrindjeri and community

- The CLLMM Research Centre could work with schools to develop projects involving students. There might be some young members of the Ngarrindjeri community interested in experience with ecological fieldwork.

Workshop 9: First Nations of the South-East communities (22 February 2024)

Attendees: Bruce Hammond, Doug Nicholls, Wendy Casey, Sonya Smith, Sharyn Ghezzi, Amanda Clarke, Peter Clarke, Des Hartman, Suzie Smith, Sasha Smith, Sarah Smith, David New, Mark de Jong, Nathan Hartman, Thomas Prowse, Ruth Cope.

Table A9. Summary of the key take-away messages from the cllmm waterbird workshop conducted on 22 February 2024.

ORGANISATION	KEY POINTS
South-East Aboriginal Focus Group (SEAFG): Bruce Hammond, Doug Nicholls, Wendy Casey, Sonya Smith, Sharyn Ghezzi, Amanda Clarke, and Peter Clarke. **Other South-East community members:** Des Hartman, Suzie Smith, Sasha Smith, and Sarah Smith. **Limestone Coast Landscape Board:** David New and Mark de Jong.	*General comments* • As some background on different First Nations groups: the Burrandies deal primarily with developing partnerships and projects, while the South-East Aboriginal Focus Group (SEAFG) helps to deploy these projects on Country and carries out field work. • SEAFG would like to be involved in field work when the projects get underway, which would also give them more opportunity to connect with volunteer groups (e.g. Friends groups). This is important to build relationships with the community and to pass on knowledge to younger generations. *Waterbird telemetry* • Black swan/Kungari, extensively use the drainage network in the South East, often breeding in this region when it has been a dry year. There have been no bird counts carried out in the drainage system, highlighting that information gathered from tracking black swan/Kungari will be crucial to understanding how the drainage system links to the CLLMM. • Magpie geese/Pangkuli are an iconic species in the South East region. Little is known of this species' local or national movements. Telemetry for this species would shed light on whether the SE population interacts with magpie geese/Pangkuli in the Northern Territory, and demonstrating this connection could have implications for cultural harvesting practices. • Australian shelduck/Wa:nyi is a species that could also be tracked to represent the herbivorous waterfowl functional group. • There will be continued conversations within SEAFG regarding totemic waterbird species, and outcomes from those discussions could inform future priorities for telemetry. *DNA-based investigation of prey availability, shorebird dietary preferences and pathogen load* • It is crucial for the food resources project to encompass sites within the CLLMM and wetlands in the broader network, to gather information on macroinvertebrate abundance over space and time. Data on food

resources in various shorebird feeding grounds across Australia could provide insight into the effectiveness of current management practices in sustaining shorebirds on Country.

Shorebird condition monitoring through community science

- Expanding this project to encompass the South East region and involve the Boandik peoples would be beneficial. Wetlands such as Lake Hawdon are undergoing restoration to support waterbirds that also use the Coorong, and thereby contribute to maintaining a broader wetland network. Providing habitat refuges for birds is critical to ensure they remain on Country, thereby preserving important totemic waterbird species for First Nations people.

Feedback on CLLMM waterbird research projects from Dr Heather McGinness and Dr Micha Jackson (12 February 2024)

Dr Heather McGinness. CSIRO Senior Research Scientist, CEWH Flow-MER 1 Waterbird Movement Research Project leader, and CEWH Flow-MER 2 program Waterbird Theme leader.

Dr Micha Jackson. CSIRO Research Projects Officer, CEWH Flow-MER 1 Waterbird Movement Research Project member, and CEWH Flow-MER 2 program Waterbird Theme core working group member, East Asian-Australasian Flyway Partnership Shorebird Working Group core team.

Waterbird movements. The broader scale waterbird connections between the CLLMM, the Lake Eyre Basin, the upper Murray Darling Basin, and regions further north are of substantial interest. Researching these connections would help us to understand the continental-scale dynamics of waterbird populations and the meaning of perceived changes in abundances and breeding at site scales. There is a significant opportunity for CLLMM waterbird researchers to collaborate with other programs on putting together that broader picture.

Heather McGinness and CSIRO Waterbirds Australia team would be interested in collaborating on how post-nesting and juvenile dispersal movements of species like spoonbill from the CLLMM might interact with or differ from those her research program has tracked elsewhere. To date, no tracked spoonbill, straw-necked ibis, Australian white ibis, great egret or plumed egret tagged elsewhere in the MDB has moved to the CLLMM region. Tracking and DNA sampling of such species from CLLMM nesting sites would be useful and has been discussed in the past. However, straw-necked ibis are less relevant for full-life-cycle water management so research on spoonbills and other species dependent on surface water for both feeding and breeding is probably a higher priority.

Research is also needed to understand how shorebird species such as the common greenshank/Terilteril are using inland wetlands, and where there are particular wetlands/sites that are often used for shorebird stopovers and if they are managed currently. Reliably catching species like common greenshank/Terilteril is very difficult in upper MDB sites, but information could potentially be gathered by catching and GPS-tagging these species in the CLLMM and other coastal sites.

Body condition monitoring/colonial nesting. The proposed project on condition monitoring via photos could be valuable for colonial nesters including spoonbill, ibis, cormorants, and egrets, especially as a corollary to CSIROs plans to investigate the link between breeding numbers/success and foraging habitats and food availability. It would be useful to match body condition scoring with biometrics and age groups for validation and modelling, and Heather would be interested to collaborate on a student project to trial this. CSIRO has many existing photos from nest camera monitoring and other fieldwork, and also photos of birds with matching biometrics (though not necessarily birds properly 'posed' for condition scoring). It might be possible to add targeted data by visiting sites and catching birds for posing and biometrics in both CLLMM and upper MDB. This sort

of research might work as one component of a broader project focusing on colonial nesters in the Lower Lakes.

Further comments. It would be useful if researchers catching birds in the CLLMM could take the same samples that Heather's program takes (if not more) – oropharyngeal swabs and cloacal swabs (stored in RNAlater and VTM preferably), feathers (stored in ethanol and RNAlater preferably), scats, and if possible, blood. This would facilitate collaboration on genetic, disease and toxin research matched with the movement research.

Summary of phone call with Samantha Blight, Coorong District Council Sustainability Officer (14 February 2024)

Samantha Blight is a member of the Friends of the Coorong, the President of Friends of the Coorong National Park, as well as the Sustainability Officer for Coorong District Council.

Background of current project- Plant aquatic reeds, *Schoenoplectus validus* into the lakebed primarily for lakeshore erosion control, with the added positive ecological outcome of providing still water habitat to increase the wetland biodiversity. Samantha has received funding from BHP to undertake this work as they see it as a link to improving the habitats of wetland and wader birds that visit their tailings dams at their Olympic Dam site and the CLLMM region.

Scale of the project- Reeds planted in a linear fashion adjacent to the lake edge for 1 kilometre, with 4 rows in total (e.g. 4 kms of reed plantings), a couple of sites on Lake Albert and Lake Alexandrina. 10 years ago, as a part of the CLLMM habitat restoration project reeds were planted, these reed beds have thickened up and could be a useful reference site. A couple of years ago, two rows of plantings were completed, although the unanticipated floods drowned many of them and ~50% of these reed beds were lost.

Potential aspects of the project- Waterbird telemetry- because of BHP mining operations at Olympic Dam banded stilt (*Cladorhynchus leucocephalus*) utilise the tailing dams. The banded stilts also utilise the CLLMM region too. Tracking this species could provide the link between areas like Olympic Dam, other inland wetlands, and the CLLMM region. It would also help to reinforce whether target species are using areas where aquatic reeds have been planted.

Visual observations- regular monitoring could take place in the areas where reeds have been planted vs. no plantings. Visual observations would aid in monitoring the benefits of this restoration activity for birds (e.g. what species use these areas, is there higher waterbird abundance in reed planting areas of the lake?)

Blue carbon- There is extensive discussion surrounding blue carbon and carbon storage in oceans, yet freshwater systems, often referred to as 'teal carbon,' receive comparatively less attention in this regard. A few years ago, Samantha planted reeds and analysed the soil from restored areas vs. areas with no reeds. There was greater organic carbon where the reeds were, likely as they slow down the water and organic matter can build-up (this aspect is not directly related to waterbirds).

Working with community- Some funding has been secured for the upcoming year to support a collaborative project to plant reeds in the area between the Narrung ferry and Raukkan on Lake Alexandrina, with local First Nations community involvement. This project aims to target the inshore wetlands and reconnect them to the lake, this will provide good fringing wetland for wading birds. The community in that area is very motivated to restore the habitat.

Samantha is supportive of the other example projects (especially waterbird telemetry and conservation modelling), these projects have the potential to be really impactful for future water management decisions.

Reed planting is an important aspect for the ecology of the lakes. A study on the benefits of reed planting to local and visiting birdlife would be beneficial for the CLLMM region.

Feedback on CLLMM waterbird research projects from Professor Sabine Dittmann (26 February 2024)

Prof. Sabine Dittmann. Professor of Marine Biology at Flinders University, The HCHB Phase One Trials & Investigations Project (Component 3 – Restoring a functioning Coorong food web) project leader.

- Shorebird and waterbird studies need to include the North Lagoon and Murray Mouth, where we higher bird numbers are typically observed than in the South Lagoon.
- We have little data on the phenology of migratory shorebirds from the CLLMM region (at least from recent years). Monitoring the arrival/departure time for migratory species could be linked back to the overall water situation in the CLLMM and the MDB more broadly, indicate shifts in migration as the climate is changing, and also reflect pressures persisting along the flyways. This could potentially be achieved with coordinated monthly/fortnightly surveys realised by community groups/Birdlife SA/Birdlife Australia, and scientists.

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