

Ocean beach ecology and threats: a stakeholder perspective

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The Goyder Institute for Water Research Coorong, Lower Lakes and Murray Mouth (CLLMM) Research Centre, based in Goolwa SA, was established in 2023 through funding by the Australian Government.



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Executive Summary

Ocean beaches in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region are ecologically, socially, and economically important, supporting threatened species, significant fisheries, and a wide range of recreational activities. However, they have received comparatively little scientific attention compared to the adjacent freshwater and estuarine systems. As such, their current condition and how they are changing over time remains poorly understood. These beaches face a range of pressures, including overharvesting, human disturbance (e.g. vehicle use), invasive species, pollution, catchment impacts (i.e. altered land and water use), and climate change. Knowledge of these threats is variable as some pressures are widely recognised while others remain underrepresented. Previous research has examined aspects of beach ecology in the region, but this work is fragmented and has not been brought together in a way that can be used easily by managers to inform future management of this area. There is also limited insight into how different stakeholders use and value these environments, and how they perceive the threats affecting them. This project addresses these gaps by integrating existing scientific knowledge with spatial data on beach use and stakeholder perspectives, providing a more complete understanding of ocean beaches in the CLLMM region to support future management and planning.

A literature review was undertaken using an ecosystem services framework (the direct and indirect benefits humans receive from nature) to clarify what is currently known about the ecology of ocean beaches in the CLLMM region, including the benefits they provide and the pressures affecting them. The review highlighted that a moderate body of research exists but has largely concentrated on a limited set of ecosystem services, particularly those that are most visible or directly linked to economic and ecological outcomes, such as fisheries (e.g. pipi and mullet) or maintaining habitats for species (e.g. shorebirds). The most commonly identified threats were overharvesting and human disturbance, especially from activities such as off-road vehicle use. These pressures were often linked to impacts on species and habitats, particularly shorebirds and fishery resources. However, broader ecological processes, including how beaches change over time and their role in protecting the coast from extreme events were rarely considered despite their importance for long-term ecosystem function. Cultural values beyond recreation, including deeper social and cultural connections to beaches, were also underrepresented. In addition, the literature generally considered threats in isolation, with limited attention given to how multiple pressures interact. Together, these findings indicate that while a moderate body of knowledge exists, it does not yet capture the full range of values and processes associated with ocean beaches in the CLLMM region.

To complement the literature review, a Public Participation Geographic Information System (PPGIS) was used to capture how people use and value ocean beaches across the CLLMM region, and how they perceive key threats. The results show that beaches are used by both local residents and visitors from outside the region, with use peaking in summer but remaining steady across seasons. A wide range of activities

were reported, including walking, swimming, fishing, four-wheel driving, and wildlife observation, with use concentrated around key access points, particularly near Goolwa. Participants generally expressed a preference for balancing recreation with environmental protection, with many supporting management actions such as limiting vehicle access and improving responsible use, either through penalties or incentives. Concern about environmental impacts was widespread, particularly in relation to vehicle use, pollution and human disturbance. Participants expressed moderate concern about climate change, with greater concern related to this issue in the longer-term, rather than the near future. Areas of highest concern closely aligned with the most heavily used locations across the coastline. Overall, the findings highlight the importance of ocean beaches for recreation and wellbeing, while also indicating growing awareness of environmental pressures and support for improved management.

To further explore these patterns, semi-structured interviews were conducted with stakeholders to understand how different groups use, value, and perceive threats to ocean beaches in the CLLMM region. Participants consistently emphasised the importance of beaches for recreation, wellbeing, and connection to nature, with activities such as swimming, walking, fishing, and socialising frequently highlighted. A strong and recurring theme was the value of the beaches' relatively undeveloped and uncrowded character, with many participants describing a sense of solitude, natural beauty, and emotional connection to the landscape. Concerns about the current and future condition of beaches were widespread. Human activities, particularly four-wheel driving, were most frequently identified as a key pressure on the environment. Participants also expressed concern about pollution, coastal erosion, population growth, and the effects of climate change. While climate change was widely recognised as a significant long-term threat, it was often perceived as less immediate or more difficult to address compared to local pressures such as recreational use. Overall, participants highlighted a need for improved management, including greater education, regulation, and shared responsibility for protecting the beach environments. These findings provide important context for understanding how communities experience and interpret environmental change, complementing both the spatial patterns identified through the PPGIS and the trends observed in the literature.

Across all three components of this project, the literature review, the PPGIS analysis, and the stakeholder interviews, a consistent pattern emerges: while a moderate amount of information exists on ocean beaches in the CLLMM region, it remains fragmented, varied in focus, and not well connected to how people use and value these environments. This includes not only the literature, but also a wide range of existing monitoring and data collection activities that are currently dispersed across different organisations and programs. The literature emphasises a limited set of ecosystem services and associated threats, the PPGIS highlights that key values and pressures are concentrated near the access points and also the Murray Mouth, and stakeholder interviews provide insight into how these issues are experienced and understood by the community. Together, these findings indicate a need for a more

coordinated and integrated approach to manage ocean beaches. Additionally, building visitor understanding of ocean beaches and promoting opportunities to engage in the protection of this important resource is fundamental to long term protection.

Better alignment between scientific knowledge, spatial data, and community perspectives can support more informed decision-making. This includes improving the synthesis and accessibility of existing information, as well as strengthening monitoring efforts to capture both environmental change and patterns of human use. The strong community concern around issues such as beach driving, pollution, and environmental degradation also highlights the importance of targeted management responses, including improved education, clearer regulations, and increased compliance where needed.

More broadly, the findings highlight the importance of moving beyond single-issue management towards approaches that recognise how multiple pressures interact across the coastline. Supporting shared responsibility for beach stewardship, including opportunities for community involvement in monitoring and management, can also be important for maintaining the ecological and social values of these environments. Together, these actions provide a pathway towards more adaptive and integrated management of ocean beaches in the CLLMM region.

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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 communities in the CLLMM region as we collectively work toward healthy, resilient and thriving lands, waters, ecosystems and communities across the region.

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We are very grateful to all the members of the public who took the time to complete our survey or discuss key issues with us. We extend special thanks to the staff at the CLLMM Research Centre for helping us to distribute the survey and help us to identify key stakeholders associated with different user groups in the region.

1 Why ocean beaches matter in the CLLMM region

Ocean beaches are often viewed by the broader public as simple, recreational environments. However, research has long recognised that sandy beaches are dynamic systems, and more recent work has further shown that they support diverse biological communities, contribute to fisheries productivity, and provide a range of social and cultural benefits (Barbier et al., 2011; Defeo et al., 2021). More broadly, these benefits can be understood through the ecosystem services they provide, that is, the ways people derive value from nature, whether through material goods, ecological processes, or cultural connections (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005). Ocean beaches have been a significant focus of coastal management (Defeo et al., 2009), yet an ecosystem-based service approach has been less widely adopted in this context, with research instead tending to focus on adjacent habitats such as estuaries, mangroves, and seagrass meadows (Harris & Defeo, 2022).

In the Coorong, Lower Lakes and Murray Mouth (CLLMM) region, ocean beaches form an important, though often under-recognised, component of a broader and highly interconnected coastal system linking the River Murray and estuarine lagoons to the Southern Ocean (Kingsford et al., 2011). These beaches form part of the longest high-energy beach system in Australia (Short, 2006) and represent the seaward boundary of a complex landscape that includes freshwater lakes, estuarine environments, and internationally recognised wetlands (Phillips et al., 2006; Kingsford et al., 2011).

Ocean beaches in the CLLMM region extend along both sides of the Murray Mouth, forming a largely continuous, high-energy sandy coastline shaped by waves, tides, currents, and wind (Short & Wright, 1983). To the west of the Murray Mouth lies Goolwa Beach, approximately 18 km in length, which is highly accessible and subject to intensive recreational and fishing use, including access from off-road vehicles.

To the east, the Younghusband Peninsula extends for around 198 km, forming a long, exposed barrier between the Southern Ocean and the Coorong lagoons (Bourman et al., 2016). While access, use, and management differ greatly between the two sides of the Murray Mouth, both are shaped by similar physical processes and remain connected through sediment transport, coastal currents, and the movement of organisms, including surf-zone fish, sand-dwelling invertebrates, and migratory shorebirds that move between beach environments on either side (Bourman et al., 2016; McLachlan & Defeo, 2017).

At a more local scale, beach systems provide a link between the marine and terrestrial environments, incorporating the foredunes, beach face, and surf zone, which together function as an integrated and highly dynamic system (McLachlan & Defeo, 2017). Across these zones, the continual movement of sand, nutrient-rich material (e.g. seaweed and other organic matter washed up by waves which is transported from the surf zone onto the beach face and foredune), and organisms (e.g. small sand-dwelling invertebrates that move between the water's edge and the upper beach to

feed) underpins both ecological processes and the services these systems provide (Dugan et al., 2003; McLachlan & Defeo, 2017).

Ocean beaches in the CLLMM region provide habitat for many organisms across multiple life stages. Beach-dwelling and surf-zone invertebrates such as pipis (also known as cockles) can occur in high densities and support both commercial and recreational harvesting (Durante et al., 2024). Surf zone waters adjacent to the Murray Mouth are also used by fish species, including mulloway (*Argyrosomus japonicus*), during spawning, recruitment, and early development, linking beach environments with estuarine and riverine systems (Ferguson et al., 2014). In addition, beaches provide feeding, roosting, and breeding habitat for shorebirds and seabirds, many of which are sensitive to disturbances such as those brought by vehicles, dogs, and people (Buick and Paton, 1989; Jones et al., 2015.) These ecological functions underpin a range of ecosystem services, including food resources and habitat support.

Beyond their ecological roles, ocean beaches offer non-material benefits to people, including recreational, aesthetic, spiritual, and educational values that contribute to quality of life and community identity (Harvey & Caton, 2003; Martin et al., 2016). Activities such as fishing, walking, camping, four-wheel driving, and nature-based recreation are common, contributing to physical health, mental wellbeing, and a broader sense of connection to the environment (White et al., 2013). For First Nations peoples, beaches and coastal areas form part of Country, with cultural, spiritual, and historical significance that extends well beyond contemporary recreational use (Birkhead et al., 2011; Bourman et al., 2019).

Ocean beaches are highly valuable environments but are inherently dynamic, shifting and changing over time in response to natural or man-made pressures. Sand movement, shoreline change, and shifts in biological communities are natural features of these systems (Short & Wright, 1983). These dynamics also interact with human pressures, including vehicle use, harvesting of organisms, invasive species, pollution, and changes to riverine flows, as well as broader climate-driven changes such as sea-level rise, drought, and flood driven outflows (Poff et al., 1997; Carpenter et al., 1998; Pejchar & Mooney, 2009; Grimm et al., 2013; Jaureguiberry et al., 2022). These pressures can act together, amplifying their effects and influence on beach structure, productivity, and ecological resilience, ultimately affecting the capacity of these systems to continue providing key services over time. Understanding what threats exist and how they interact is important to support more informed management of beaches and future research priorities.

Despite their importance, ocean beaches in the CLLMM region have received comparatively little coordinated, long-term environmental research compared to the nearby estuarine and wetland systems, which have been the focus of substantial scientific and management attention (Department for Environment and Water, 2025). This report brings together current knowledge and outlines why a more systematic approach may be needed to understand both the value these ocean beaches provide, and what pressures they face.

2 Purpose of this report

This report forms part of a project examining existing scientific and monitoring knowledge of ocean beaches in the CLLMM region, the benefits people receive from these environments, and how different groups perceive threats to those benefits. It brings together this information to help inform future management and planning through three complementary components: a comprehensive literature review that collates existing scientific and monitoring information, a spatial survey of beach use and perceived threats using a Public Participation Geographic Information System (PPGIS), and semi-structured interviews with a range of stakeholders.

The literature and data identification component draws together information from peer-reviewed literature, technical reports, theses, and other grey literature relating to the ocean beaches of the CLLMM region that has not previously been collated. Rather than assessing beach condition or proposing new monitoring programs, this component clarifies what information already exists, how it has been generated, and where important gaps remain. A detailed academic paper has been prepared as part of this work (see Appendix A). The paper provides a systematic overview of the literature relating to the benefits provided by, and pressures acting on, ocean beaches in the CLLMM region.

A Public Participation Geographic Information System (PPGIS) study was designed to capture how a broad range of ocean beach users and stakeholders – including 4WD users, fishers, boaters, surfers, birdwatchers, conservation groups, equestrian users, and other general public community members – use ocean beaches, what they value in different locations, and where they perceive key threats. An interactive mapping tool was developed and implemented across the CLLMM region, allowing participants to identify important places and describe their experiences and concerns in their own terms. The approach aimed to capture a wide range of perspectives across stakeholder groups, generating spatially explicit insights into patterns of use, value, and perceived threats across the coastline. Appendix B presents the survey used for this component.

Semi-structured interviews were conducted with a subset of participants who have experience with the CLLMM beaches to provide a more in-depth understanding of these perspectives. These interviews explored how different people perceive and prioritise threats, how they value ocean beaches, and how they view potential management responses, including the role of climate change and human activities. This component provides important context for interpreting both the spatial patterns identified through the PPGIS and the themes emerging from the literature. The questions used in the interviews are provided as Appendix C.

Supported by results from these three components, this report provides an integrated summary of key findings to support broader discussion and decision-making. The literature review establishes what is currently known and identifies key knowledge gaps, the PPGIS analysis highlights where beach use and community concern are concentrated across the region, and the stakeholder interviews provide deeper

insight into how these values and concerns are experienced by different people. Together, these findings can support decisions such as prioritising future monitoring and research, inform vehicle access and use policies, and guide education and engagement initiatives aimed at protecting the services these beaches provide.

3 Scope and characteristics of the existing CLLMM literature

The amount of published work relating to ocean beaches in the CLLMM region is greater than is often assumed, but it is also dispersed across a wide range of sources. A systematic review identified approximately 80 documents containing information relevant to ocean beaches, spanning more than four decades from the early 1980s to the present (see Appendix D). These include peer-reviewed journal articles, government and consultancy reports, postgraduate theses, and community-based studies.

Only a small proportion of these documents focus directly on ocean beaches. More commonly, beaches are considered part of broader work on fisheries, specific taxa such as shorebirds, coastal processes, or regional environmental management. As a result, information relevant to beaches is spread across different disciplines, agencies, and reporting contexts, often using varying spatial scales, timeframes, and methods.

This makes it difficult to understand the services these beaches provide and their value to people, and to build a clear, consistent picture of beach condition or change over time, even where data exist. Bringing these different strands of information together is therefore a key step in improving understanding and highlights the importance of synthesis alongside the collection of new data.

3.1 *Insights from broader ocean beach ecology literature*

Over the past few decades, research on ocean beaches has primarily focused on their physical characteristics and geomorphological dynamics, rather than their ecological functioning and the ecosystem services they provide (Harris & Defeo, 2022). Across a wide range of regions, studies consistently report relationships between wave energy, sediment properties, and the abundance and composition of invertebrate assemblages, as well as patterns of shorebird and fish use (McLachlan & Defeo, 2017). These relationships underpin many of the ecological processes that support the services provided by ocean beaches, including habitat provision, food resources, and trophic linkages. While local conditions influence how these relationships are expressed, the recurrence of similar patterns across different beach systems indicates that many of the underlying processes are broadly consistent.

A central concept in beach ecology is the role of physical beach type in structuring biological communities. Beaches are commonly described along a continuum from reflective to dissipative, based on wave energy, sediment grain size, and beach slope (Short & Wright, 1983; Jackson & Short, 2020). Dissipative beaches, which tend to be wide, gently sloping, and composed of finer sands, often support higher abundances of infaunal invertebrates than narrower, steeper reflective beaches (McLachlan & Defeo, 2017). These invertebrate communities form the basis of food webs that support shorebirds and surf-zone fish, linking physical processes with ecological function and, ultimately, the services these systems provide (Brown & McLachlan, 2010).

Goolwa Beach is an example of a high-energy, dissipative ocean beach, and research on its pipi populations and surf-zone processes aligns with patterns observed in similar systems elsewhere (McLachlan et al., 1996). More broadly, studies from both Australia and other regions show that beaches with comparable physical characteristics tend to support similar ecological assemblages and processes (McLachlan & Defeo, 2017). This suggests that many of the ecological patterns observed in the CLLMM region are not unique but reflect widely recognised relationships between beach form and function.

Shorebird ecology on ocean beaches has also been examined extensively on global scales. Many studies report strong links between beach characteristics, prey availability, and shorebird foraging behaviour and distribution (Defeo et al., 2009; Schlacher et al., 2016). Research further indicates that human disturbance, including vehicle use, and presence of domestic animals such as dogs, can alter behaviour, reduce feeding efficiency, and affect breeding success, particularly on wide, accessible beaches (Schlacher et al., 2013; 2016). Predation by introduced pest species, such as foxes, has also been identified as a threat to shorebird nesting success in Australia (Maguire et al., 2009). Observations from beaches in the CLLMM region are broadly consistent with this body of work, reinforcing the applicability of these general ecological principles in a local context.

4 Sources of information and approach

4.1 Literature and data identification

Information for the review was drawn from a combination of published academic research and grey literature, including peer-reviewed journal articles, government databases, consultancy reports, university theses, and other locally relevant documents. A broad and flexible search approach was used to capture documents relating to ocean beaches in the CLLMM region, recognising that much of the available knowledge sits outside traditional academic sources.

Searches were conducted using major academic databases, including Web of Science and Google Scholar, alongside targeted searches of government and institutional repositories such as Enviro Data SA, Primary Industries and Regions South Australia (PIRSA), and university digital collections. Reference lists from relevant documents were also used to identify additional sources.

To complement this, regional stakeholders, including researchers and community groups, were contacted to help identify information that may not be publicly available or easily accessible online (see Appendix D).

Key information from each document was compiled into a metadata table (see Appendix E). This included basic details such as authorship, year of publication, and document type, as well as the main focus of each study. Information on threats affecting ocean beaches was also recorded, grouped into broad categories such as catchment impacts, climate change, human disturbance, invasive species, overharvesting, and pollution.

To organise this information in a consistent way, the review used an ecosystem services framework to describe the different benefits provided by ocean beaches. An ecosystem services approach was used as it offers a way to connect ecological condition with the values held by different user groups, individuals, and decision-makers, supporting the integration of scientific, spatial, and community data that is central to this report. More broadly, an ecosystem services approach is well suited to coastal management because it translates ecological condition into terms that are directly relevant to policy and planning decisions, and provides a common vocabulary through which stakeholders with differing values and priorities (e.g. from fisheries and conservation interests to local communities and recreational users) can engage in shared decision-making (Barbier et al., 2011; Granek et al., 2010). This framing necessarily foregrounds the benefits nature provides to people. Other frameworks, such as relational or intrinsic-value approaches, also offer useful ways of capturing human-nature relationships, however they fall outside this scope, for instance, where value does not reduce to a benefit or service at all. These frameworks are valuable for different purposes but are less suited to the applied, cross-stakeholder integration task at the centre of this report.

Services were grouped into broad categories, including provisioning (e.g. food resources), regulation and maintenance (e.g. habitat provision and coastal

processes), and cultural services (e.g. recreation and connections to place). This provided a common structure for comparing how different documents describe the value of ocean beaches and the pressures acting on them.

4.2 Public Participation Geographic Information System (PPGIS)

4.2.1 Research Design and Planning

A Public Participation Geographic Information System (PPGIS) was developed as part of this project to capture spatial information on how ocean beaches in the CLLMM region are used, valued, and perceived by different stakeholder groups. The PPGIS aimed to capture perspectives across multiple stakeholder groups, including recreational users, community members, and those with professional or management roles connected to ocean beaches. The PPGIS framework enabled participants to contribute georeferenced information through a structured, interactive mapping exercise, facilitating subsequent analysis of both spatial and social data. Prior to survey development, key information requirements were defined, encompassing spatial data (point geometries), associated attribute information, and participant demographic data. Target participant groups were identified through consultation with the Goyder Institute network and relevant community stakeholders. By collecting spatially explicit data, the PPGIS provided an opportunity to explore patterns of use and value at different locations and identify areas where perceived pressures may be concentrated. The geospatial layers generated can also be compared to other existing geospatial layers, for example, vegetation types or known wildlife populations, effectively providing a tool for inter-disciplinary interrogation of an issue.

4.2.2 Survey Design and Instrument Development

The PPGIS tool was designed to be accessible and flexible, enabling participants to identify areas they use for specific activities and to highlight locations they consider particularly special. Participants were also able to indicate locations where they perceived threats or pressures, helping to build a spatial understanding of how different values and concerns are distributed across the coastline. The tool was implemented both online and, where needed, with in-person support to ensure participation from a broad range of users.

The survey instrument was developed using ESRI's Survey123 platform, which supports the integration of conventional questionnaire items with map-based spatial data collection. Survey123 Connect with XLSForm coding was used to construct the survey, enabling advanced question types, conditional logic, and flexible spatial input methods. An overview of the design and implementation of the PPGIS is shown in Figure 1.

The survey comprised three sequential components. The first was a participant information section, capturing demographic characteristics, self-reported familiarity with the study area, and informed consent. The second was a thematic questionnaire that explored participants' experiences and values in relation to the CLLMM area,

including areas of environmental concern or impacts they identified as being associated with beach management and visitor use. This also included a self-rating of where participants felt their overall value system laid in terms of protecting ocean beaches. They were asked to indicate this using a scale ranging from an anthropocentric approach represented by “access and recreation” as the highest priority to a biocentric approach labelled “conservation and nature preservation”. This priority continuum was originally developed by Dunlap and Van Liere (1978) in their seminal work developing the New Environmental Paradigm (NEP) scales and was used extensively by Brown and Weber in various protected area PPGIS studies (e.g. Brown & Weber, 2011). The third, and central, component consisted of a series of spatial mapping questions forming the core of the PPGIS exercise. Participants were first presented with a checklist of predefined recreational activities, with an option to specify additional user-defined activities. Conditional logic was then applied to generate a tailored series of mapping questions corresponding to each selected activity, enabling participants to delineate the spatial extent of their recreational use. Beyond activity mapping, participants were invited to identify places of personal significance, areas visited during particular seasons, specific place values, and locations where they perceived environmental degradation or impacts on visitor experience. Consent statements and university ethics approval information were incorporated into the survey introduction screen.

The survey was configured with selectable basemaps and integrated search functionality to assist participants in accurately locating and mapping their points of interest. Instructions and contextual examples were provided throughout to support the accurate placement of mapped points. Validation rules were applied to required fields, and the instrument was piloted and tested prior to deployment.

4.2.3 Participant Recruitment and Data Collection

Participants were recruited via multiple channels. Initially all groups that had some type of stake in the area were identified through a brainstorming activity. This list was then provided to CLLMM staff to interrogate. They added some additional users (e.g. horse riders), and provided contact details of representatives of various groups where they were available. The research team found contact details of other groups via web searches and snowball methods. Groups initially contacted via phone or email included:

- 4WD Australia
- 4WD SA
- 4WD Victoria
- Birdlife Australia
- Breakaways Club of SA
- Country Fire Service
- David Jolley Horse Racing
- Friends of the Coorong
- Friends of Jallarah
- Garden Groups

- Goolwa Coastcare Group
- Hindmarsh Island Landcare Group
- Landcruiser Club of SA
- Lions Club
- Oval Playground Support Group
- OzFish Unlimited
- Meningie Progress Association
- Probus & RSL
- Rotary
- River Lands and Coorong Action Group
- SA 4WD Club of SA Inc.
- SA State Emergency Service
- Summit Trax 4WD Inc
- Surf Lifesaving Goolwa
- Women of Worth Milang Old Schol House Community Centre

First Nations groups were not included at this stage because it is hoped they will form a separate study component in future work. In addition to emails and phone calls, the research team visited several of these groups to locate further participants. Unfortunately, this stratified sampling approach did not yield a sufficient sample (n = 14 hardcopy and 36 electronic), so convenience sampling was also employed. Recruitment methods included online distribution through community groups, social media platforms (Facebook, YouTube, and Instagram) and the Goyder Institute network, as well as through in-person community events, for example the Goolwa Market and the CLLMM Research Centre Community Advisory Forum meeting. The project was also advertised on community notice boards and networks. These methods generated 93 individual responses.

Because the research team was aware there was much use of the area by people visiting from Victoria who may not be reached using the above methods, a commercial panel survey company (Pure Profile) was employed to increase the geographic reach. A further 108 people responded to this survey. A comparison was made between all survey items and there were minimal differences so the data was merged for the purpose of analysis. Of note, there were more local representatives in the data we collected and the open-ended responses were more extensive in our data set, compared to Pure Profile data set.

The survey was made accessible via a public web link and QR code. To maximise accessibility, a paper-based alternative version of the survey was developed, containing equivalent questions to the online instrument, with a modified mapping format that allowed participants to mark locations on a series of printed maps produced at an appropriate scale for accurate spatial data collection. Paper-based responses were subsequently digitised into the project database.

Data collection followed three modes: (1) self-administered online participation via the web link or QR code, (2) facilitated completion at community events, where participants were guided through the survey by a researcher, and (3) invited

participation where researchers provided paper copies with stamped self-addressed envelopes to representatives from specific user groups. This multi-method approach supported both broad community reach and engagement with populations less likely to participate independently.

Ethical considerations were embedded throughout all stages of the study. Informed consent was obtained from all participants prior to data collection. Participant anonymity and data privacy were maintained throughout, and all data were stored securely with appropriate access controls in accordance with the approved ethics protocol.

4.2.4 Data Management and Preparation

Survey responses were stored within the ArcGIS Online environment as hosted feature layers. Following the close of the data collection period, ArcGIS Notebooks were used for initial data processing, including the standardisation of categorical attribute fields and the conversion of point geometry data into a structured format suitable for spatial analysis. Data were then reviewed for completeness and accuracy, with incomplete responses and spatially invalid entries — including points placed outside the defined study area boundary — removed prior to export. Attribute tables were organised into structured feature classes within a file geodatabase, and survey metadata, field names, and coding conventions were documented to support reproducibility and transparency.

4.2.5 Spatial Analysis

Processed data were exported to ArcGIS Pro for spatial analysis and map production. Exploratory analysis involved symbolising point data by response category and examining the spatial distribution of participant responses. Point density analysis and kernel density estimation (heat mapping) were the primary analytical techniques applied, enabling identification of areas of highest spatial concentration for each activity type and mapped attribute. Where relevant, overlay analysis with environmental and land-use layers — including habitat mapping, land use classifications, and hazard data — was conducted to contextualise participant responses and identify areas of high use, high value, or potential conflict. Thematic static maps were produced to communicate spatial patterns and support interpretation of findings in relation to the study objectives.

The design of the PPGIS was informed by the literature review and in turn helped to inform interview questions. While the literature provides an overview of existing knowledge, and interviews offer in-depth perspectives, the PPGIS adds a spatial dimension, showing where values and concerns are located across the region. The findings from the PPGIS component are presented in Section 8 (*Spatial patterns of values and use*).



Figure 1: Overview of PPGIS survey development and implementation

4.3 Semi-structured interviews

To further explore and better understand the findings from the PPGIS survey, we conducted a series of semi-structured interviews. A total of 25 participants were interviewed, all of whom reported having some level of experience with beaches in the CLLMM region. Participants were recruited through social media advertisements and snowball sampling via CLLMM Research Centre networks. Interested individuals were provided with a Participant Information Sheet, which outlined the study requirements and eligibility criteria. To be eligible for participation, individuals were required to have previously visited one or more beaches within the CLLMM region. This eligibility criterion was used to ensure that all interview participants had relevant experience and knowledge of the study area. Two participant submissions were removed after it became clear they had no personal experience with the beaches and were instead reading their answers from generative Artificial Intelligence (GenAI). These cases were removed following initial identification by the interviewers followed by inter-rater assessment. This left a final participant number of 23.

The semi-structured interview followed the general structure of:

- Building rapport by asking participants about their relationship to the area, community involvement, work, and family
- Values section - asking participants how they spend their time on the beaches, what impacts their enjoyment, and are their favourite memories of the coast
- Threats section - this section started by asking participants broadly what they believe is negatively affecting the beaches in the area. They were then specifically asked about the 5 threats that emerged from the systematic review conducted as part of this broader project:
 - Invasive species
 - Water flow
 - Overharvesting of certain species
 - Climate change
 - Human behaviours
- Vehicle use on beaches emerged as a potentially under-examined pressure, both in the literature review, which linked it to direct mortality of intertidal organisms such as pipis (Schlacher et al., 2008), and in initial discussions with staff from BirdLife Australia (a national bird conservation organisation). Given this, the last section of the interview asked participants about beach driving, including whether they participate in beach driving, then what motivates them to do so, and what impact they believe beach driving has on the coastal environment.

The semi-structured approach meant that while each interview followed the above overarching structure, this was a flexible and fluid structure, where researchers could ask follow up questions, or change the order of questions to allow for a more natural conversation.

Interview responses were analysed thematically, with key topics including values, perceived threats, beach use (including driving), and broader reflections on coastal change. The findings from these interviews are presented in Section 8.

4.3.1 Participants

Interviewees were recruited through a variety of channels; posts on relevant social media groups (e.g., community Facebook Pages), emails sent to distribution list provided by CLLMM Research Centre, and general snowballing. The recruitment advertisements stated that participants must have experience with beaches in the CLLMM region, and during the initial stages of recruitment this experience was confirmed via email to ensure we interviewed participants with varying levels of experience. The gender split among interviewees was 11 men and 12 women. Experience with the CLLMM region varied greatly, with some interviewees living in the region for 30+ years, to a couple who had purchased holiday homes in the area within the past 10 years. Four interviewees did not live (or have a holiday home) in the CLLMM region: three work in the region, and one other has surfed in the region regularly for multiple years.

4.3.2 Data analysis

All interviews were recorded and interviewers also took handwritten notes. After each interview, data were entered into an Excel spreadsheet. Following the interviews, recordings and notes were reviewed using a combination of content analysis (Neuendorf, 2016) and thematic analysis (Braun & Clarke, 2013). This was employed provide both a systematic summary of participants' responses and a deeper interpretation of recurring patterns and meanings. Content analysis was used to identify and categorise key topics and concepts while thematic analysis was undertaken to explore broader patterns within the data and to identify themes that captured shared experiences, perceptions, and perspectives. The two interviewers independently reviewed the interview data, developed preliminary codes, and then met to compare and refine categories and themes through discussion. Any discrepancies were resolved by consensus, ensuring consistency in the interpretation of the findings.

5. Dominant themes in the CLLMM-specific literature

The literature specific to the CLLMM region revealed several strong and recurring themes, reflecting historical research priorities and management focus. A visual summary of these themes is provided as Figure 2.



Figure 2: Links between ecosystem service sections (provisioning, regulation and maintenance, and cultural) and threats identified in the reviewed literature on ocean beaches of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. The width of flows represents the relative frequency of associations recorded across 80 unique documents. 'Unidentified' refers to documents in which no ecosystem service was mentioned or able to be inferred, while 'Unspecified' refers to documents in which no threat was mentioned or able to be inferred.

5.1 Fisheries and provisioning services

One of the most prominent themes identified was the harvesting of species associated with ocean beaches. Fisheries represent the dominant provisioning services identified for ocean beaches in the CLLMM region, centred on food from wild-caught animals. Those fisheries support both recreational and commercial activities, contributing to local livelihoods while also supplying interstate and export markets (Ferguson et al., 2023). The prominence of fisheries in the review reflects both their economic importance and the fact that they are routinely monitored and regulated (Lopez-Rivas & Cardenas, 2024).

Two species of particular importance are pipis (*Latona deltoides*) and mullet (*Argyrosomus japonicus*). Research on pipi populations at Goolwa Beach extends back several decades and includes repeated assessments of abundance, recruitment, size structure, and responses to harvesting pressure (King, 1985; McLachlan et al., 1996). These studies underpin contemporary fisheries management and represent some of the longest continuous datasets directly linked to beach environments in the region (Ferguson et al., 2023). Mullet also feature prominently, particularly in studies examining the role of the Murray Mouth and adjacent surf zones in spawning and recruitment (Ferguson et al., 2014). Several studies have explored links

between freshwater flows, estuarine conditions, and mullock recruitment success, highlighting the importance of connectivity between river, estuary, and ocean systems (Loneragan, 1999; Ferguson et al., 2008). While framed primarily in fisheries terms, this body of work also provides insight into how beach environments contribute to broader ecological processes, particularly through their role as nursery and feeding habitats.

The literature also highlights pressures that can affect fisheries and provisioning services. Overharvesting is the most commonly recognised, with the potential to reduce stock availability and alter population dynamics over time. Other pressures are less consistently considered, despite their potential influence. For example, vehicle use on beaches can cause direct mortality of intertidal organisms such as pipis through crushing impacts (Schlacher et al., 2008), while changes to estuarine flows can disrupt nutrient delivery and coastal productivity (Loneragan, 1999; Ferguson et al., 2008). At broader scales, climate-driven processes including ocean warming, marine heatwaves, and altered flow regimes may influence species distributions and productivity, with implications for the sustainability of these fisheries (Gillanders et al., 2011; Hobday et al., 2016; IPCC, 2022; Falkenberg et al., 2020).

5.2 Nursery habitats and species support as key regulating services

Regulation and maintenance services underpin how ocean beach ecosystems function, supporting processes such as habitat provision, nutrient cycling, and the maintenance of ecological communities (McLachlan & Defeo, 2017). Within the CLLMM literature, these services are most commonly represented through the role of ocean beaches and adjacent surf zones as nursery habitats for key species. Many fish and invertebrates depend on these environments during vulnerable early life stages, meaning that the condition of these habitats can have disproportionate effects on population dynamics and broader ecosystem functioning (Beck et al., 2001; Ferguson et al., 2014).

This emphasis is particularly evident for species of economic and ecological importance, such as mullock, which rely on the surf zone at the Murray Mouth as a critical spawning and nursery ground (Ferguson et al., 2014). As a result, regulating services are often framed in terms of their contribution to sustaining fisheries and supporting species persistence, reinforcing a close link between ecological processes and provisioning outcomes.

Across the literature, threats to these nursery functions are most frequently associated with direct human pressures. Disturbance from activities such as off-road vehicle use can degrade habitat quality and disrupt ecological processes (Davies et al., 2016), while overharvesting can reduce the reproductive capacity of species that depend on sandy beach environments (Ferguson et al., 2023). These pressures highlight the sensitivity of nursery habitats to localised impacts and the importance of maintaining habitat integrity to support both ecological resilience and the services these systems provide.

5.3 *Shorebirds as a focal system for understanding human disturbance*

Another major theme highlighted in the literature concerns shorebirds that use ocean beaches for feeding, resting, and breeding. Across the CLLMM literature, numerous studies document patterns of bird abundance, distribution, and behaviour, with particular emphasis on species that are highly sensitive to disturbance. These taxa can be used as indicators of ecological condition due to their reliance on dynamic beach habitats and their vulnerability during key life stages, particularly breeding and foraging periods (Jackson et al., 2024).

Across both regional studies and global syntheses, human disturbance is consistently identified as a major pressure affecting shorebirds. Activities such as off-road vehicle use, dog walking, and general recreational pressure are significant drivers of ecological impact. These disturbances can disrupt foraging behaviour, displace birds from preferred habitats, reduce breeding success, and in some cases cause direct mortality (Buick & Paton, 1989; Schlacher et al., 2013; Jones et al., 2015; Schlacher et al., 2024). Within the CLLMM region, such impacts are most frequently documented on accessible beaches, particularly Goolwa Beach, where repeated surveys and long-term observations have enabled detailed assessment of disturbance effects (Jones et al., 2015). In contrast, comparatively little is known about shorebird dynamics on more remote sections of the Younghusband Peninsula, highlighting a spatial bias in current knowledge.

5.4 *Cultural services centred on recreation and wildlife interactions*

Cultural ecosystem services associated with ocean beaches in the CLLMM region are most commonly framed through recreation and interactions with wildlife. Beaches are widely recognised as important spaces for leisure, tourism, and everyday social activities, contributing to physical health, psychological wellbeing, and community identity (Harvey & Caton, 2003; Martin et al., 2016). Within the reviewed literature, these benefits are most often discussed in relation to accessible coastal areas where recreational use is concentrated, reinforcing the role of ocean beaches as key “blue spaces” that support human wellbeing.

A notable feature of this body of work is the connection between cultural services and ecological values, particularly through wildlife experiences. Shorebirds, in addition to their ecological importance, contribute to cultural services by supporting activities such as wildlife observation and nature appreciation (Ruíz-Luna et al., 2025). Some studies that document human disturbance to shorebirds also address impacts on cultural services, as disruptions to bird populations can diminish opportunities for people to engage with and appreciate coastal wildlife (Marasinghe et al., 2020).

Taken together, these findings show how different ecosystem services of ocean beach ecosystems such as in the CLLMM region are linked to a range of threats across the literature. Table 1 provides a summary of these relationships, highlighting how frequently different services and threats are considered together.

Table 1. Summary of how the three key ecosystem service sections provided by ocean beaches are linked to seven different threats in the CLMM literature.

SECTION	CLASS (ECOSYSTEM SERVICE)	THREAT							Total occurrences	Unique documents
		Catchment impacts	Climate change	Human disturbance	Invasive species	Overharvesting	Pollution	Unspecified		
Provisioning	Animals reared by in-situ aquaculture for nutritional purposes								0	0
	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition or materials								0	0
	Wild animals (terrestrial and aquatic) used for nutrition, direct use, or processing								30	26
	Seeds, spores and other plant materials collected for maintaining or establishing a population								0	0
	Animal material collected for the purposes of maintaining or establishing a population								0	0
	Surface and marine water for drinking, material use, and energy								0	0
	Ground (and subsurface) water for drinking								0	0
	Mineral substances used for nutritional or material purposes								1	1
	Non-mineral resources used for nutritional or material purposes, or solar energy								1	1
Total Provisioning Ecosystem Services		3	0	1	0	24	2	2	32	
Regulation & Maintenance	Bioremediation and filtration/storage by organisms								8	8
	Smell reduction, noise attenuation and visual screening								0	0
	Regulation of erosion and water flows								9	9
	Maintenance of nursery populations and habitats, including dispersal functions								48	44
	Biological regulation of soil quality and structure								1	1
	Regulation of the chemical condition of salt waters by living processes								2	2
	Regulation of atmospheric, oceanic, and climate conditions								2	2
	Water quality regulation								7	7
	Mediation of nuisances by abiotic structures or processes								0	0
	Abiotic regulation of mass, liquid, or gaseous flows								0	0
	Maintenance and regulation by inorganic natural chemical and physical processes								1	1
	Other: Seed, larval and gamete dispersal by physical processes								0	0
Total Regulation & Maintenance Ecosystem Services		10	6	28	11	14	2	7	78	
Cultural	Characteristics of living systems that enable nature-based interactions that support health and well-being								11	10
	Characteristics of living systems that hold scientific, educational, cultural, and aesthetic value								10	8
	Elements of living systems that enable symbolic, spiritual, and place-based cultural value								2	1
	Elements of living systems that enable contemporary or inter-generational values								7	7
	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions								6	6
	Natural, abiotic characteristics of nature that enable intellectual interactions								0	0
	Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions								1	1
	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value								0	0
Total Cultural Ecosystem Services		5	1	19	1	8	0	3	37	
Total occurrences		18	7	48	12	46	4	12		
Documents per threat		9	4	25	6	22	4	12		

6 Beaches as part of a connected system

A consistent theme across the literature is that ocean beaches in the CLLMM region form part of a broader, interconnected system linking the River Murray, the Lower Lakes, the Murray Mouth, and the Southern Ocean. Many studies recognise that factors such as freshwater flows, mouth openness, and estuarine conditions influence coastal productivity, fish movement, and the structure of nearshore habitats (Loneragan, 1999; Ferguson et al., 2008; 2014). In this way, ocean beaches are closely tied to processes occurring both upstream and offshore and are best understood with context from the wider coastal system.

This connectivity is particularly important in the CLLMM region, where the Murray Mouth acts as a key point of exchange between freshwater, estuarine, and marine environments. Changes in river discharge, for example, can influence nutrient inputs, sediment movement, and salinity gradients, with downstream effects on beach environments and the species that use them (Loneragan, 1999; Ferguson et al., 2008; Bourman et al., 2019). These linkages mean that pressures acting in one part of the system, such as altered flow regimes or catchment inputs, may have consequences for ocean beaches that are not immediately visible at the local scale.

While these connections are widely acknowledged, they are most often described in general terms. They are less commonly examined in ways that allow the condition of ocean beaches themselves to be clearly assessed or tracked over time (Defeo et al., 2009). As a result, beaches are often treated as transitional environments that reflect broader processes, rather than as systems with their own measurable characteristics and pressures (Brown & McLachlan, 2010). Strengthening understanding of these connections, while also recognising beaches as distinct components of a system, is an important step toward improving how they are monitored and managed.

7 What the literature did not capture well

7.1 *Non-harvest threats to provisioning services*

While overharvesting was consistently identified as the primary threat to provisioning services in the CLLMM region, other pressures that may substantially influence fishery productivity and sustainability, such as human disturbance and climate change, were rarely considered in the reviewed literature. This limited attention risks overlooking key processes that affect the availability of species such as pipis and mullet, both of which underpin local fisheries, potentially leading to management approaches that address harvesting pressure without accounting for other factors influencing stock sustainability.

Human disturbance, particularly from off-road vehicle use, is an underrepresented threat. Vehicle traffic on beaches can cause significant mortality of intertidal invertebrates through direct crushing, with documented impacts on pipi populations (Schlachter et al., 2008). It can also degrade habitat structure and reduce invertebrate diversity and density (Davies et al., 2016). Despite this, these effects were seldom linked to provisioning services within the CLLMM literature, even though reductions in these populations have clear implications for fishery yields and ecosystem productivity.

At broader spatial scales, alterations to estuarine flow regimes can also influence provisioning services by modifying the delivery of nutrients that support coastal food webs (Loneragan, 1999; Ferguson et al., 2008). Changes associated with the management of the River Murray barrages may affect both the timing and magnitude of freshwater inputs, with consequences for fish productivity in the surf zone and the habitats that support early life stages of key species. In addition, excessive or poorly timed flows can transport nutrients from upstream agricultural areas, contributing to declines in water quality and act as a form of pollution (Carpenter et al., 1998).

Climate change introduces additional risks to provisioning services that remain largely unrepresented in the literature. Processes such as ocean warming, marine heatwaves, ocean acidification, and reduced estuarine flows are expected to alter species distributions, reduce productivity, and increase the vulnerability of fisheries to overexploitation (Gillanders et al., 2011; Hobday et al., 2016; Pörtner & Peck, 2010; Falkenberg et al., 2020). These changes have direct implications for the reliability of provisioning services and the communities that depend on them.

Provisioning services in the CLLMM region are likely influenced by a broader suite of interacting pressures than is currently reflected in the literature. Expanding future research to more fully consider non-harvest threats will be essential for understanding and managing the long-term sustainability of ocean beach fisheries and other forms of provisioning services.

7.2 *Broader regulating processes*

While the reviewed literature frequently recognised regulation and maintenance services, this was largely framed through biologically visible functions, particularly the role of ocean beaches as nursery habitats for key species. In contrast, many broader physical and ecological processes underpinning these systems received comparatively little attention. This creates an incomplete picture of how ocean beach ecosystems operate and the services they provide.

Processes such as erosion control and water flow regulation, including how water moves from the land to the coast, are fundamental to maintaining beach structure and productivity (Brauman et al., 2007). In the CLLMM region, these processes are especially important given the strong influence of river discharge and catchment inputs on coastal morphology and nutrient dynamics (Thom et al., 2020). However, these regulating functions were rarely explicitly linked to ocean beaches in the reviewed literature, despite their central role in shaping these systems.

Regulating services that buffer environmental extremes are also becoming increasingly important under climate change. Functions such as dune stability and sediment movement help maintain shoreline integrity and support ecosystem resilience in the face of storms, floods, and marine heatwaves (Defeo et al., 2009; Everard et al., 2010; Barbier et al., 2011). In the CLLMM region, the ocean beach dune system is undergoing long-term geomorphic change, with foredunes retreating landward in response to shifting sediment dynamics and rising sea levels (DaSilva et al., 2024). Projected sea-level rise is expected to further alter shoreline configuration across sandy coastlines globally (Odériz et al., 2022), with direct implications for the width of beaches, how sand is gained or lost, and the ability of ecological communities to persist over time.

Despite their importance, these broader regulating processes were seldom a focus of the literature and were rarely connected to the ecosystem services framework. As a result, key functions that support the long-term stability and resilience of ocean beach systems remain underrepresented. Addressing this gap will be important for developing a more complete understanding of how these ecosystems function, and how their capacity to provide services may change under increasing environmental pressure.

7.3 *Cultural services beyond recreation*

Although cultural services were recognised in the reviewed literature, they were most often framed through recreation and wildlife interactions, particularly those involving shorebirds. This emphasis likely reflects that these values are the easiest to observe and measure - visitor numbers, activity types, and popular access points can all be tracked in ways that spiritual, emotional, or heritage-based values cannot. As a result, the literature captures only a subset of the cultural benefits that ocean beach ecosystems provide.

Other dimensions of cultural services are harder to observe but no less real. Sense of place, heritage, and the broader social and emotional connections people have with coastal environments were rarely documented in the CLLMM literature. This is a pattern seen across the broader ecosystem services literature, where cultural and spiritual values are consistently harder to capture than material or visitation-based benefits, as they resist the kind of straightforward measurement that recreational activity allows (Granek et al., 2010). This is a significant gap: beaches are understood to hold deep spiritual, aesthetic, and cultural significance around the world (McLachlan & Defeo, 2023). This significance is well established in the Australian context specifically, where beaches have long been tied to national identity and community life (Harvey & Caton, 2003; Voyer et al., 2013; Ellison & Hawkes, 2016). Coastal environments have also been shown to support personal and community wellbeing in ways that are relational and experiential rather than purely material, meaning their value cannot be captured through recreational visitation figures alone (Fudge et al., 2023). By concentrating primarily on recreational use, the literature risks overlooking less visible but equally important ways in which people value and relate to these environments.

Threats to cultural services were also unevenly represented. Human disturbance, particularly through its impacts on shorebirds, was the most frequently documented pressure. While this highlights an important link between the health of the environment and cultural value, other threats with clear implications for cultural services were not often considered. For example, declines in water quality and changes to beach condition driven by pollution can reduce the suitability of beaches for recreation and tourism (Schuhmann et al., 2019; Furey et al., 2022). Similarly, climate change is increasingly affecting cultural values on coasts globally, including the loss of coastal heritage sites due to sea-level rise (Reimann et al., 2018). Even studies that do capture the broader social and cultural values of beaches, such as Voyer et al., (2013), tend to focus on a narrower set of threats, typically overdevelopment, illegal fishing, and conflict between user groups, rather than the full range of pressures that can affect cultural value.

Despite these broader pressures, the extent to which they are reshaping cultural services in the CLLMM region remains poorly understood. This suggests that changes to how people experience and value ocean beaches may be occurring without being systematically documented. Broadening research to better capture these less visible but important cultural values will be important for understanding the full value of ocean beach ecosystems and how that value may shift under future environmental change.

7.4 First Nations perspectives

First Nations connections between people and ocean beach environments in the CLLMM region are strong and ongoing. For the Ngarrindjeri and other First Nations peoples, these coastal areas are not just places where resources are used, but are sites deeply connected to culture, identity, sense of responsibility, and relationships

with Country (Ngarrindjeri Nation Yarlurwar-Ruwe Plan, 2007). However, perspectives of First Nations people were largely absent from the literature reviewed.

While some of the reviewed literature mentioned cultural values, they rarely made clear links between these values and the benefits provided by ocean beaches. This is especially noticeable for species such as pipis, which are often discussed as an important recreational and commercial fishery resource, but are also a traditional food for First Nations peoples. Their importance goes beyond nutrition, playing a role in cultural practices and community life, as shown by the many shell middens (accumulations of shells and other materials left behind from long-term harvesting and use over thousands of years) found across the Coorong and Murray Mouth (Clarke, 1994; Clarke, 2002).

The limited representation points to a broader issue in how the literature describes the value of ocean beaches. Much of the focus has been on economic uses and recreation, which can overlook other important ways or knowledge systems that could strengthen our understanding and management of these environments. It is important to note that this gap may partly stem from the ecosystem services framing itself, which centres benefits to people and can be poorly suited to capturing Indigenous and other nonmaterial values (Gould et al., 2025; Swiderska et al., 2025). Swiderska et al. (2025) describe a value of “under nature”, the notion that all decisions are governed by nature, analogous to the Aboriginal notion of “Country” that in a simplistic definition acknowledges the interrelationship between all living entities and their inherent responsibility for caring for land, water and skies. This holistic notion is difficult to address using traditional approaches and will require approaches that go beyond the literature reviewed here and are centred on direct engagement with appropriate First Nations knowledge holders.

Greater inclusion of First Nations perspectives would help provide a more complete understanding of ocean beach ecosystems such as the CLLMM region. This includes recognising cultural connections alongside other benefits and supporting approaches that involve and learn from First Nations knowledge and caring for Country.

7.5 Interacting and cumulative threats

The reviewed literature largely considered threats to ocean beach ecosystems in isolation, with relatively little attention given to how multiple pressures may interact. In reality, ecosystems are rarely affected by a single pressure. Instead, changes often result from several pressures occurring at the same time, which can combine and amplify their impacts. This is particularly important under climate change, where factors such as warming ocean temperatures, altered flow regimes, nutrient inputs, and human use of beaches increasingly overlap. Considering these pressures separately may not fully capture how ocean beach ecosystems respond to real-world conditions, where their combined effects can be difficult to predict.

A recent harmful algal bloom (HAB) event in South Australia provides a useful example of how these interactions can play out, although it is important to note that this event is very recent and would not yet be captured in the literature reviewed here. Since

March 2025, the bloom has affected around 20,000 km² of coastal waters and has been linked to widespread mortality across hundreds of marine species (Government of South Australia, 2025; Murray et al., 2025). The event has been associated with a combination of conditions, including elevated sea surface temperatures linked to marine heatwaves and increased nutrient inputs from catchment runoff and coastal upwellings. Together, these factors appear to have created conditions that allowed the bloom to develop and persist.

Beyond ecological impacts, such events can also affect economic and cultural values. Beach closures and declines in environmental quality can disrupt fisheries, tourism, and recreational use, while also reducing the wellbeing benefits people derive from coastal environments. Experiences typically associated with enjoyment and connection to nature may instead become linked to avoidance or concern. As climate change is expected to increase the frequency and severity of episodic events such as marine heatwaves and HABs, these types of disruptions may become more common.

Despite these risks, the reviewed literature for the CLLMM region rarely examined how multiple threats combine or how their impacts may change over time. Addressing this gap will be important for developing a more realistic understanding of ocean beach ecosystems and for supporting management approaches that can respond to complex and changing conditions.

8 Spatial patterns of values and use (PPGIS)

A public participation geographic system (PPGIS) study was conducted to provide spatially explicit data related to how people use different areas within the CLLMM area, the values they associate with different places, and where the areas of greatest concern are located. This section begins with an overview of respondents to allow the reader to understand the diversity of participants who completed the survey. It then discusses the activities people participate in, with special attention to four-wheel driving. Values, motivations and benefits respondents associate with their experience in this region are discussed, as are special places they associate with the area. The section concludes with results related to threats and preferred management strategies as perceived by respondents.

8.1 Overview of Participants

A total of 201 participants completed the survey. The sample was reasonably evenly balanced between female (43.2%) and male (47.9%) participants, with the remainder (8.9%) comprising people who identified as non-binary or preferred not to identify their gender. The average age of participants was 56 years (range 20-86 years). A total of 41% of participants were from Victoria and 59% from South Australia. Of the South Australian respondents, 14% indicated their primary residential address was a postcode within the study area. The source of respondents is presented as Figure 3. The most common group types were partners (25.9%) and families (27.9%), with solo visitors (15.4%), groups comprising families and friends (15.9%), organised groups (10.4%) and groups of friends (4.5%) making up the remainder.

Respondents' postcodes:

- A. Adelaide metro
- B. Melbourne metro
- C. SA/VIC overview

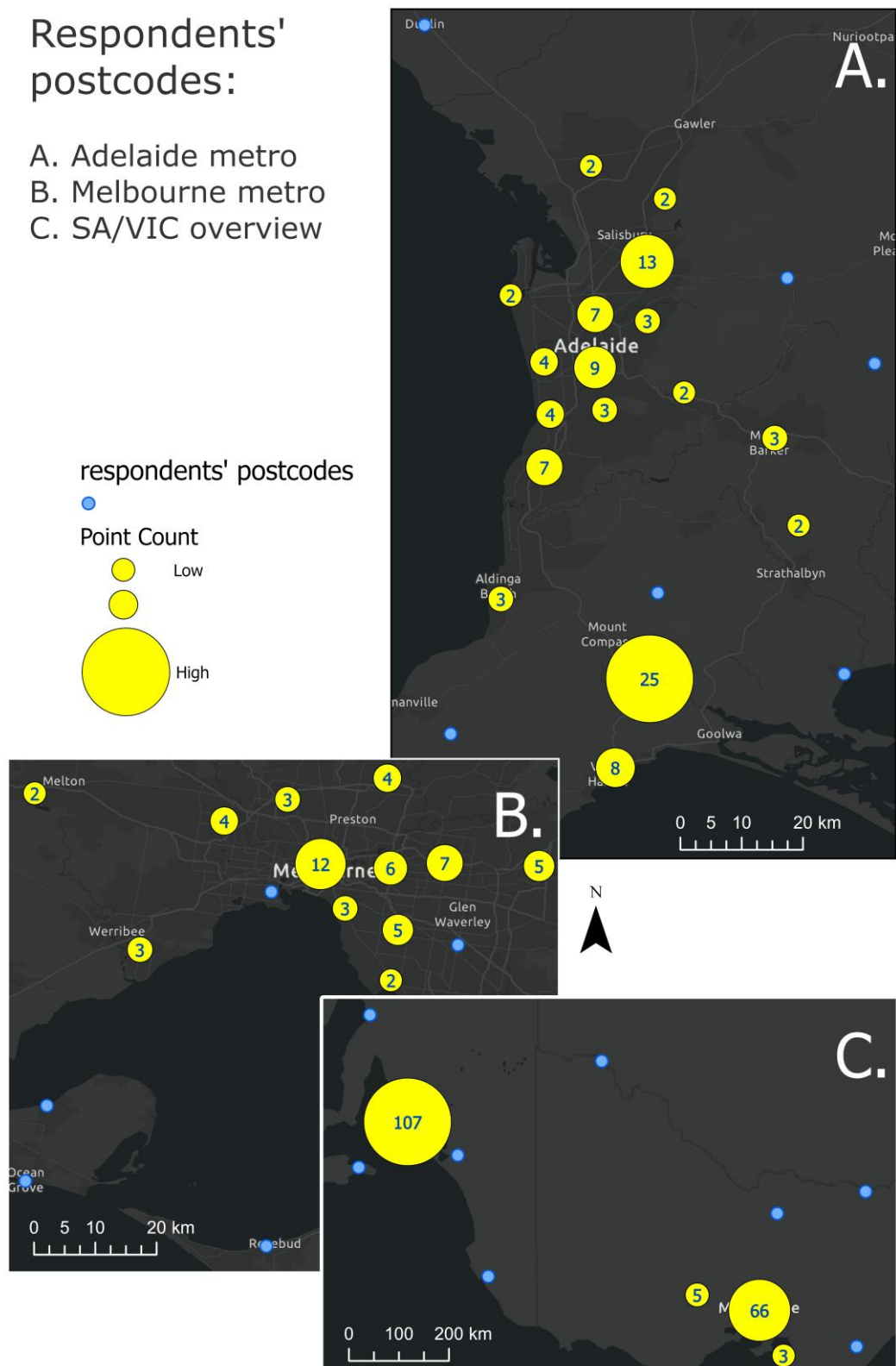


Figure 3. Analysis of postcodes indicating residential address of respondents (number of respondents from each area is indicted within the yellow circles).

Respondents were asked to indicate where they believed their value system lay in relation to the protection of ocean beaches in the region using the spectrum below (Figure 4).



Figure 4. Values Spectrum

Results presented in Table 2 show that almost half of the participants believe there should be a balance between conservation and recreation, and the remainder are skewed towards the conservation/preservation end of the spectrum. What is clear from the results is the participants tended not to be extreme in their views related to ocean protection with only three (1.5%) of participants believing access should be the highest priority. Even when considering the 42.6% of participants who indicated their values aligned in the area between a balance and the biocentric end point, two thirds (67.8%) did not consider conservation and nature preservation as the very highest priority. This suggests the sample was quite balanced in terms of perspectives on conservation.

Table 2: Conservation values of respondents (n=197)

SPECTRUM	PERCENT
1. Access and Recreation Highest Priority	1.5
2.	2.0
3.	6.6
4. Balance of Conservation and Recreation	47.2
5.	14.7
6.	14.2
7. Conservation and nature preservation highest priority	13.7

Figure 5 shows that there was a range in the frequency with which respondents accessed the CLLMM beaches. While almost one quarter of respondents reported visiting frequently throughout any year, 46% of respondents visited only twice per year or less. This is unsurprising considering the distances many of the respondents travelled to visit the site. The fact that only 2% of visitors suggested they visited frequently but avoided summers, suggests that crowding (exceeding social carrying capacity) is not an issue at this point in time, but it is always challenging to determine if visitor displacement as a result of perceived crowding has already occurred.

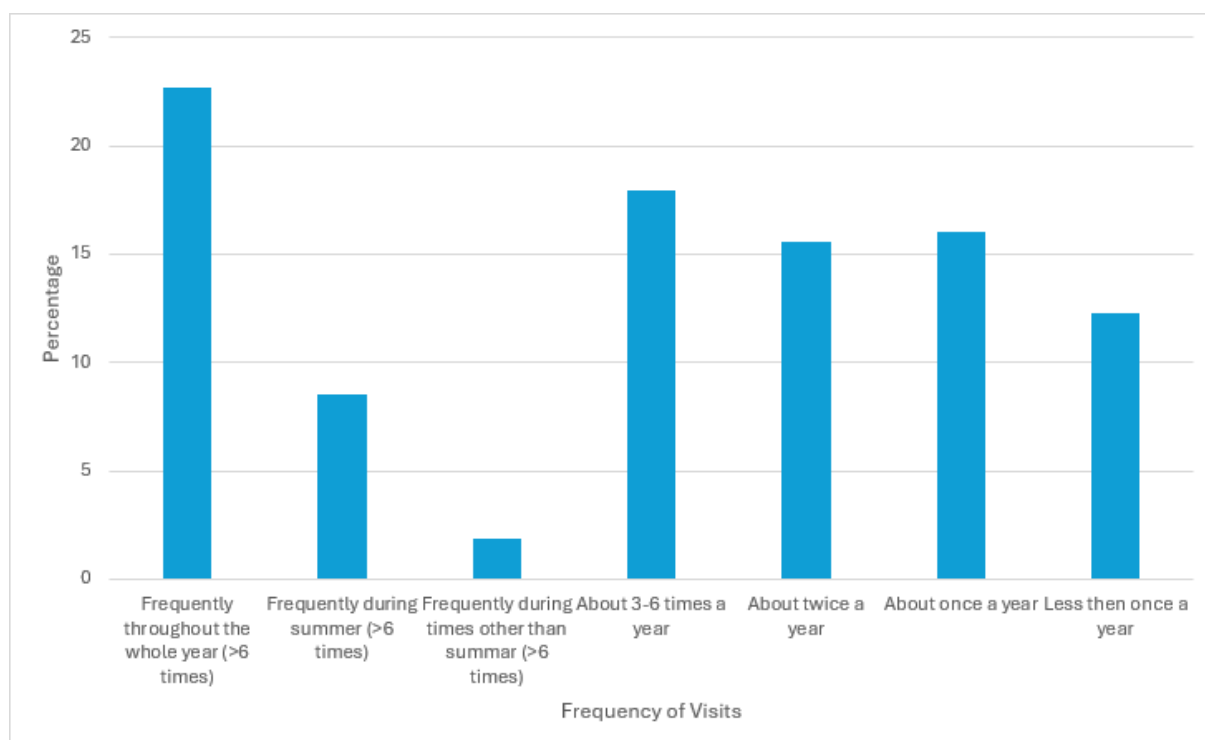


Figure 5. Frequency of visits to the ocean beaches in the CLLMM region as reported by respondents (n=201)

8.2 Activities

Respondents participated in a diversity of activities (Figure 6). The most popular activities were walking, swimming and picnicking. Many people also participated in four-wheel driving, photography, fishing and birdwatching. There was greater participation in land-based activities (shown on left) than water-based activities (right side) amongst respondents.

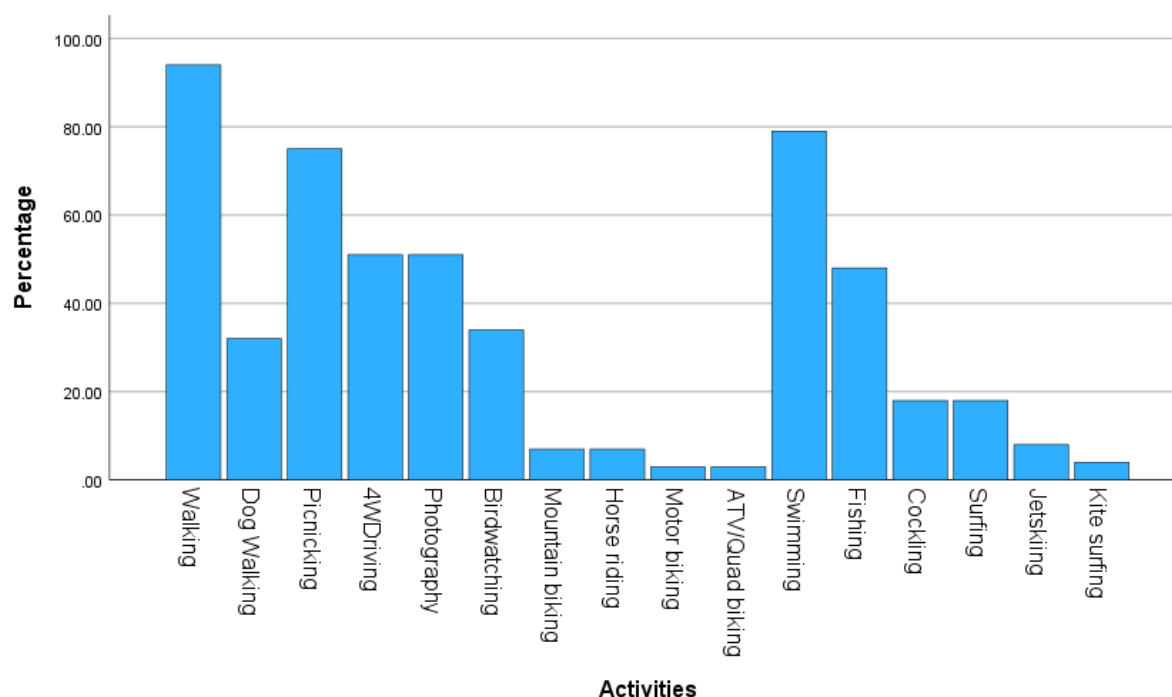


Figure 6. Percentage of respondents participating in land-based (left side) and water-based activities (right side) in the study region.

Additional activities that were noted but not included were sailing, camping, knee-boarding, beach sports, sandcastle building, wooden boat activities, visiting for inspiration for artwork, weeding, cleaning up rubbish, and rescuing 4WD drivers. A total of 8% of respondents were involved in at least one of these activities.

A series of heat maps were devised to indicate the areas in the study site that people were using for particular activities. These are presented as Figure 7a – f.

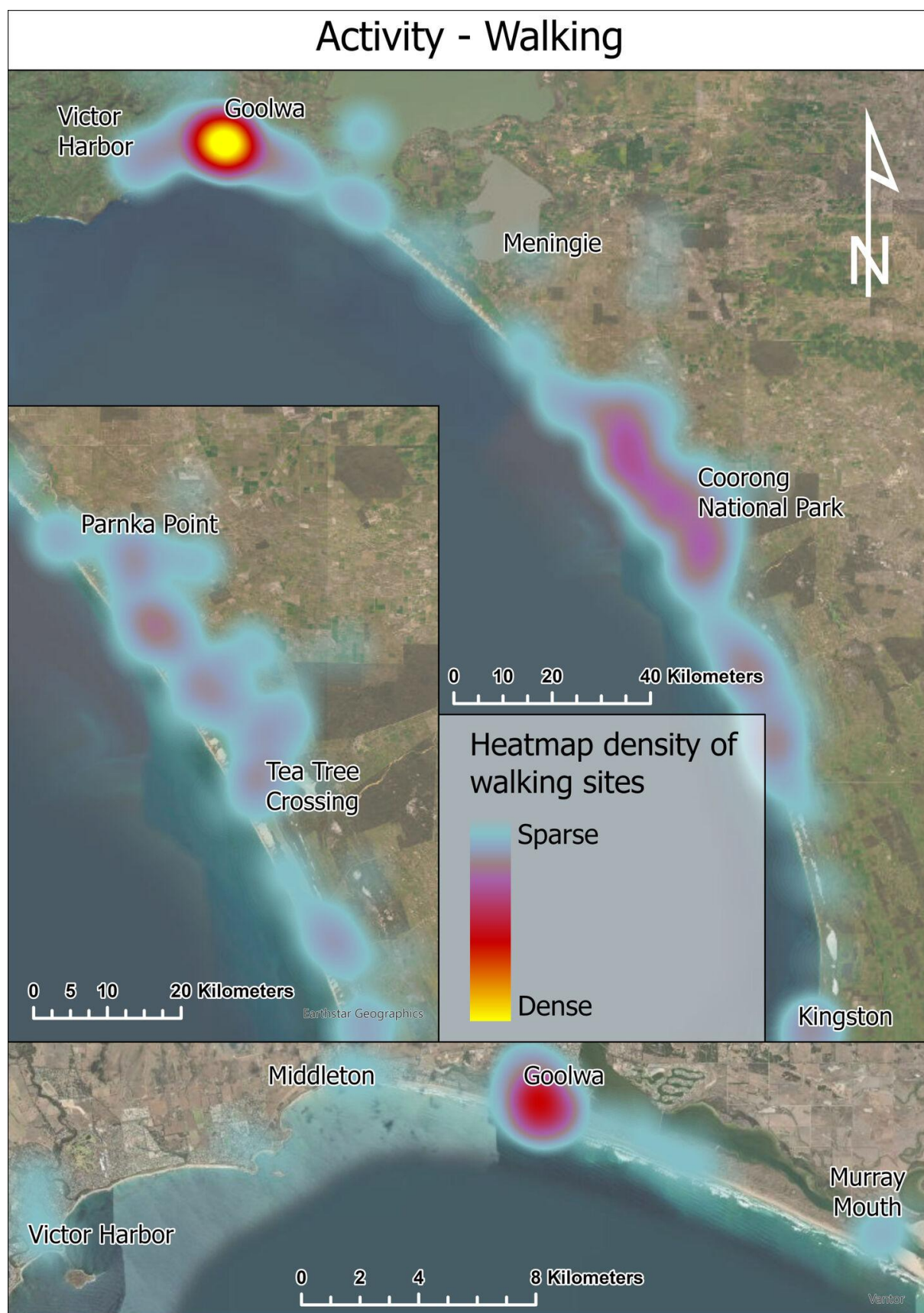


Figure 7a. Heat map of walking use patterns

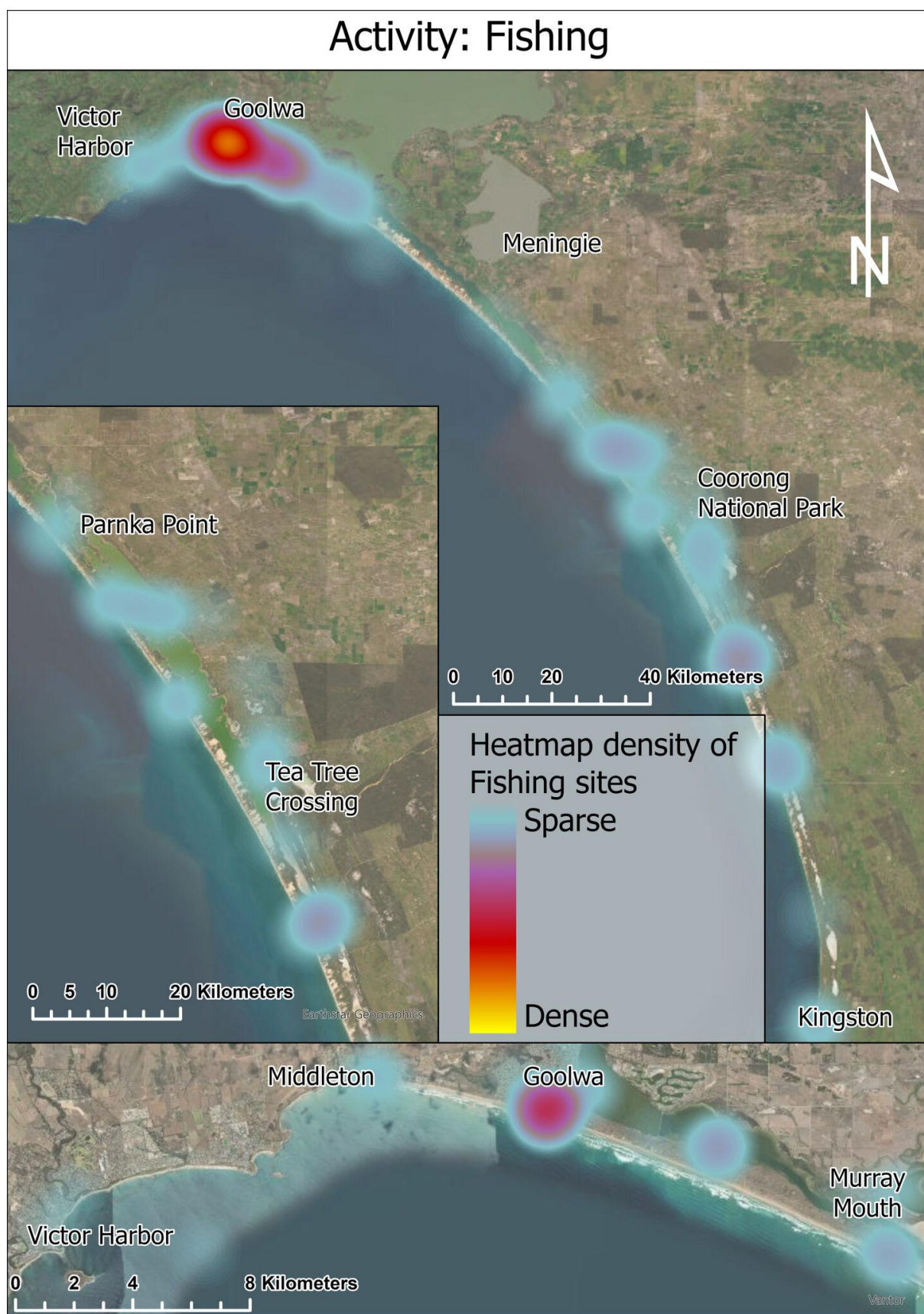


Figure 7b. Heat map of fishing use patterns

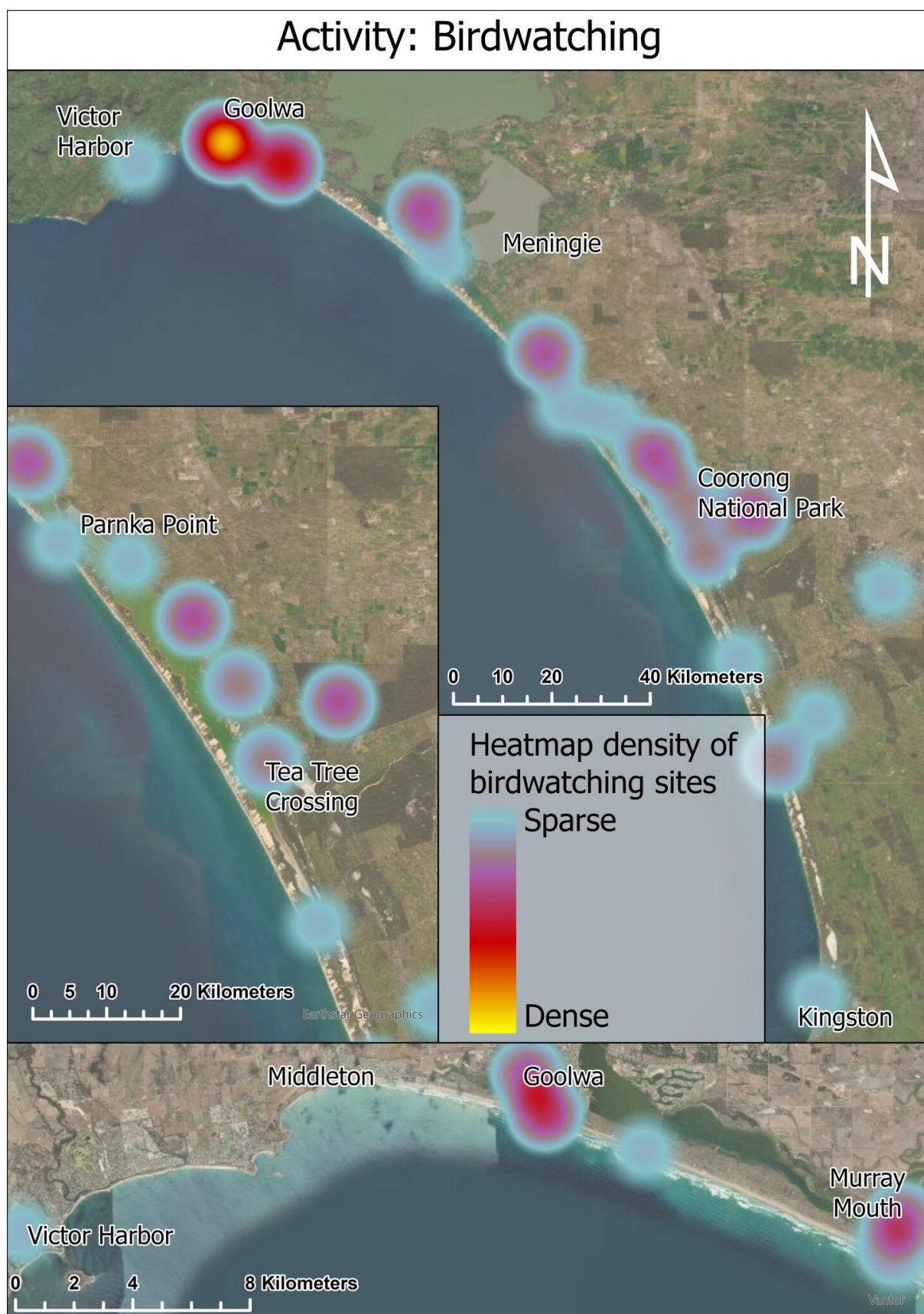


Figure 7c. Heat map of birdwatching use patterns

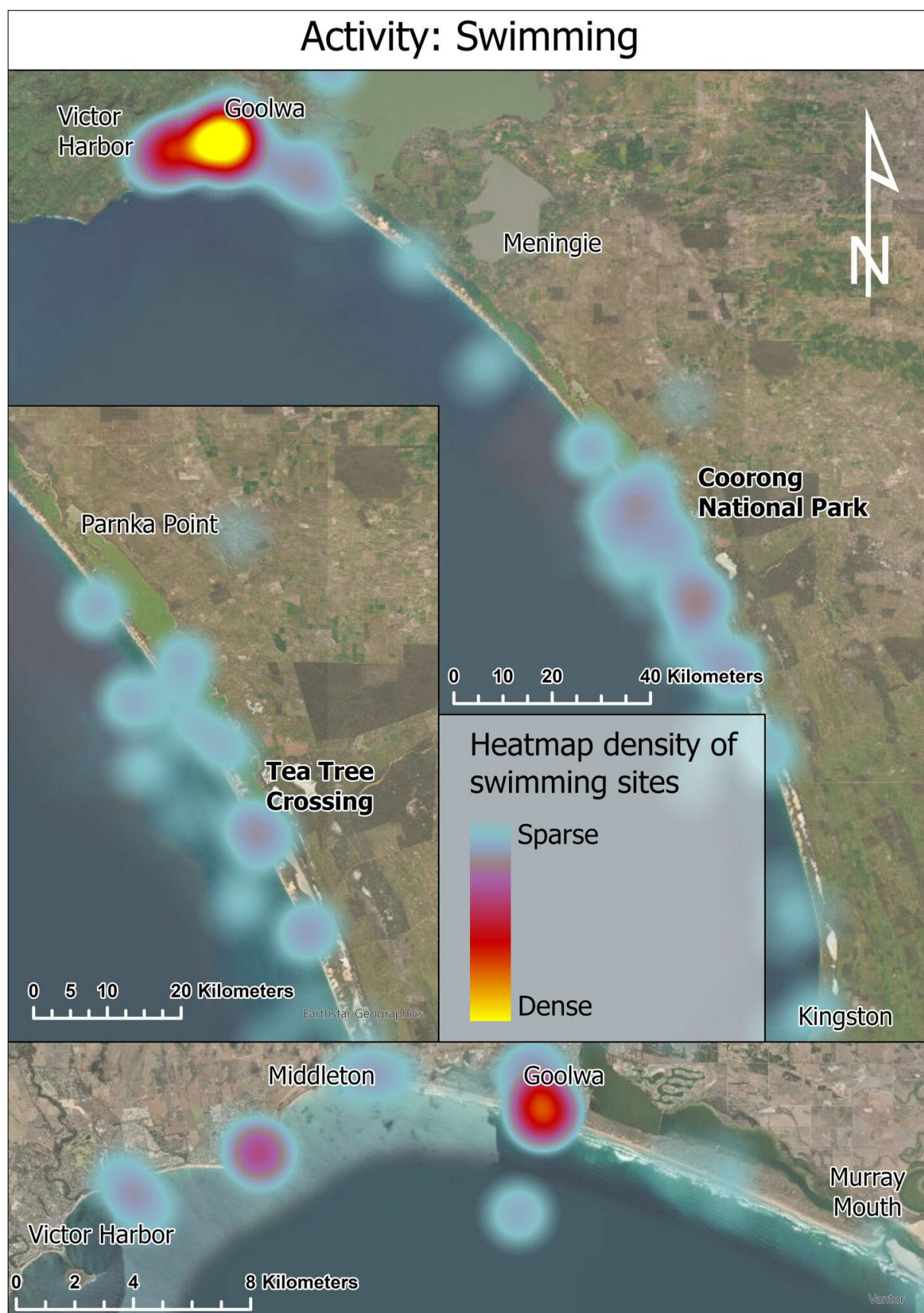


Figure 7d. Heat map of swimming use patterns

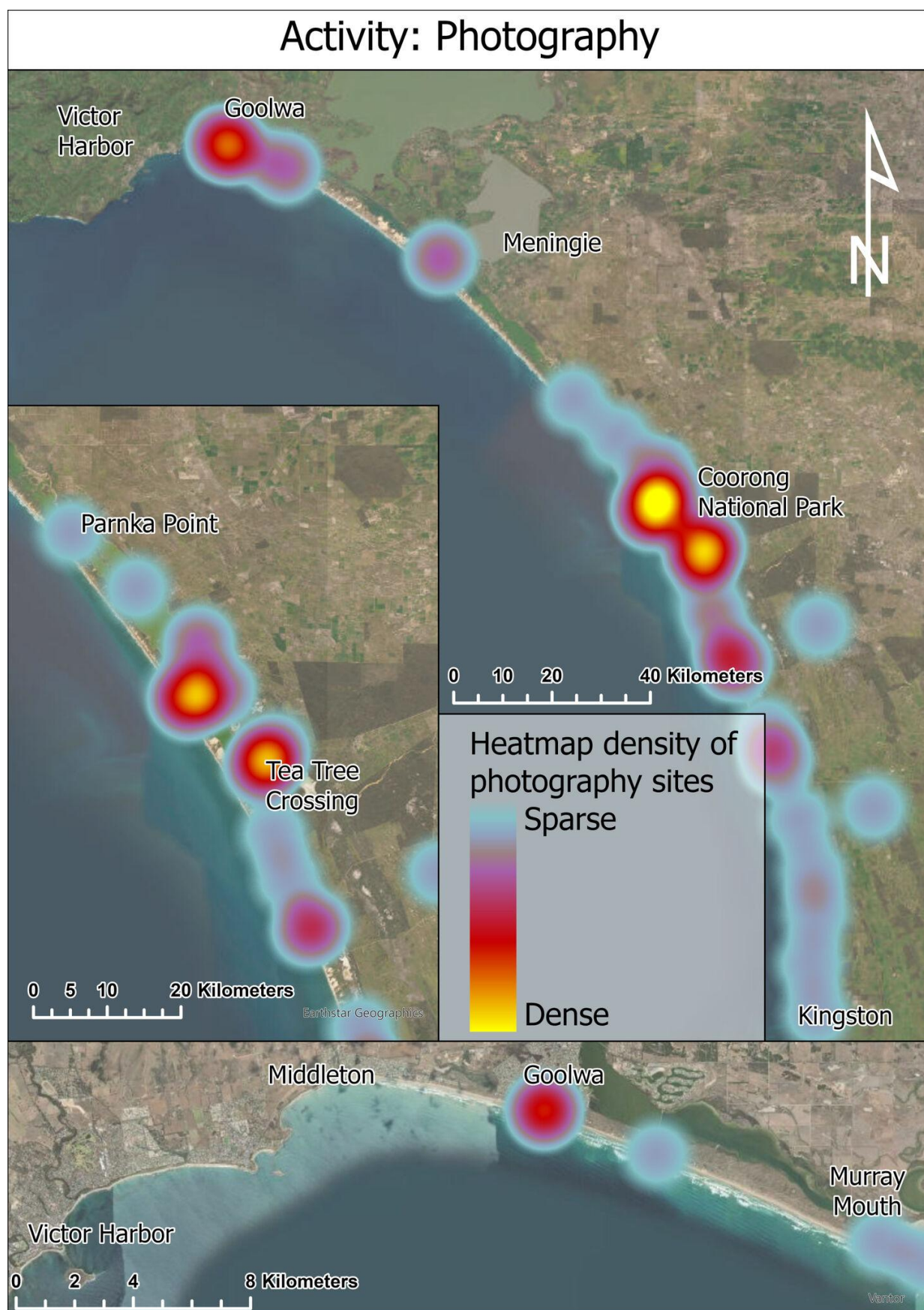


Figure 7e: Heat map of photography use patterns

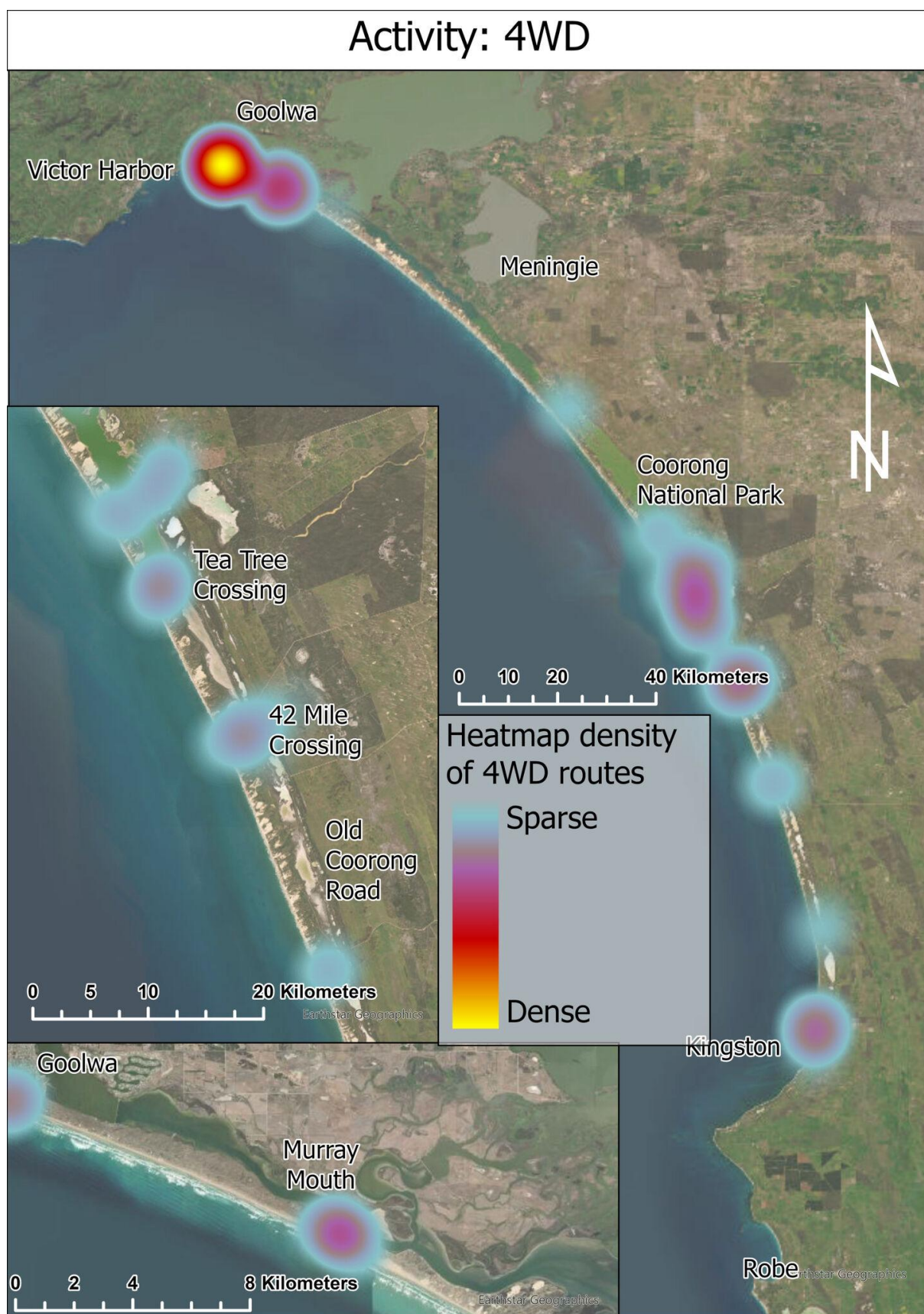


Figure 7f. Heat map of 4WD use patterns

A total of 199 people responded to a question “do you usually drive (or sit in a car that someone else is driving) on the beach when you visit the beach in the CLLMM region, with 38.7% (n=77) responding that they did drive on these beaches (the remaining 61.3% said they did not drive on the beach). Figure 8 shows the most frequented four-wheel drive routes in the study area, along with the percentage of drivers using those routes.

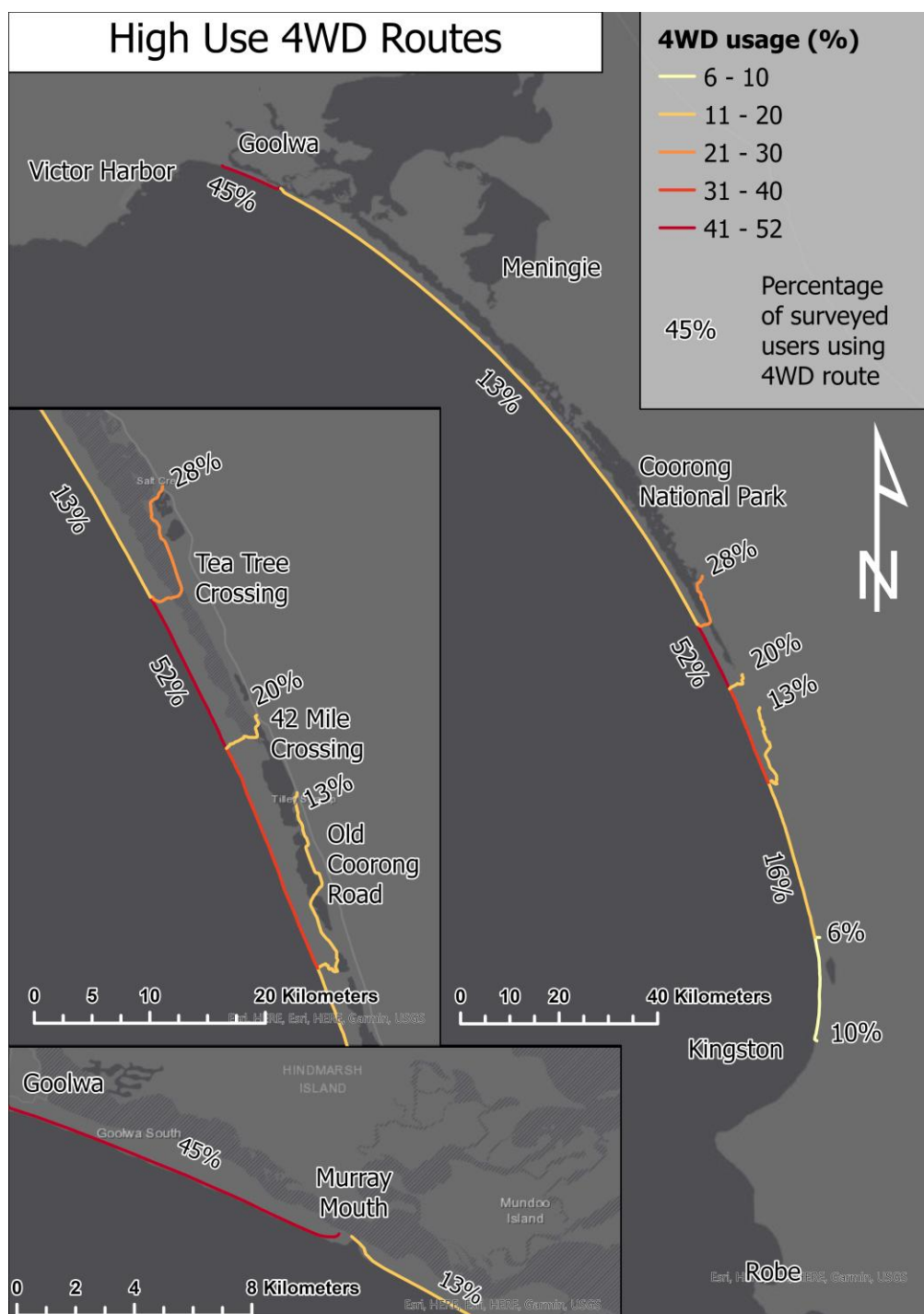


Figure 7. Common Four-Wheel Drive Routes in the Study Area and percentage of respondents driving those routes.

Figure 8 shows that two beach sections of the region are particularly popular for interview respondents. One is the section between Tea Tree Crossing and south of 42 Mile Crossing Old Coorong Road. The other was the section between Goolwa and the Murray Mouth. National Parks and Wildlife Service South Australia list 42 Mile Crossing as the safest, most popular access point for driving along the beach and a variety of internet sites list the area south of this point as one of the most scenic stretches of the Coorong. It is also a section that allows camping. The national attention related to the Murray River combined with human propensity to enjoy travelling to “superlative” destinations (e.g. source and mouth of a river, highest peak, oldest city, longest trail etc) readily explain the attraction of driving to the Murray Mouth. The other routes are likely influenced by practical constraints such as time availability, daylight hours, and tide conditions, for example, people driving about an hour from the access point or timing their trip around low tide.

Those participating in four-wheel driving were questioned about their motivation for driving. While the literature review noted limited research attention to cultural services such as social and emotional connections, this study found enjoying time with family and friends is very important to many respondents (Table 9). Respondents were asked to rank the three most important motivations for driving, which are colour coded below as primary, secondary and tertiary motivations. The novelty of being able to four-wheel drive in such a location and the sense of adventure as well as the opportunity to test and develop new skills are also very important motivations to many visitors to the area (Table 9).

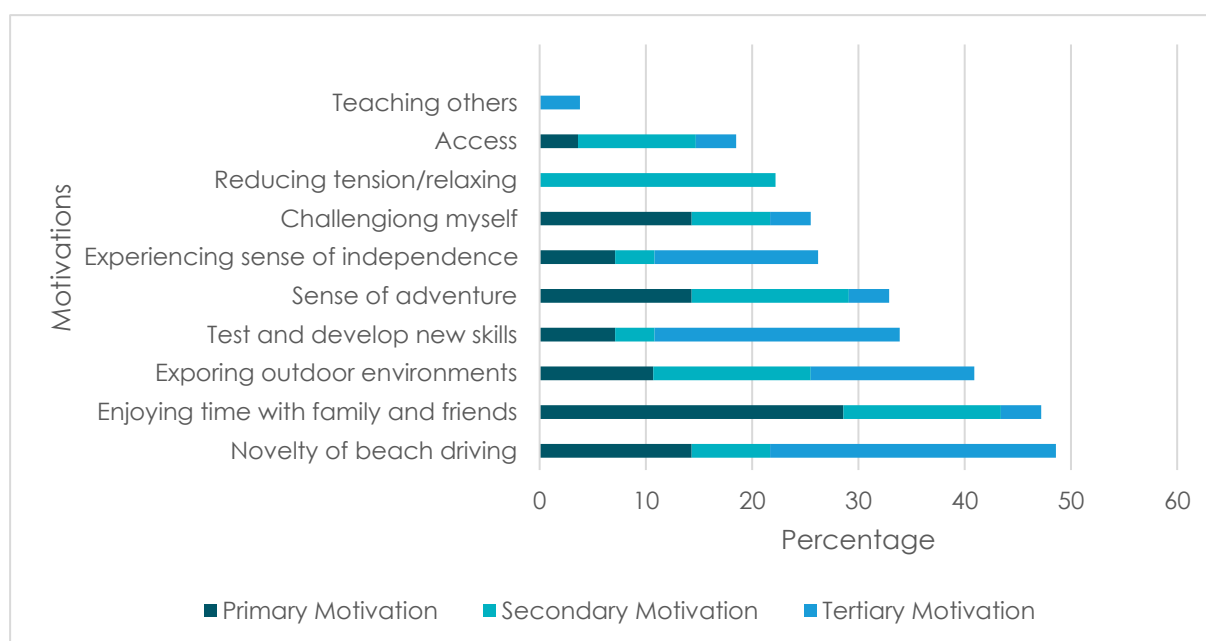


Figure 8. Primary Motivations for Sand Driving on beaches within the CLMM region (as a percentage, n=28)

The self-perceived sand driving skills of respondents are shown in Figure 10. A total of 72 respondents indicated they drove on the sand with the largest cohort (40.3%) considering themselves “competent and able to navigate most situations”. A further

third considering themselves only fairly competent (27.8%) or a novice (5.6%), with the final quarter (26.4%) considering themselves “very experienced to expert”.

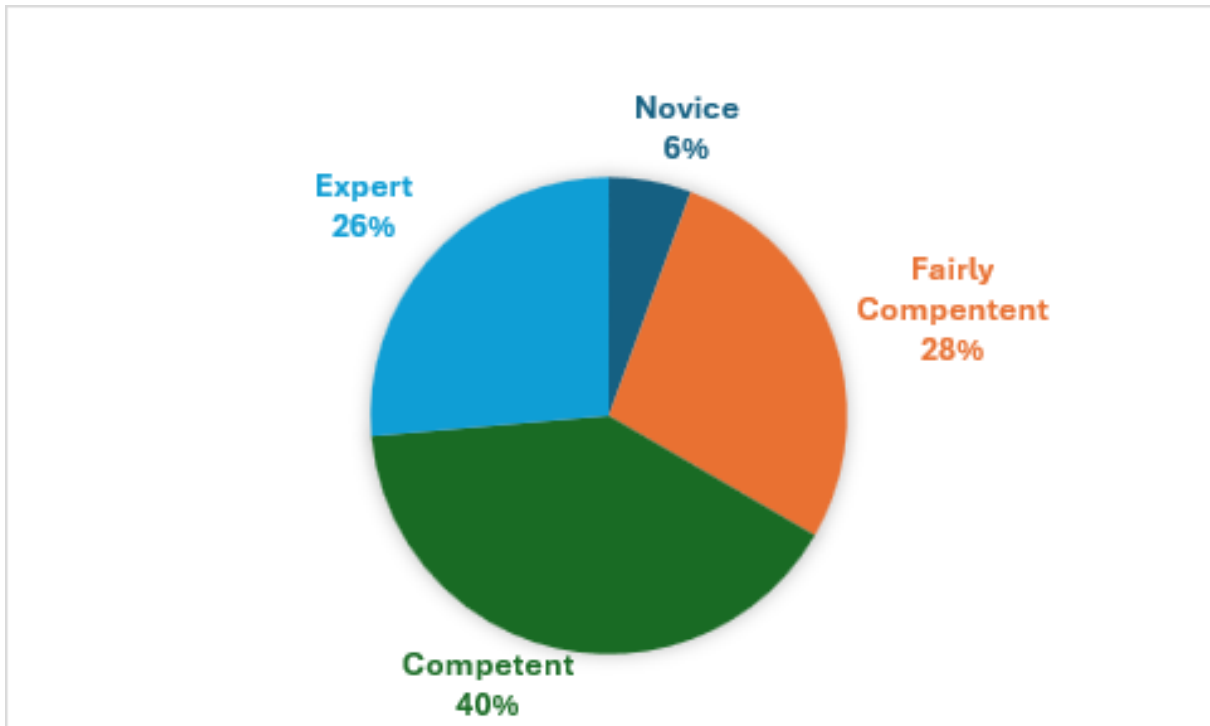


Figure 9. Self-perceived skill level of Four Wheel Drivers in the CLLMM Study area (n=28).

Of those 4WD driving, a total of 28 respondents indicated their “driving style” with many indicating they drove to minimise environmental damage (28.6%), with some noting sometimes that was difficult to assess. Almost one third (32.1%) said they drove to “maximise enjoyment” and a further quarter (25.0%) said they used the most direct route. The remaining 14.3% suggested they used a combination of the above.

8.3 Values, Motivations, and Benefits

The Coorong is renowned for its long stretches of wild coastline so it is not surprising that scenery was the dominant value visitors associate with this landscape. A total of 93.8% of participants listed scenery/aesthetics as one of their top values (Figure 11). Figure 11 highlights that spending time with family and friends was also very important to most visitors. Conservation and challenge/adventure were the two most important secondary values.

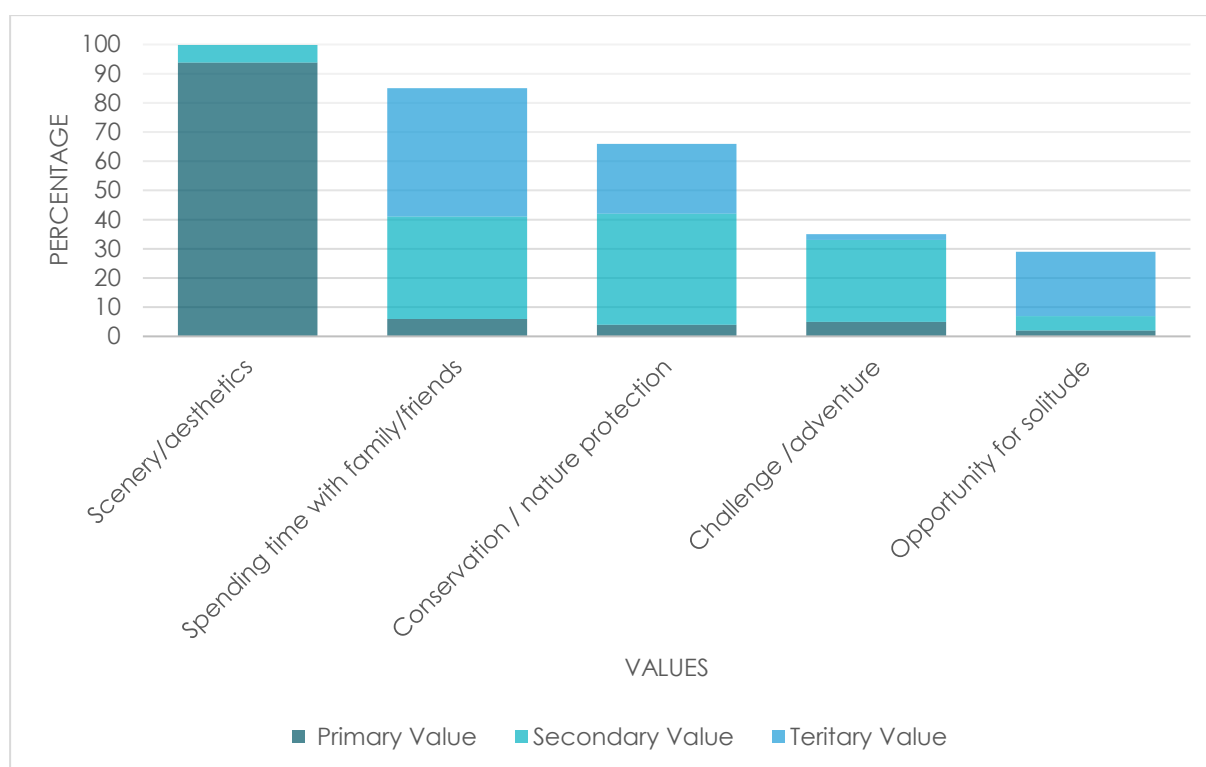


Figure 10. Most important values (respondents associated with ocean beaches in the CLLMM area (n=175)

The benefit domains developed by Driver (1983) and adapted for Australia by Weber and Anderson (2010) were used to examine the key recreation experience preferences visitors associated with their experiences in the CLLMM study area. Figure 12 shows, that simply getting outdoors to experience the sounds and smells of nature, along with enjoying the scenery were primary motivators for many visitors. Spending time with family, reducing stress and the opportunity to engage in specific activities were also important. Combined with the data on frequency of visits, these results suggest the region is likely to be associated with strong place attachment. Spending time with family and friends has often been linked with place identity or social bonding, and areas that facilitate specific activities that people enjoy are often associated with place dependence or functional attachment (Raymond et al., 2010). Strong place attachment—the emotional and functional bond between people and their environment is a valuable asset for managers of natural areas because it can increase the willingness of visitors to engage in behaviours that support environmental protection. It is also generally a strong predictor for management support. Managers can leverage this human attachment to facilitate future improvements directed at fostering a sense of shared ownership in the need to protect and monitor beaches in the CLLMM region.

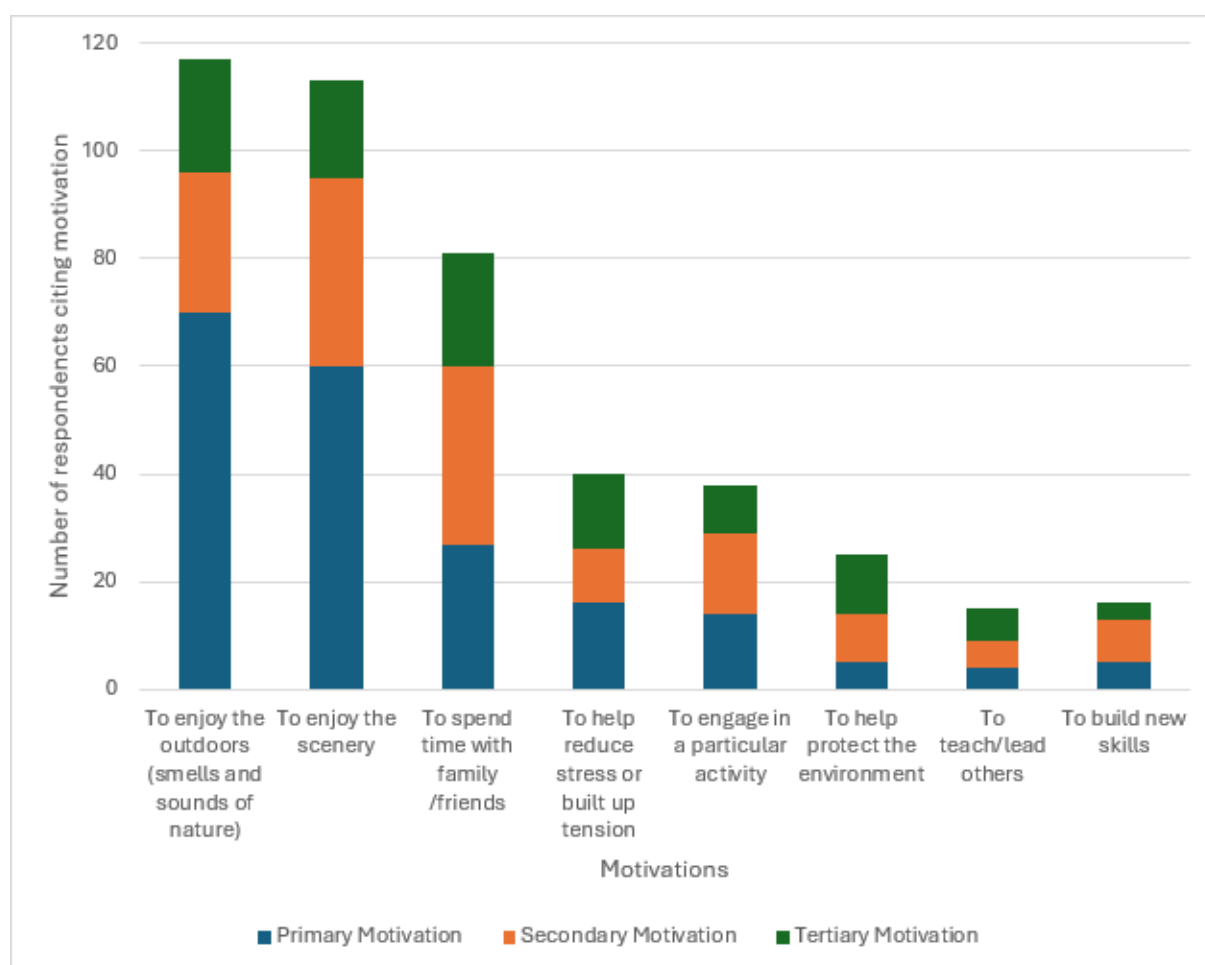


Figure 11. Recreation Experience Preferences for visiting the CLLMM ocean beach (n=201).

8.4 Special Places

A range of locations considered special to respondents were noted. The most frequently cited location was the “Coorong National Park”, with other locations including the Murray Mouth, Goolwa Beach, Goolwa Barrages, Victor Point, Meningie, Port Elliot, Kingston, and Robe. When asked to explain why the areas were special to them, many people highlighted enjoying the scenery and experiencing a sense of relaxation. Other cited positive family memories, including weddings, honeymoons and family holidays. Such comments also support the notion of strong place attachment being associated with the area. Respondents were asked to map the areas that were most special to them and this data is presented as a heat map in Figure 13.

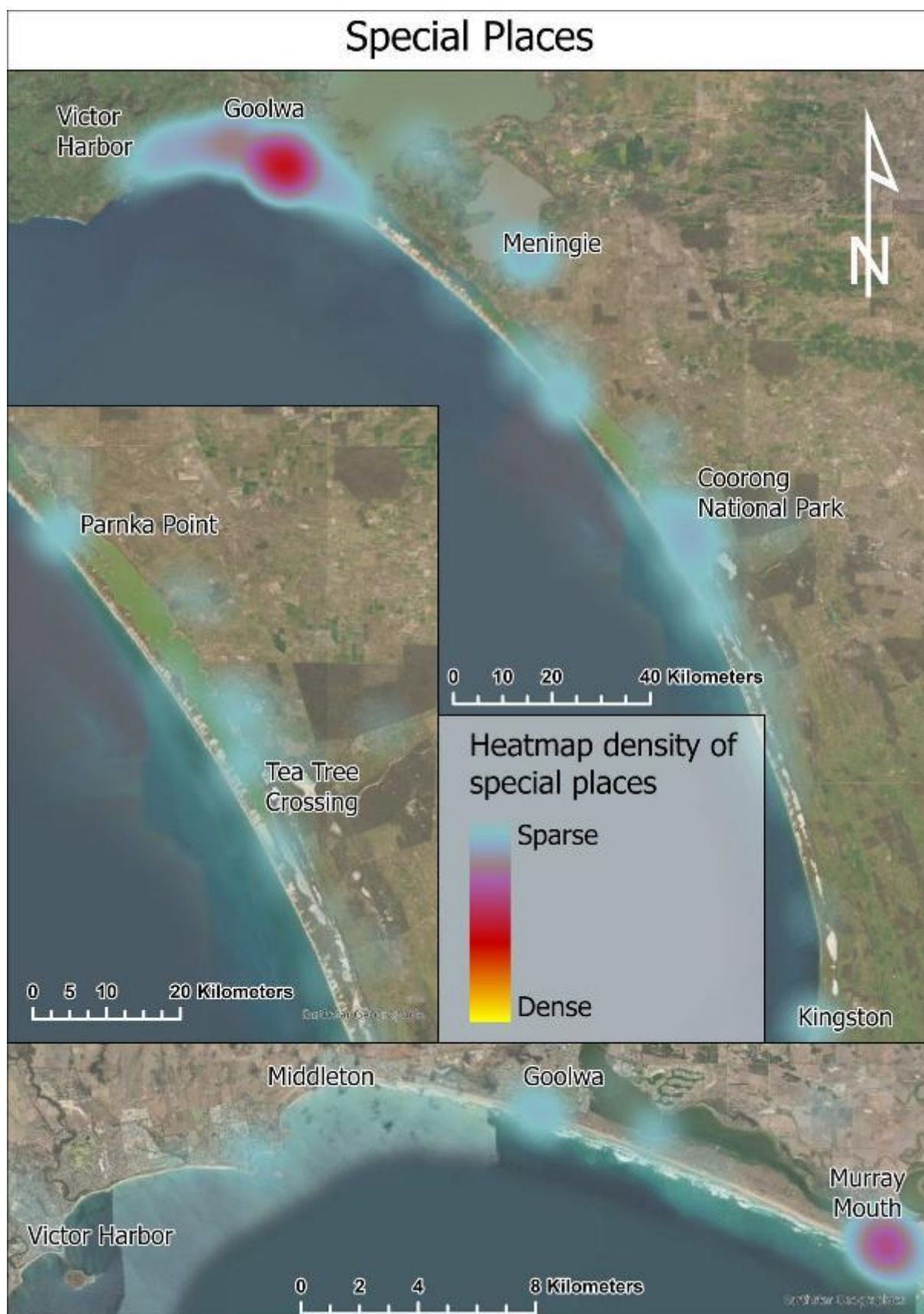


Figure 12. Heat map showing areas considered special by participants

The sites participants visited at different times of the year are similar (Figure 14), with more usage in summer, spring and winter than autumn. The beach access points are popular throughout the year. The map suggests that people may travel further distances in the spring.

The area between Tea Tree Crossing and the Murray Mouth is typically closed to vehicles between October 24 to December 24 but given the hooded plover breeding season can begin in August, the additional distance people are driving in spring, is potentially problematic.



Figure 13. Most frequented sites as a function of season.

8.5 Perceived Threats and Environmental Concerns

Respondents were provided with a list of seven threats to coastal areas identified through the literature search. They were asked to rank the three threats they considered most important, second in importance and third in importance. The results presented as Figure 15 show the overall most common threats were pollution and human disturbance, followed by climate change and invasive species. The biggest concerns were pollution (n=35), human disturbance (n=33), climate change (n=30), beach driving (n=26), and invasive species (n=25). These results differ to what previous studies have found in the CLLMM region. For example, in a number of studies overharvesting has been considered the primary threat in the CLLMM region (Ferguson et al. 2023; King, 1985; McLachlan et al. 1996), and in our literature review we found inconsistent evidence on human disturbance as a threat. That said, consistent with these results, the World Economic Forum's Global Risk Report (2025) lists climate change and pollution as threats perceived to have the greatest impact in the next ten years, and the most recent state (SA EPA 2025) and federal State of the Environment Report (Commonwealth of Australia 2021) lists climate change as the key threat. There is greater diversity in perceptions of the second and third most important threats. The attention on pollution is likely a result of the timing of the survey which corresponded to the presence of a significant algal bloom in South Australia.

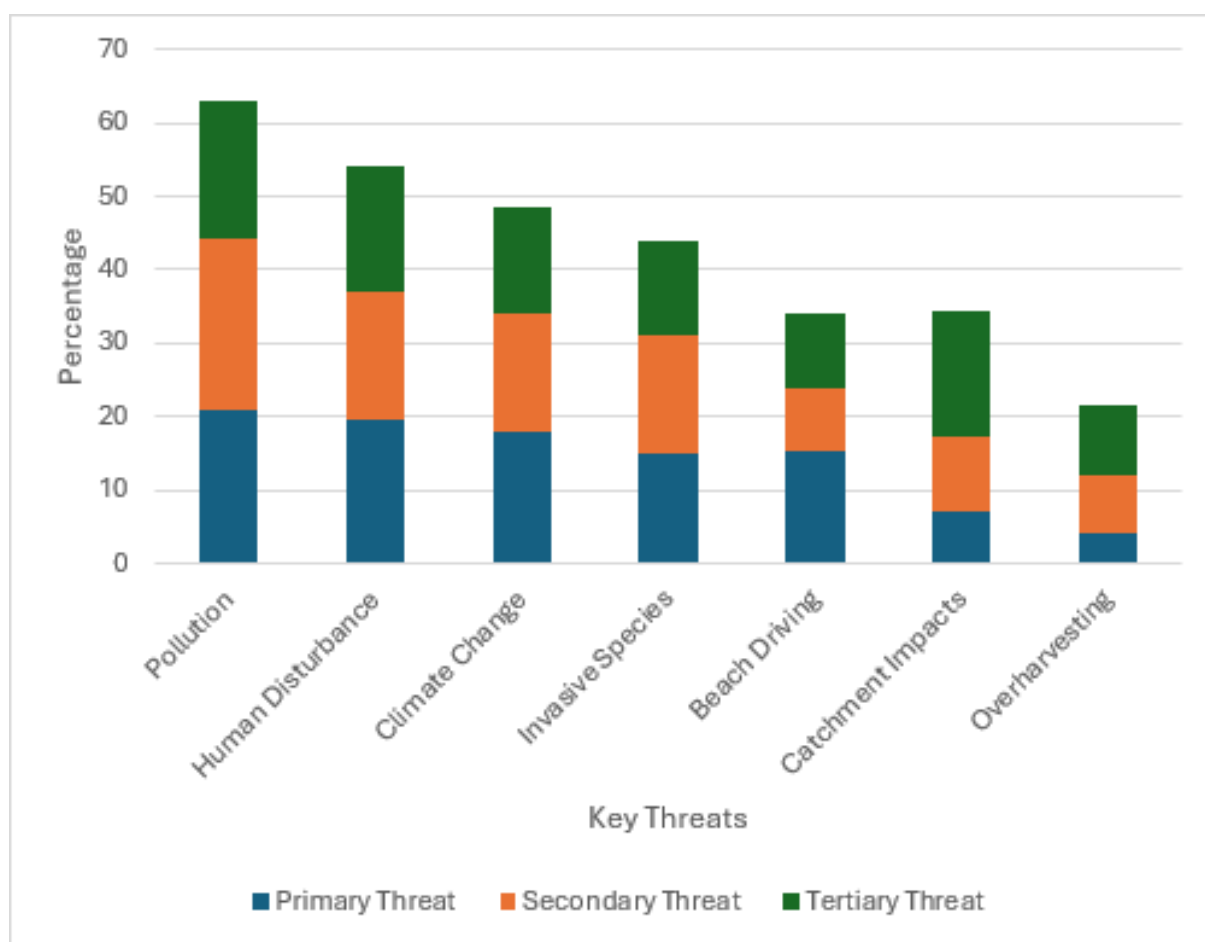


Figure 14. Percentage of respondents identifying key threats to beaches in the CLLMM region as perceived by respondents (n=165).

Twelve percent of respondents included additional threats that they believed were significant, these included:

- Reduction in Murray River water flow as a result of over usage upstream
- Duck shooters
- People camping on the beach
- Irresponsible and environmentally damaging driving by some individuals and groups
- Apathy
- Dividing people and not using the area as a resource to educate others about our First Nations use of the area; It is a thing of balance and needs to be there for all to respect and enjoy
- Government red tape
- Untrained visitors in non 4wd Vehicles getting bogged in the entry track
- The worst impact to the beach I have observed is big winter storm swells
- Local Councils not monitoring issues
- The constant dredging and saltwater ingress during high tides (much higher the last year or so), daily up and down water levels above the barrages being noticed
- Fishing trawler debris
- Risk factors for harmful algal bloom
- Murray river water quality, lack of flow and loss of SE aquifer flows into southern end of Coorong
- A permit system that always leads to costs for beach-users
- The 10 % of 4WDDrivers who are unskilled, ego driven idiots!
- The harmful algal bloom in general

Respondents were also asked to map areas where they perceived the greatest environmental concern. The aggregate data is presented as a heat map in Figure 16. It shows the Goolwa and Murray Mouth area, but also the entrances at Tea Tree Crossing to be of major concern to respondents. Not surprisingly, there is a correlation between high use areas and observing environmental threats.

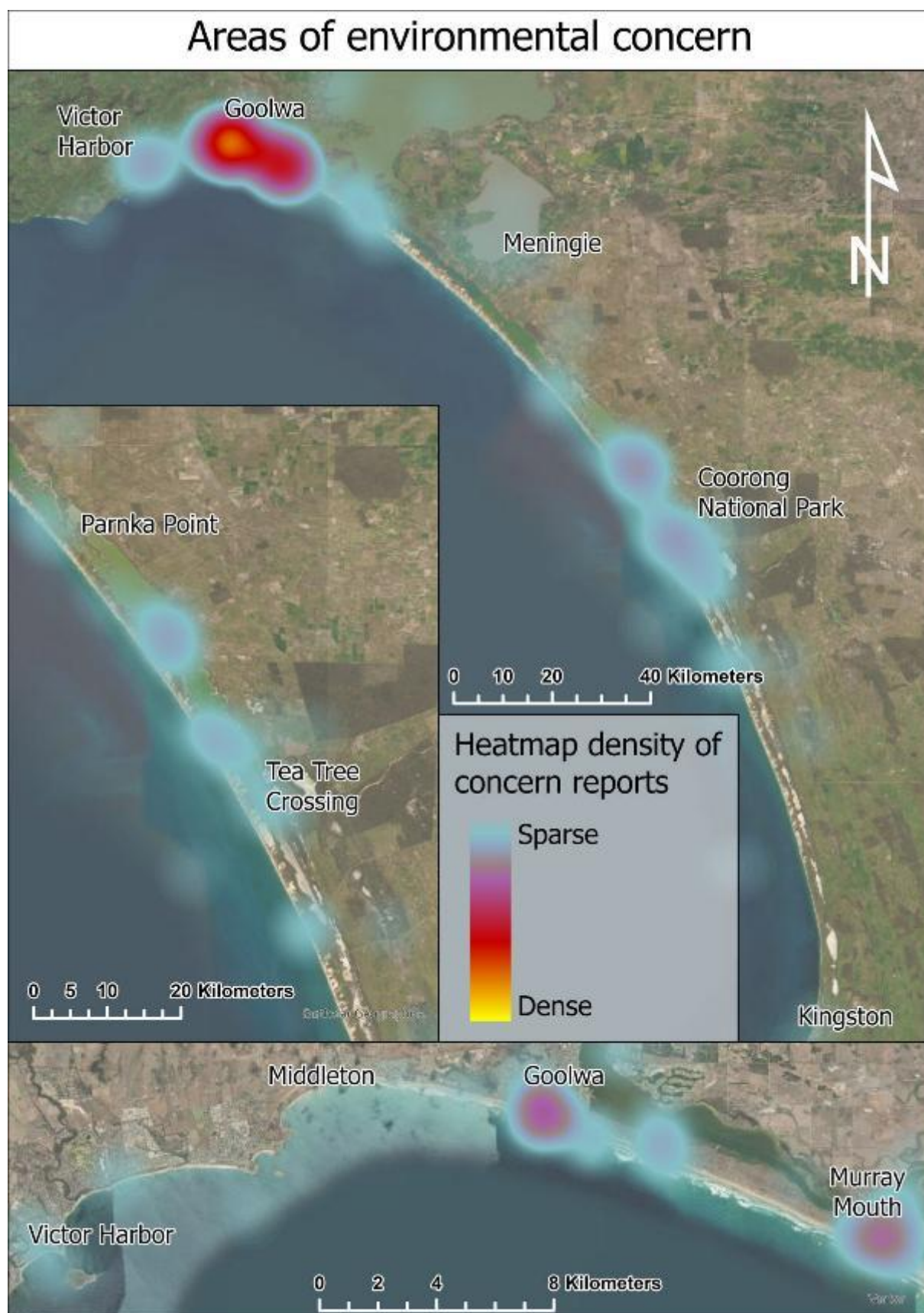


Figure 15. Heat map showing location of perceived environmental concerns

Climate change was identified as a largely unrepresented risk to provisioning services in the literature review. To gauge visitor concern about this issue, respondents were also asked how likely they thought climate change would significantly impact the beaches in this region in the future. Table 3 shows that respondents perceived the impact would be greater in the future but only had moderate concern in the next 5–10 years.

Table 3: Respondent's beliefs in relation to the impact of climate change on beaches in the CLLMM Region

TIMEFRAME	N	MINIMUM	MAXIMUM	MEAN*	STD. DEVIATION
Within 1 year	165	1	7	4.28	1.745
Within 5 years	163	1	7	4.74	1.586
Within 10 years	165	1	7	5.28	1.621
Within 30 years	162	1	7	5.65	1.703

*rating calculated using scale where 1=not at all, 4=neutral, and 7=very likely.

The table suggests that people's concerns regarding the potential impact of climate change remain moderate with slight increases in time. Despite climate change being mentioned as one of the key threats to the area, this figure does not suggest people are particularly concerned about the implications of this to the region, at least not in the immediate future.

In regard to the harmful algal bloom affecting South Australia at the time of the surveys, respondents were asked to rank their level of agreement to a series of eight statements, using the scale 1=strongly disagree and 7= strongly agree. These results are shown in Table 4.

Table 4. Behaviour changes as a result of the current algal bloom.

ITEM	MEAN	SD
I have stopped going to the beach myself	3.85	1.88
I have stopped taking my family to the beach	3.92	1.89
I have stopped taking my dog to the beach	4.03	2.03
I have reduced the time I spend on the beach and / or changed what I do there	4.37	1.87
I have reduced the amount of seafood I consume	3.62	2.01
I have changed the way I interact with coastal environments in general	4.07	1.71
I have involved myself in activities to help monitor the effects of or to promote recovery from the bloom	3.61	1.97
I expect those in charge to do more to help protect beaches and the coastal environment	5.06	1.49

Table 4 suggests the harmful algal bloom had a minor effect on most people's behaviour. Respondent's do expect those in charge to be doing more to protect beaches and the coastal environment. This can be contrasted with the lowest ranking item that pertains to what they have done themselves. While this is understandable, it does perhaps reflect an opportunity to encourage a greater sense of shared ownership in relation to protection of the region.

8.6 *Concern and Management Preferences*

Participants were asked to rate their level of agreement to a series of statements related to overall concern regarding long-term environmental damage and then seven potential management strategies that could be employed to reduced impact. They rated the statements using a Likert scale, where 1= strongly disagree and 6 = strongly agree. The results are presented as Table 5. The results suggest that most people (78%) share concern about the long-term environmental damage to beaches caused by vehicles. In terms of strategies that could be implemented to manage potential damage, the strongest support was for limiting the number of vehicles on the beach at one time, with 87.6% of respondents agreeing or strongly agreeing to this strategy. A permit system that penalises irresponsible driving was supported by 82.2% of respondents. Seasonal restrictions were also a popular strategy amongst respondents. Before such strategies would be recommended, attention should be directed to the amount of impact considered acceptable and the most appropriate indicators and standards that should be monitored to maintain acceptable conditions. Manning (2007) and Brown et al., (2015) offer extensive examples on potential indicators and standards that could be considered.

Table 5. Participant support for potential management strategies

ITEM	% SD	% D	%N	%A	% SA	N	MEAN	SD
I am concerned about long-term environmental damage to beaches caused by vehicles	3.7	7.7	10.7	36.3	41.7	167	4.05	1.08
I think closure to all people in some areas of the study site are necessary	9.7	9.1	15.2	40.6	25.5	165	3.63	1.23
I think temporal restrictions (based on time of year) on people are needed in some areas	3.0	3.6	21.2	40.6	31.5	165	3.94	0.97
I support limits to the number of vehicles on the beach at one time	0	1.4	9.5	41.9	45.7	105	4.31	0.76
I support a permit system that rewards responsible driving with greater access	8	5.6	17.9	35.2	33.3	162	3.80	1.19
I support a permit system that penalises irresponsible driving	4.3	1.2	12.3	32.7	49.4	162	4.22	1.01
I think greater attention to ecological restoration of this area is needed	5	17	42.5	15	20.0	161	3.38	1.13

9 Insights from stakeholder interviews

Throughout the 23 interviews several topics were identified, with the results structured here to unpack the identified themes according to the major focus sections of the interview script. These sections include Values, Threats, Beach Driving, and Additional Insights. Each section is then further divided into sub-categories. The Threats section is divided into participant's perceived problems and perceived changes to the beaches respectively. This section then explores participant's perceptions of Specific Threats identified through the systematic reviews as part of the broader project including Invasive Species, Water Flow, Overharvesting, Climate Change, and Human Behaviours.

9.1 Values

9.1.1 How participants use the CLLMM beaches

When asked how participants spent their time on the beaches in the CLLMM area, respondents reported swimming-based recreational activities (e.g. swimming, surfing, snorkelling) as the most popular activity. At times, this was referenced in relation to it being a high energy beach – *"I'm not actually a 'beach person'. I don't like sitting on the sand and relaxing... it's all about the waves."* or the high quality of the water, *"[The water is] crispy cold, but it's also crispy clean. It's really a nice place to be."*

This was followed closely by walking (including dog walking) along the beaches, which was often associated with personal contemplation, *"Writing poetry in my head as I walk"*, or socialisation, *"Also, everyone is friendly down there. When you're walking along nearly everyone with a dog stops and talks. The dogs play with each other and, yeah, it was just a great feeling to be on the beach."* Other social aspects of attending the beach also ranked highly, with many participants identifying socialising with friends and family as a key activity. This was equally as salient as the region's most iconic activities: ocean harvesting (i.e. fishing and Pipi collection). Also of note were activities associated with stimulus and novelty, with participants often emphasising the opportunity provided by the landscape itself and the associated wellbeing benefits such as *"The Southern Ocean is never still" and it is nice to "go to bed with the ocean in your ears"*.

These results are consistent with findings from the PPGIS survey, although in that survey walking was cited as the most popular activity, followed by swimming.

9.1.2 Why the Beaches were Valued

Participants generally enjoyed the beaches on account of their environmental/wildlife value, cleanliness, beauty, and their ability to engage with recreational activities in these spaces. However, the most prominent theme was the uncrowded nature of the area. Most participants identified solitude, *"Rugged natural beauty"*, quiet, or minimal

development as an important factor in their enjoyment of the beach. The theme was often referred to in the context of profound emotional connection and freedom:

"It's hard to describe. I have this... um... it's just this thing inside of me that just needs to be in a wild space without looking at 50 million houses and 4WDs and people and I just need... you know to be in an open space that doesn't have all that clutter in it."

"Just the quietness. And the capacity to look out to sea and you don't know what you're going to see."

"Rugged natural beauty"

Additionally, the uncrowded theme was often associated with the other popular themes of cleanliness, beauty, and environmental/wildlife value, *"I do like it pristine, as clean as I can get it, as quiet as I can get it... The wildlife, the being in nature."* The uncrowded theme was also regularly paired with recreational engagement. Surfers particularly noted that the beaches in the area produce consistently good breaks for surfing and that the waters were not too crowded. Similarly, anglers enjoyed the remote nature of available fishing spots and the ability to drive on the beach to access them, further highlighting recreationalists' interest in engaging with their desired activities in a solitary setting.

"I do like it pristine, as clean as I can get it, as quiet as I can get it... The wildlife, the being in nature."

"...what I value about it is just the environment itself. Being able to drive along the beach and find a little spot for yourself and enjoy it."

These findings are also consistent with the PPGIS findings and point to the importance of monitoring both social and physical carrying capacity. Preventing crowding in this area will reduce environmental impacts and avoid impacting the experience of visitors.

9.1.3 Limitations on Enjoyment and Suggested Improvements

In response to questions on what limited participant's enjoyment of the beaches, the most widely reported themes identified were environmental destruction (including pollution, rubbish, erosion, or wildlife harm) and irresponsible public use by others (including improper or destructive behaviour, lack of emotional interest or investment, or ignorance of how to act by others). These themes were often tied to busy periods during which the beaches experienced large influxes of tourists or non-local beach goers.

"I think I really notice over the holidays, when there's lots of tourists in the area, there's probably less respect for the beach, like, there's often cars on the beach. Yeah, so maybe that lack of respect."

Participants often speculated on whether poor behaviour was founded in ignorance or poor assessment of beach driving's impacts. For example, some participants observed that these behaviours were mostly unintentional from well-meaning beach goers, but these behaviours still resulted in negative impacts.

"Even if people are doing the right thing, they've got no hope. I don't think anyone is out there trying to run over hooded plover eggs... and probably a lot of people are being responsible, but that doesn't mean that there's not serious impacts or consequences."

However, there were also reports of extreme disregard by others, such as a lack of compliance; *"Compliance is minimal... like, deplorably"*, and the intentional destruction of infrastructure designed to protect areas;

"A number of years ago we did try to put up exclusion zones around the Murray Mouth because of the dredging. Lasted 12 hours. And the fishermen... the fishermen just destroyed what we put up, um, even large concrete slabs were put up, and, you know, they found ways to dig under them so the slabs would sink..."

Regarding suggested improvements, a common theme was improved management and conservation efforts (including infrastructure, regulation, policing, education, and revegetation programs).

"There needs to be some sort of management in place for driving on the beach."

"I guess as a teacher, like I'd love more education about the importance of the dunes and perhaps more community days, and money put into conservation of the beach."

Another common theme was the need to maintain the status quo. This was often related to preserving the area's natural appeal or maintaining access to it. For example, when asked if access to the beaches needed to be changed, a participant responded:

"No. Leave it alone"... "It's a beautiful environment. It's handling the um...ahh, usage that's occurring at the moment"... "It's really important not to reduce or impact on that."

9.2 Threats

9.2.1 Perceived Problems

During the interviews, participants were asked to broadly identify problems that negatively affected the beaches in the area. Almost half of the participants (47.8%) believed that beach driving negatively impacted the beach environment, making this threat the most common perceived risk. At times, this was directly attributed to the impact of vehicles on the beach (39.1%). However, it was also often cited as a means of facilitating irresponsible or destructive behaviour. While some participants expressed concern about damage caused by beach drivers breaking the rules, others indicated that beach driving causes damage to the beach regardless of whether rules were adhered to or not. Beach driving is further unpacked in a section below.

"Sometimes, especially um, public holidays, Christmas, Easter, it's just the number of cars up there is so many. And I just think it's not just the cars going up the beach that potentially cause damage, it's all the people up there, and, you know I just think well, where are they going to the toilet and doing things? They're obviously going up into

the sand hills and, and stuff, so that... that's definitely something I... I feel needs to be kept in check."

Pollution represented another salient perceived threat, with more than a third of participants (43.5%) expressing concern about run-off from both agricultural practices and household use. Other responses included concern about pressures from population growth and related infrastructure development or overcrowding (34.8%).

"I guess with urbanisation, native plants are also getting removed, but there's not necessarily space or money for the council to plant. Like, the Alexandria council were advised to increase the native plant species in the area by, I think it was like, 5%. But, they just simply said they don't have the money, and I think that the community has to agree on certain plants as well. So it's really complex to be able to implement those sorts of programs."

The recent HAB, concerns about overharvesting, and coastal erosion attracted 30.4% of respondents each. Interestingly, each of these threats are tangible and observable. While most participants later identified climate change as the largest threat to the beaches in the area, this less observable phenomenon was not immediately explored by many participants.

"Clean up the algal bloom. That is all it would take"

Additionally, more than one fifth of participants believed that introduced species, including off-lead dogs and invasive species such as foxes, presented a problem to the beach environment.

"Quite often, people come here and think that they can do what they want. Like in Adelaide, they have the dogs on a leash, but here, zero. You know, 'we always come here!'..."

While most responses highlighted environmental threats, a small portion of participants highlighted conservation management decisions as a negative impact on the beaches. For example, closing the beach during breeding seasons for migratory shorebirds was perceived as negatively impacting the beach. Participants who expressed this belief also noted that there were not enough fish to catch and that individuals breaking the rules were ruining beach access for the majority of people who followed the law.

9.2.2 Perceived Changes to the Beaches

Participants were asked if they had noticed any changes to the environment of the CLLMM beaches. An increase in extreme weather events, climate, and seasonality changes was common changes noticed by participants along with changes in the shape and size of dunes. Interestingly, several participants attributed coastal erosion almost entirely to natural processes with little to no recognition of potential anthropogenic impacts.

"I don't know, the beaches are always changing with the tides and rocks, but I don't think there's been a huge change."

The HAB and related changes, such as dead marine life washing ashore, was another salient response from participants, with some noting social and behavioural impacts from these changes, with fewer tourists using the beaches when mass fish deaths were occurring. Others noted that their own behaviour had been impacted by these changes and they visit the shore less frequently during acute periods of the bloom.

"I've only gone down to the beach a couple of times, and I don't want to see dead animals all over the beach."

Additionally, some participants noted changes in water flow (e.g. flooding, tides rising) and salinity in the area, while others explained that the dynamic nature of the beaches in the area makes it difficult to detect anthropogenic changes. Though some respondents perceived no changes in the beaches in the area.

Some participants noticed changes in population and visitation to the area. This included increases in urban development on the shore, population growth, an increase in recreational visitation, and the subsequent impact on the beach environment. While some respondents expressed concern about the perceived increase in beach driving and the associated management challenges, others were concerned about changes in species abundance from harvesting pressures.

"I remember as a kid, we would just go collecting cockles or pipis and there would just be so many... It would be easy to go out and get a whole bucket load for bait or whatever."

"[Beach driving] was probably more manageable when I was younger because there wasn't as many people, but now it's just like... a crazy amount of people, which obviously increased impact as well."

9.2.3 Specific Threats - Invasive Species

Knowledge of invasive species varied across participants, with some expressing little to no knowledge of invasive species both generally and within the region. Others were able to detail specific species and the threats they posed to the area. Some participants demonstrated misconceptions about invasive species, naming sharks, seals, and the native noisy miner bird (*Manorina melanocephala*) as invasive.

Commonly identified invasive fauna included foxes, hares, rabbits, carp, and cats, with participants emphasising predation impacts on shorebirds related to foxes and cats, while the threat posed to the beaches by European carp was not clear. Less frequently mentioned species included deer, goats, some sea star species, and sea urchins (although to note, there are no known introduced sea urchins in South Australia). The perceived threats from herbivores, such as rabbits and hares, included structural changes to the dunes through burrowing and impaction and grazing on native plant species. Consensus regarding the level of risk to the beaches varied, though some participants cited low risk on account of current effective management. Others believed that the risk was moderate to high, and that more action is needed to mitigate risk.

"As far as vegetation goes, I don't think we have that much of a problem... at least that I'm aware of. The coastal dunes and that are still in pretty good nick. Rabbits would be the worst thing we've got, but also carp from the River Murray."

Compared to invasive fauna, invasive flora was not as commonly mentioned by participants. Participants who did mention these listed boxthorn, gazania, euphorbia, sea lavender, spiny rush, some coastal spinifex species, and salvation jane as species of concern. The perceived risk of invasive flora was considerably lower than invasive fauna. While some participants expressed concern regarding how they displace native species, others highlighted their value in promoting dune stability.

"Yeah [gazania is] spreading a lot. But people have been putting in the effort for a long time and it's still there. It's a losing battle really."

9.2.4 Specific Threats - Water Flow

Knowledge of freshwater flows also varied between participants. While some expressed great concern and interest about water flow in the CLLMM region, others indicated that they had little to no awareness of this process. Participants with less knowledge about water flow mentioned specific human interferences, including the barrages and dredging, as tangible actions that they knew affected the flow of the Murray River into the ocean.

Conversely, participants who expressed greater knowledge about water flow highlighted the tension between human and environmental needs in terms of water flow. Concern clustered around the quality of the water flowing through the CLLMM (e.g. run-off from agriculture) and the low volume of flow. Some participants noted the importance of freshwater flows in distributing nutrients to saltwater environments, while others noted that varied salinity levels in the area were important for species which breed and live in different environments. The limited allocation of environmental flows was a concern for knowledgeable participants.

Impacts on the beach largely centred around the 2022/2023 Murray River floods, with many participants recalling the sight and smell of dead European carp that washed up on the beaches. Several participants attributed the HAB to the flood of nutrients pushed into the ocean from the flood. Some participants also highlighted the interconnectedness of water in the area, and that nutrient flow from the mouth into the ocean would have flow-on effects on species on the beach. The understanding of risk varied, with many participants unsure of how water flow may directly impact beaches in the area.

"Everyone on Facebook seems to be an expert about water management in the Coorong, just ask them."

"I'm glad to see that the diversions are trying to do their best, I'm not sure how much more we can do without destroying a heap of farmland... There's consequences, it's a really tricky one."

"It's really hard to get your head around, it must have a long-term detrimental effect."

9.2.5 Specific Threats - Overharvesting

While participants expressed awareness of overharvesting broadly, there was little understanding of overharvesting in the CLLMM region specifically. An anomaly to this trend was pipis, which many participants perceived to be overharvested by recreational fishers.

Recreational fishers displayed the greatest concern and insight compared to other stakeholders. Some fishers believed that exploited stocks meant that overharvesting may occur even when people are following bag limits, with some participants emphasising their desire for minimum size requirements to be increased for species such as mullet. Some fishers suggested that catching fish has become increasingly difficult in the area, though some areas seem to be more productive than others. Fishers demonstrated concern for specific species, including mullet, black bream (*Acanthopagrus butcheri*), whiting (*Sillaginodes spp.*), garfish (*Hyporhamphus melanochir*), congoli (*Pseudaphritis urvillii*), and mullet (*Aldrichetta forsteri*). Concern was generally greater for species with "old" fish such as congoli. Participants who expressed limited knowledge about overharvesting discussed Australian salmon (*Arripis truttaceus*) and southern bluefin tuna (*Thunnus maccoyii*) as two potentially overharvested species in the area.

Commercial fishing attracted concern and confusion from participants. While some were unsure if commercial fishing occurred in the area, there was some concern about the impact of commercial fisheries operating in the area. Specific concerns surrounded the use of nets and unreported bycatch from their use. However, other participants noted that commercial fishing seemed to be more well-regulated compared to commercial harvests. Overall, concerns about overharvesting were mixed across commercial and recreational efforts. Owing to bycatch impacts and scale, perceived risk was high for commercial fisheries while recreational fishing was low to medium largely attributed to existing depleted stocks, flow-on effects along the food chain, and concerns regarding small size limits.

"It's harder for people to catch because there's less."

"I just feel like the ecosystem is probably declining in health and it's really struggling at the moment, but our consumption is also increasing. So it's kind of like the worst of both... I think it's just like a consumeristic culture as well. When we were kids, we'd just go and catch a couple of fish for dinner or like put a couple in the freezer. Now, it's just like, oh let's just get as many as we can and sell them."

"Pipis are growing for a reason, obviously... they're doing a job, they're flushing things out or they're doing something. To just to pull them all out, it... it's got to have a flow on effect."

9.2.6 Specific Threats - Climate Change

Participants generally indicated good foundational knowledge of climate change. Most participants discussed human activities driving carbon dioxide emissions which is shaping climate and resulting in an increase in extreme weather events. Several participants mentioned climate change in the onset of the 2025 HAB event. Some

participants noted an increase in storm surges, sea levels, water temperatures, dune erosion, and shift in annual patterns with wildlife. However, others noted that it is difficult to determine whether these changes can be attributed entirely to climate change.

Climate change was almost unanimously regarded as the largest threat to the future of the beaches in the area. Several participants recognised that these impacts are compounded by other threats (e.g. development on the dunes, nutrient-loaded water flowing in from the Murray). The general sentiment of answers suggested that participants felt helpless about climate change, and that while other threats could be managed at local levels, addressing climate change required a global effort that felt less achievable.

*"I'm not sure if it will be manageable or go back to what we call normal."
"It's going to ruin [the beaches]... the beaches will be much further back. It will be immense. Hopefully it won't be in the blink of an eye."*

9.2.7 Specific Threats - Human Behaviours

When asked to explain what human behaviours negatively impact the beaches in the area, participants shared a diverse range of activities and impacts. Several salient behaviours identified included driving on the beaches and dunes, walking dogs on the beach, urban development, general disturbance of wildlife, littering, walking on the dunes, allowing domestic cats outside, runoff from agriculture and personal use, and climate change.

The perceived risk of human behaviours varied depending on which behaviour was being discussed, but most responses were in the medium to high-risk category. When asked why, some participants explained that the impact of human behaviour was noticeable, but not as threatening as other risks like climate change. Others noted that the smaller scale of human behaviour is easier to manage than something global like climate change. However, some participants identified that all risks, including climate change, are largely attributable to human behaviour. Thus, human behaviour was considered high risk on account of its role in causing other threats.

"I guess everything is a human impact in a way, like if humans weren't here, the environment would probably go back into balance because there wouldn't be things degrading the environment... I think we often put economy above looking after the environment."

"High because they are unnatural impacts that natural things can't adapt to cope with. I used to sit on this board of old white men and... their big plan for the Coorong was to drive ecotourism through the roof so that people come and care about it, but I was like... no, no, no... people will come visit and destroy it. This is 100% the wrong way."

9.3 Beach driving

9.3.1 Why Participants Drive on Beaches

Of the 23 participants interviewed, 14 (61%) had driven themselves, or had been a passenger in a vehicle driving, on the CLLMM ocean beaches in the last two years. Of these, the majority reported having engaged in the practice for longer than ten years and often related having started the practice in childhood or young adulthood. The main reason for having started beach driving aligned with improving accessibility for desired activities (e.g. fishing, picnicking, setting up for a beach day). Unsurprisingly, this theme often aligned with the second most popular themes: Improved ability to gain isolation and facilitating socialisation with friends and family. Evidently, participants loved the remoteness offered by the beaches and being able to enjoy activities or the company of their loved ones on it.

"You can't walk to most of the spots; it's just not an option."

"You can drive down there and find a spot, you know, and just enjoy it on your own if you want to".

Participant: *"It was just the... the freedom to be able to, um, have the car close by. To be able to, you know, set up a sunscreen a, little bit of a camp there. And, ah... be able to spend the day, really."* Interviewer: *"So it's access and convenience, as well as the area's you get to?"* Participant: *"Yeah! Definitely convenience. So that you're not carrying everything down to the beach and then getting hot. Like everything's there. You've got, you know, drinks and food in the car. You've got, um, boogie boards in the car, you can just, yeah, get changed down there and no one is going to see you. Like that's, that's pretty much... pretty much why we enjoy doing it."*

When asked how they felt after a day of beach driving, the most popular themes identified were those of positivity, including elation, or relaxation and rejuvenation.

"Really good. It's such a relaxing environment."

"Oh! Bloody awesome! Feels like the, yeah no it...it... It feels like... yeah... work's a mile... mile away. I've actually even sat on the beach, and down there, and my husband has been boogie boarding and I've been on my laptop, and working. And it doesn't feel like you're working."

However, some drivers also related feelings of anger, having witnessed other drivers doing the wrong thing including littering, speeding, or driving on the dunes. Drivers who had discontinued the practice also related feelings of regret or concern.

"...maybe we should not be doing that anymore."

9.3.2 Perceived Impacts of Beach Driving

For the most part, both beach drivers and non-beach drivers perceived beach driving to have some negative impacts. For example, both groups often identified fauna harm (e.g. impacts on sand nesting birds or other animals), sand and soil impacts (erosion or compaction), and impacts from irresponsible drivers (human safety or environmentally irresponsible behaviour - e.g. dune driving) with roughly equivalent frequency. However, while non-beach drivers often identified pollution as an associated impact (vehicle emissions, litter), beach drivers regularly perceived vehicle impact to be contingent on rule compliance.

"It does have an effect, and definitely for particular bird species that will be sheltering and nesting in the rivets of the tyres, which is why the beaches get closed down for periods of time while they are nesting... If people use it the right way, then it doesn't have a huge impact."

"When driving in the tidal zone, minimal. In the dunes, dramatic over time as more and more cars use the same spot. It's more of the late-night people who are the problem, who go there and do the wrong thing for thrills when they can't be seen."

This sentiment was at times also present with non-beach drivers, who suggested the impacts to be case dependant:

"One group you see are... are families. And they just get in their 4WD, go down the pass and drive along a few hundred meters, and set up camp all alone. And in a way that seems quite good. But ah... but ah... And others, yeah, just love 4WDing, and yeah, they're the ones who probably want to push the boundaries..."

However, some non-beach drivers perceived any vehicle access to the beach as detrimental, and beach drivers themselves as the minority causing impacts. For this group, it appeared the inherent risks of beach driving did not justify the benefits.

"They don't need to be there"... "I don't see why for the sake of 20 or 30 people that want to go down the beach, they are allowed to go down the beach."

These findings are consistent with the findings of the PPGIS study and offer some insights in terms of understanding how people are evaluating such threats.

9.4 Additional insights

When asked if there was anything else participants would like to add about how they felt about the beaches in the CLLMM region, most participants cited a need for management and practical action. These included a need for better public education about the beaches, the need to translate research into practical results, and the need for increased buy-in from stakeholders.

"I'd really love to see people getting educated about why we shouldn't drive on the beach or why we should only drive at low tide... I feel like we have signs saying 'keep off the dunes', or 'don't do this', and lots of rules, which don't necessarily hit home with people."

"I think that's where, that's where the problem lies. You know. Like, it seems to be plenty of research gets done, but, yeah, not much action."

"You know, invest in it! You can't just enjoy a site and not invest in its long-term future, if you know what I mean?"

Additionally, appreciation for the beaches and concern for their future emerged as a salient response.

"I think they're beautiful, and I want to keep accessing them for as long as I can and keep them pristine as much as I can."

Finally, participants often mentioned profound emotional connections with the area and its importance for their wellbeing.

"The ocean has always been seen as a great mystery and a great cleansing experience, and as something pristine and unchangeable. And I think one of the problems now is when I look at it, I see it damaged. And when I watch that wave curling in, my reaction to it has sadness, not... no longer joy. No longer a simple joyful reaction to pure nature, but a much more complex reaction to damaged nature."

"So, when you walk on a nice clean pristine beach, um, yeah... your whole world just melts away really. And you just... you could walk for miles and not even be stressed."

10 Conclusions

Ocean beaches are often perceived as simple environments by the broader public because they appear less complex than other habitats such as mangroves or wetlands (Wahler et al., 2023). However, drawing on a synthesis of approximately 80 documents, spatial data from more than 200 survey participants, and 23 stakeholder interviews, this project shows that the ocean beaches in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region are ecologically diverse and productive, socially and economically important, and closely connected to broader coastal processes. These beaches support an abundance of species, contribute to a range of ecosystem services, and form part of an integrated coastal system linking the River Murray to the Southern Ocean. They should therefore be recognised as important components of the CLLMM system rather than simple environments in between other ecosystems.

The amount of scientific information that exists on ocean beaches in the CLLMM region is larger than expected yet remains fragmented and distributed across various sources such as academic literature, government databases, and technical reports. Research has largely concentrated on visible and well-studied components of the ecosystem, and the threats to those components, particularly the overharvesting of fisheries species (pipis and mullocky) and the relationship between shorebirds and human disturbance. In contrast, broader ecological processes, cumulative pressures, and many cultural values are less well represented. This fragmentation was the starting point for this project: as outlined in the Introduction, a key aim was to bring together this scattered scientific knowledge with spatial and community data to build a more complete picture of these environments. The PPGIS and interview components, discussed below, were designed specifically to fill the gaps this literature synthesis exposed by providing a clearer picture of overall beach condition, how these systems are valued by people, how they are changing over time, and what current and future pressures they face.

By combining a synthesis of existing literature and data with spatial mapping through PPGIS and stakeholder interviews, this project provides a more complete understanding of ocean beaches than any single approach alone. The literature identifies key services and pressures, the PPGIS highlights where values and concerns are concentrated, and interviews provide insight and narrative into how these environments are experienced and understood by people as components of the ecosystem. Together, these approaches reveal not only what is known, but how that knowledge aligns with community values and perceptions.

Across all three components of this project, several consistent patterns emerge. Ocean beaches are highly valued, particularly for recreation, being close to nature, solitude, and interactions with wildlife. At the same time, multiple pressures are recognised, most often linked to immediate and visible impacts such as beach driving, pollution, and general disturbance. Beach driving is a clear example of competing values, being both widely valued as a form of access and frequently identified as a source of impact. This highlights the challenge of balancing use and protection, where

the same activities that enable people to experience these environments can also contribute to their degradation. Understanding and managing this balance will be critical for maintaining the values that people associate with ocean beaches in the CLLMM region.

While climate change is widely recognised as an important issue, its perceived urgency varied by method. Ranked-choice responses tended to prioritise more immediately observable pressures, such as pollution, human disturbance, and recent events like the 2025 harmful algal bloom, while climate change was ranked as a comparatively moderate concern. In contrast, when participants were prompted to reflect on climate change specifically, it was consistently identified as the greatest long-term threat to the region's beaches. This suggests that climate change concern may be underrepresented in tools that rely on immediate or ranked responses, and that its significance becomes clearer through more reflective engagement. Capturing this dimension of concern will be important for future monitoring and community engagement around ocean beaches in the CLLMM region.

The pattern of climate change perception is consistent with the concept of psychological distance, where risks that are abstract, temporally distant, or difficult to observe directly tend to receive less immediate attention than risks that are concrete and visible (Spence et al., 2012). In contrast, immediate and visible factors, such as high visitation, vehicle use, and localised environmental degradation, are more strongly associated with current environmental decline. Temporary events, such as the recent harmful algal bloom, were noted as affecting beach experience but were not consistently identified as drivers of long-term change, despite their potential to contribute to longer-term impacts. This difference between visible and less visible pressures reflects a broader, well-documented pattern in how people perceive and respond to environmental risk and may have implications for which issues receive the most attention in management and decision-making.

Taken together, these findings show that the fragmentation identified at the outset of this report is not only a fragmentation of scientific literature, but of understanding more broadly: the same gaps that leave beach condition poorly tracked in the literature are mirrored in how community concern is captured, with less visible or immediate issues, such as climate change and broader ecological processes, consistently underrepresented across all data sources. The information about ocean beaches of the CLLMM region is dispersed across disciplines and collected for different purposes. As a result, ocean beaches are not well represented in system-scale monitoring and reporting frameworks, and their condition is not consistently tracked over time. This contributes to the broader perception that existing knowledge is not being effectively translated into coordinated management action. Despite this fragmentation, many of the components required to assess ocean beach condition are already available. Ecological, physical, and social data exist but are not currently integrated. At the same time, there is clear community support for improved management, particularly for measures that reduce environmental impacts while maintaining access, including support for managing vehicle use on beaches. This presents a clear opportunity to better align and synthesise existing information with community support for

management, and to incorporate ocean beaches into broader system-scale assessment and reporting frameworks, such as those developed by the Murray-Darling Basin Authority for the CLLMM region. Doing so would improve the visibility of these environments, support more balanced management, and provide a clearer understanding of how long-term environmental change is shaping both ecological condition and human experience across the coastline.

11 Future directions

This project was initiated in part due to a community perception that relatively little work had been undertaken on ocean beaches in the CLLMM region, or that existing knowledge had not been brought together, despite growing awareness of issues such as beach driving and other pressures. The findings presented here suggest that, rather than a lack of information, the key challenge lies in how existing knowledge is integrated, interpreted, and applied. This is reflected in the breadth of data collection activities already underway across ocean beaches in the CLLMM region, including long-term shorebird surveys at sites such as Goolwa Beach (SA Shorebirds Foundation, pers. comm., 2025) and targeted monitoring of breeding colonies such as fairy terns (BirdLife Australia, pers. comm., 2025). In addition, national and state databases contain relevant information, including wildlife observations, pest species records, and remotely sensed data on shoreline change (e.g. iNaturalist, Geoscience Australia, Integrated Marine Observing System (IMOS)). Despite this breadth of monitoring and data collection, much of the available information remains dispersed across different organisations, programs, and formats, and has not yet been brought together into a coherent picture of ocean beach condition or change over time. Bringing this information together more effectively, and making it more accessible, may help strengthen links between ecological condition, patterns of use, and the pressures acting on these environments, and support its use in management and decision-making.

One way of bringing information about the condition of ocean beaches together may be to explore how existing monitoring could be incorporated into broader assessments of the CLLMM ecosystem, such as the CLLMM Report Card on ecosystem health carried out annually by the Murray-Darling Basin Authority (Murray Darling Basin Authority, 2025). For example, this could involve reporting a small number of ocean beach indicators into the existing framework, allowing beach condition to be considered both in its own right and alongside other components of the CLLMM system (e.g. the upstream Murray and adjacent Coorong/estuarine areas). An initial framework could draw on a combination of ecological indicators (e.g. key species such as pipis, shorebirds or fish), physical measures (e.g. shoreline and dune dynamics), indicators of pressure (e.g. patterns of human use, vehicle access, disturbance and water quality), and social dimensions (e.g. spatial patterns of use and perceived condition identified through PPGIS and interviews), broadly reflecting the types of indicators already used in system-scale reporting and ensuring assessment across a range of ecosystem services, including provisioning and regulation and maintenance services. A staged approach, beginning with a relatively small number of indicators, may provide a practical way to test how this could work in practice.

In addition to supporting system-scale assessment, indicators that are accessible and clearly linked to observable change may also help improve understanding of ocean beach systems among the public and strengthen connections between what people experience on the beach and the processes driving change. Ensuring monitoring outcomes are visible and interpretable, particularly where this involves community

participation, can help build environmental literacy and support a stronger sense of shared responsibility (Pocock et al., 2023). As an example of this type of monitoring already in place, community monitoring of pipis aligns well with commonly used criteria for selecting indicators in ecological reporting (McIntosh et al., 2019), including their relevance to users, ecological significance, responsiveness to environmental change, cost-effectiveness, and their ability to reflect multiple ecosystem services. They occur in areas that are widely used and valued, are directly collected and fished by the public, underpin a local fishery, and are culturally important to First Nations people, while also potentially reflecting broader ecological change, including responses to pressures such as vehicle impacts (Schlacher et al., 2008). Structured monitoring of pipi populations has been undertaken across multiple sites and seasons along Goolwa Beach, including before and after major disturbance events such as the 2013 fish kill (Nature Glenelg Trust, pers. comm., 2025), and citizen science initiatives have generated multi-year datasets (e.g. The Great Goolwa Cockle Challenge, 2018). There may also be value in exploring the role of the CLLMM Research Centre as a local base for supporting and coordinating monitoring activities, building on existing initiatives such as the Great Goolwa Cockle Challenge, given its proximity to the system and its potential to act as a focal point for ongoing beach research and engagement. In doing so, there is also an opportunity to better incorporate First Nations knowledge and connections to these environments within monitoring approaches.

As noted in our literature review, First Nations perspectives and knowledge systems are not strongly represented in the existing literature on ocean beaches in the CLLMM region, despite their clear relevance to understanding these environments. Ocean beaches have long-standing cultural significance and are associated with ongoing connections to Country, including knowledge of species, seasonal patterns, and environmental change developed over long timeframes. While this report has captured a broad range of perspectives from the general public on values, uses and perceived threats, it does not represent the perspectives of the Ngarrindjeri community. Given the backgrounds of the research team, we believe the incorporation of such information is best conducted by researchers with experience in First Nations research methodologies, preferably an Aboriginal researcher with existing ties to the community and it is the intention of the research team of this report to engage such a person in follow up work. Given the magnitude of this issue, the history of poor decisions by non-Aboriginal people in this region, and the existing cultural burden First Nations leaders have, as a first step we wanted to coordinate, collate, and summarise information related to visitors to their Country, so as to engage in meaningful Two-Way dialogue in the future. Addressing the current gap will require working with Traditional Owners to identify appropriate indicators, interpret change over time, and inform how monitoring outcomes are communicated and applied.

The findings also highlight the importance of human behaviour in shaping pressures on ocean beaches. While most respondents expressed a preference for a balance between conservation and recreation, this was not always clearly reflected in reported behaviour. In particular, four-wheel driving was identified as both a highly

valued activity and a potential source of impact, with many users reporting relatively limited experience and a tendency to prioritise enjoyment or convenience over minimising environmental disturbance. Respondents also tended to frame impacts in terms of local and visible pressures, with climate change more often seen as a longer-term concern, even though some impacts may already be occurring. Further work is needed to better understand how different types of use and behaviour translate into ecological impacts on beaches, and how these vary across users, locations and conditions, a gap that has been noted previously (Petch et al., 2018).

Overall, the findings of this project suggest that the next phase of work on ocean beaches in the CLLMM region is less about generating entirely new data, and more about integrating, extending and applying existing knowledge in ways that support ongoing assessment and understanding. This includes developing approaches that bring together ecological, physical and social information, improving the accessibility and interpretability of monitoring, and addressing key gaps in relation to First Nations perspectives and the links between human behaviour and ecological impact. Ocean beaches are already widely used, highly valued, and subject to a range of pressures, yet remain only partially represented in broader system-scale assessments. Incorporating these environments into ongoing reporting and research frameworks offers a pathway to improve how they are understood, monitored, and managed over time.

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13 Statement on the use of generative Artificial Intelligence (AI) in this report

Generative AI tools (ChatGPT and Claude) were used in a limited capacity to assist with PPGIS coding/map creation and to support preliminary brainstorming and structural organisation of report content. These tools were not used for data analysis or interpretation. All analysis, interpretation, and final text were developed and verified by the authors, who take full responsibility for the report.

Appendix A Complementary scientific publication

Threats to ecosystem services provided by ocean beaches: a case study of the Coorong, Lower Lakes and Murray Mouth region

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ABSTRACT

Human wellbeing, societies, and economies rely on diverse ecosystem services, yet these are increasingly threatened by human activities. While well-documented in some systems, such as coral reefs, mangroves, and seagrasses, others, such as ocean beaches, remain largely overlooked. Here, we highlight how this imbalance can be addressed through examination of existing literature, documenting services and threats using a case study of ~213 km of ocean beach in South Australia's Coorong, Lower Lakes, and Murray Mouth region. Our review identified key ecosystem services recognised identified in the region include regulation and maintenance of nursery populations and habitats, as well as the provisioning of wild animals used for nutrition, direct use, or processing. Major threats documented include human disturbance and overharvesting. Recognising the currently valued services and perceived threats provides an important baseline for future management, particularly as ecosystem use and associated threats are modified under a changing climate.

INTRODUCTION

Ecosystems provide a diverse array of services that underpin human wellbeing and contribute to the functioning of our societies and economies (Daily & Matson, 2008). These ecosystem services represent the ways in which people derive value from nature, whether directly through material goods, or indirectly through ecological processes and cultural connections (Costanza et al., 1997). The ecosystem services framework offers a way to articulate and assess these benefits, typically under three broad categories; provisioning services, which include the supply of food, fresh water, and raw materials; regulating services, such as climate regulation, coastal protection, and nutrient cycling; and cultural services, which encompass non-material benefits including recreation, aesthetic experiences, and spiritual or symbolic values (Millennium Ecosystem Assessment, 2005). Identifying and valuing ecosystem services under this framework offers a means to better recognise the multiple functions ecosystems perform, and to set informed conservation and management priorities (De Groot et al., 2012).

Anticipating which ecosystem services will be provided in the future requires knowledge of both the services currently provided, as well as the pressures that threaten them (Villamagna et al., 2013). Anthropogenic pressures increasingly undermine the capacity of ecosystems to maintain structure and function, leading to cascading consequences for both biodiversity and human wellbeing (Diaz et al., 2006; Rockstrom et al., 2009). Among the most pervasive threats contributing to ecological degradation and the loss of associated services are climate change (Grimm et al., 2013), overharvesting of natural resources (Jackson et al., 2001), the introduction of invasive species (Pejchar & Mooney, 2009), human disturbances (including direct pressures from recreation and development; Jaureguiberry et al., 2022), addition of

pollutants (Carpenter et al., 1998), and alterations of natural flows (e.g., water; Poff et al., 1997). These threats can disrupt key ecological processes, reduce ecosystem resilience, and result in the decline or collapse of services (Diaz et al., 2006) and are often experienced in combination, potentially amplifying their impacts (Dade et al., 2019). Where the connections between ecosystems, services, and threats are well understood, opportunities for proactive or adaptive conservation can be pursued. Despite the contributions made by diverse ecosystems, some ecosystems and regions are characterised by limited baseline understanding of services they provide and the threats they face, compromising our capacity to implement informed management approaches (G Millennium Ecosystem Assessment, 2005). Addressing this knowledge imbalance requires first developing a comprehensive understanding of the services sustained by different ecosystems and the ecological and social contexts that shape them. Despite their global extent, ocean beaches have received comparatively little attention in the way of ecosystem services they provide, particularly when compared to other coastal systems such as coral reefs, mangroves, or seagrasses (Harris & Defeo, 2022). Ocean beaches are dynamic ecosystems that are broadly recognised to support both ecological and social values (Defeo et al., 2021). They can provide a diverse range of ecosystem services, from shoreline protection to habitat provision, recreational opportunities, and cultural or spiritual significance (Barbier et al., 2011, Defeo et al., 2009). However, these services are likely to be increasingly at risk from anthropogenic pressures such as climate change and coastal development (Defeo et al., 2009; Schlacher et al., 2016). The underrepresentation of this ecosystem in studies of service provision has contributed to significant knowledge gaps regarding which ecosystem services are documented for specific ocean beaches and the extent to which they are threatened (Defeo et al., 2009).

While cohesive syntheses are currently lacking for ocean beaches in general some information on the ecosystem services that individual beaches provide and their potential threats is dispersed across documents in the academic literature, technical reports, and local knowledge. By synthesising such understanding, we can systematically report the services recognised as being provided by these ecosystems and the pressures acting upon them, creating a comprehensive overview of what is known. Here, we apply such an approach to a case study of the longest high-energy beach system in Australia (Short, 2006), which extends along the Coorong, Lower Lakes and Murray Mouth (CLLMM) region of South Australia. Using a comprehensive review of peer-reviewed and grey literature, we provide a baseline synthesis of documented ecosystem services and perceived threats for this coastline, identifying key knowledge gaps and supporting more informed management and future research priorities.

METHODS

DEFINING OCEAN BEACHES

For this review, ocean beaches are defined as unconsolidated sedimentary shorelines on open coasts, with profiles, slopes, and sediments continually reshaped by waves, tides, currents, and wind (Short & Wright, 1983). They form the interface between marine and terrestrial systems, encompassing three closely connected zones, the: foredunes, beach face, and surf zone (McLachlan & Defeo, 2017). The foredunes are wind-shaped sand formations extending landward from the dune base, the beach face is the non-vegetated surface between the dune and low-water mark, and the surf zone is where waves break and dissipate their energy (McLachlan & Defeo, 2017). Together, these zones operate as an integrated coastal system, characterised by the

continual movement of sand, organisms, and nutrients across their boundaries (McLachlan & Defeo, 2017). Beaches are shaped by differences in wave conditions, tides, and sediment grain size to various forms along a spectrum from wide dissipative systems with fine sands to steep reflective beaches with coarse grains (Short & Wright, 1983; Jackson & Short, 2020). Unlike sheltered beaches within estuaries, bays, or lagoons, which are shaped by attenuated hydrodynamic forces, ocean beaches are directly exposed to oceanic swells, producing distinctive physical and ecological characteristics such as high wave energy and faunal communities adapted to frequent disturbance (Jackson & Short, 2020). These beach systems provide critical habitat for coastal and marine species, regulate sediment and nutrient flows, and underpin a wide range of social, cultural, and economic values (Defeo et al., 2009).

CASE STUDY REGION: OCEAN BEACHES OF THE COORONG, LOWER LAKES AND MURRAY MOUTH (CLLMM)

The 'Coorong coast', stretching ~213 km along South Australia's south-eastern margin, is the longest high-energy beach system in Australia (Short, 2006). It begins close to a small cluster of rural townships near Middleton Point and extends southwards ~15 km to the Murray Mouth, a large estuarine outlet at the end of the Murray-Darling Basin (Figure 1). Immediately landward of the Murray Mouth lie the Lower Lakes, specifically Lake Alexandrina and Lake Albert, which are two broad, shallow, and predominantly freshwater systems that form the terminal sink of the River Murray and connect intermittently to the Southern Ocean through the Murray Mouth (Tibby et al., 2020). Beyond the Murray Mouth, the ocean beach continues for a further ~198 km south, with much of this stretch of beach along the Younghusband Peninsula, a narrow, linear sand barrier that encloses the Coorong Lagoon System (Bourman, et al., 2016). This barrier-dune complex is shaped by persistent swell, strong longshore currents, and wind-driven sand transport, and is characterised by exposed surf zones, wide sandy beaches, and mobile dune fields, forming a highly dynamic coastal system (Bourman et al., 2016).

Together, the Coorong, Lower Lakes and Murray Mouth (CLLMM) region encompasses a diverse mosaic of marine, coastal, and estuarine ecosystems, including a Ramsar-listed wetland of international importance (Phillips et al., 2006; Kingsford et al., 2011), with each component having received differing levels of attention. Notably, the Murray Mouth estuary forms the critical connection between the river, lakes, and the ocean, influencing tidal exchange, nutrient flows, and the ecological functioning of the broader wetland system (Kingsford et al., 2011). However, freshwater flows to the estuary and lagoons have been substantially reduced since the construction of a series of upstream barrages, altering the hydrology and salinity regimes of these wetland systems (Walker & Thoms, 1993; Brookes et al., 2009). Disruption of this region also has cultural implications, as it holds deep significance for the Ngarrindjeri people, the Traditional Owners, whose connection to these lands and water spans thousands of years and is embedded in cultural, spiritual, and ecological knowledge systems (Birkhead et al., 2011; Bourman et al., 2019). While the wetlands have consequently received significant scientific and management attention, the ocean beaches along the seaward margin of the CLLMM region, although directly influenced by processes at the Murray Mouth, have remained comparatively understudied. These beaches form an integral but distinct component of the broader system, shaped primarily by oceanic swells rather than estuarine hydrodynamics, and thus require dedicated consideration.



Figure 1: Map of the Coorong, Lower Lakes, and Murray Mouth (CLLMM) region in South Australia. The ocean beach system extends from Middleton Point to Cape Jaffa.

LITERATURE SEARCH STRATEGY

This review aimed to capture insights to the services provided by, and threats to, ocean beaches of the CLLMM region from both peer-reviewed and non-peer reviewed documents (i.e., grey literature). We therefore adopted a comprehensive, exploratory, and region-focussed approach to identify all available literature relevant to the ocean beaches of the CLLMM region. An iterative and flexible search strategy was used to capture information, which allowed for the inclusion of diverse document types and context-specific knowledge that may be underrepresented in formal databases.

Initial searches were conducted using scholarly electronic databases (Web of Science and Google Scholar) to identify papers published in English language journals related to the ocean beaches of the CLLMM region. A wide range of keywords were used for the searches, typically pairing geographic descriptors with ecological or social terms:

e.g., ("Coorong" OR "Murray Mouth" OR "Younghusband Peninsula") AND ("beach*" OR "ocean beach*" OR "sandy shore*" OR "sandy beach*"). A full list of search terms and representative Boolean combinations used in the literature search is provided in Table S1. In Web of Science, the titles and abstracts of all retrieved records were screened for relevance, while in Google Scholar we limited consideration to the first 10 pages (i.e., 100 results). This restriction was placed on our Google Scholar search results as preliminary screening indicated the relevance of results declined substantially beyond the first five pages (or 50 records). However, to minimise risk of missing pertinent material, we reviewed an additional five pages. We also searched institutional and agency repositories for grey literature, including Enviro Data SA (hosted by The Department of Environment and Water), Primary Industries and Regions South Australia (PIRSA), University of South Australia Digital Repository, and The University of Adelaide Digital Repository. Searches of these repositories were conducted using combinations of the same keywords employed in the scholarly electronic database searches. All databases were searched between May and September 2025. No restrictions were placed on year of publication and reference lists of retrieved documents were used to identify further relevant information sources. To supplement the literature search we also contacted regional stakeholders, including researchers and community groups, to identify any records that may not have been identified through the online search.

CONTENT ANALYSIS

From each document that contained information on the ocean beach system of the CLLMM region, core details were extracted into a metadata table. The recorded information included: (1) author(s); (2) document title; (3) year of publication; and (4) document type (categories were peer reviewed journal article, and grey literature sources of book, book chapter, conference proceedings, inquiry, management plan, newsletter, report, and thesis). Content-related details included: (5) study focus, defined as the primary ecological or social subject of the document (e.g., biota such as shorebirds, fishes, invertebrates, or vegetation; ecosystem attributes such as physical habitat, geomorphology, or water quality; or human use and management such as fisheries, recreation, or conservation policy).

We also recorded: (6) primary threats that were explicitly mentioned in each document. Threat categories followed the global framework of Defeo et al., (2009) but were adapted to the regional context of the CLLMM, resulting in six categories: Catchment impacts refer to alterations to freshwater river flows, including regulation, extraction, and diversion that affect coastal hydrology. Climate change encompasses large-scale stressors such as sea-level rise, ocean warming, and acidification. Human disturbance includes direct pressures from recreation (e.g., trampling, off-road vehicles) and coastal development or engineering (e.g., armouring, nourishment). Invasive species covers the establishment or accumulation of non-native flora and fauna that disrupt beach ecosystems. Overharvesting refers to exploitation of resources and associated incidental impacts on non-target species and habitats. Pollution includes inputs of plastics, sewage, oil, industrial waste, and nutrient enrichment that degrade beach environments. Documents that did not identify any threats were recorded in a category labelled unspecified. Examples of these documents with unspecified threats include, but are not limited to, biodiversity assessments, historical records, and publications describing coastal processes without reference to specific drivers of change. If a study focused on multiple threats, it was

counted once for each threat (i.e., each recorded as a separate entry in the database), while maintaining a unique document count to avoid duplication.

Lastly, we recorded: (7) ecosystem services, guided by the framework from Harris & Defeo (2022), which identified 56 ecosystem services relevant to ocean beaches using the Common International Classification of Ecosystem Services (CICES V5.1). Using this list, we reviewed each document obtained from our search to record whether a service from this list was explicitly mentioned in the document or could be strongly inferred based on clear ecological reasoning or well-established functional links. For analysis and presentation, CICES service classes were aggregated from the most detailed codes to the next hierarchical level (e.g., 2.2.1.1-2.2.1.4 were combined into 2.2.1). The full list of aggregated classes, showing how classes were collapsed to the next hierarchical level creating a list of 29 classes, is provided in Table S2. The list of all documents and associated metadata including recorded threats and ecosystem services is provided in Table S3.

RESULTS

In total we gathered 80 documents related to the ocean beaches of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region, with publication year spanning from 1981 to 2025. Of these documents, journal articles ($n = 34$) comprised the peer-reviewed component, while the remaining grey literature included reports (27), newsletters (8), theses (4), books (3), management plans (3), and technical reports (2), along with a book chapter (1), conference proceeding (1), and a parliamentary inquiry (1).

ECOSYSTEM SERVICES

A total of 147 occurrences of ecosystem services were identified across the three sections and 29 collapsed ecosystem service classes. Of the service sections, most were identified within regulation and maintenance (78 occurrences), followed by cultural (37 occurrences) and provisioning (32 occurrences). Notably, while the vast majority of documents identified at least one ecosystem service provided by these beach systems (68 documents, or 85%), some did not identify any specific ecosystem services (12 documents, or 15%). The identification of ecosystem services in the CLLMM region has increased steadily over the past four decades, with the most rapid growth occurring since approximately 2008 (Figure 2). Cultural and regulating services were recorded earliest in the reviewed literature, while provisioning services appeared later. All three service categories show an accelerating rate of recognition over time.

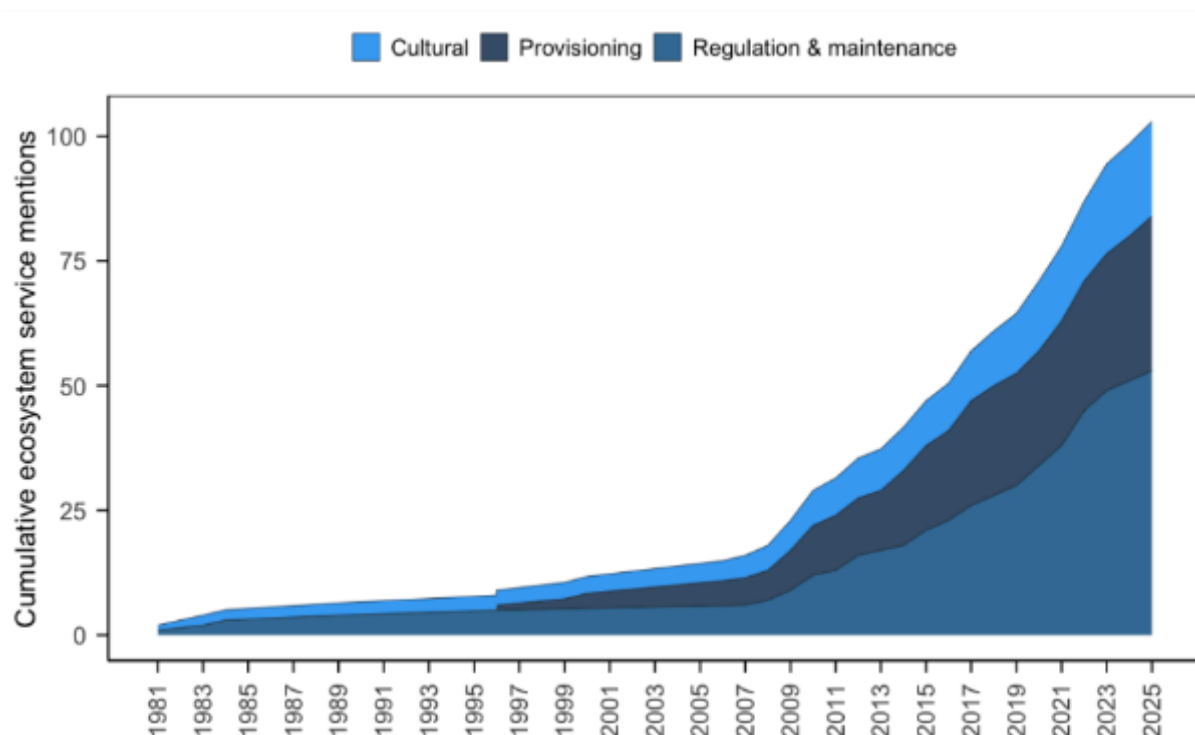


Figure 2. Cumulative mentions of ecosystem services compiled from 80 unique documents relevant to the ocean beach system within the Coorong, Lower Lakes and Murray Mouth (CLLMM) region between 1981 to 2025. Each document could be assigned to multiple ecosystem services categories with services classified into three sections – provisioning, regulation and maintenance, and cultural (CICES V5.1).

Provisioning services were documented 32 times, accounting for 22% of all ecosystem services identified in our review (Table 1). Within this section, services were represented almost exclusively by *Wild animals (terrestrial and aquatic) used for nutrition, direct use, or processing*, which made up 94% of occurrences. This class was the second most documented in the literature, and was dominated by fisheries, particularly pipi (*Latona deltoides*) and mullocky (*Argyrosomus japonicus*), which were repeatedly identified as key sources of food. The only other provisioning services identified were *Mineral substances used for nutritional or material purposes* and *Non-mineral resources used for nutritional or material purposes, or solar energy*, each contributing 3%.

Regulation and maintenance services were the most frequently documented section with 78 occurrences, accounting for 53% of all ecosystem services across the reviewed documents (Table 1). Within this section, the most frequently represented service class was *Maintenance of nursery populations and habitats, including dispersal functions*, which made up 62% of occurrences and was the most reported service class overall. This service was most often linked to the provision of habitats for shorebirds, as well as nursery areas for fisheries. A small number of other services had moderate representation, including *Regulation of erosion and water flows* (12%), *Bioremediation and filtration/storage by organisms* (10%), and *Water quality regulation* (9%). All remaining services were recorded between zero and two times (for $\leq 3\%$).

Cultural services were documented 37 times, accounting for 25% of all ecosystem service occurrences identified in our review (Table 1). Within this section, the most frequently represented services were *Characteristics of living systems that enable nature-based interactions that support health and well-being* (30%) and

Characteristics of living systems that hold scientific, educational, cultural, and aesthetic value (27%). The next most documented services were *Elements of living systems that enable contemporary or inter-generational values* (19%), and *Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions* (16%). Other services were less frequently identified, including *Elements of living systems that enable symbolic, spiritual, and place-based cultural value* (5%), *Natural, abiotic characteristics of nature that enable spiritual, symbolic and other interactions* (3%). Two cultural classes, *Natural, abiotic characteristics of nature that enable intellectual interactions* and *Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value*, were not identified in the reviewed literature.

Table 1: Ecosystem service-threat matrix for studies conducted along ocean beaches of the Coorong, Lower Lakes and Murray Mouth (CLMM) Region. Ecosystem services are presented in a collapsed form from the Common International Classification of Ecosystem Services (CICES v5.2), grouped by section (provisioning, regulation and maintenance, and cultural). Shading indicates the number of occurrences of each threat-service pairing across the literature. See Table S2 for the hierarchical structure used to aggregate CICES classes into the collapsed classes presented here; Table S4 for the full (non-collapsed) service-threat matrix. The list of documents and associated metadata are available.

SECTION	CLASS (ECOSYSTEM SERVICE)	THREAT						Total occurrences	Unique documents
		Catchment impacts	Climate change	Human disturbance	Invasives	Overharvesting	Pollution		
Provisioning	Animals reared by in-situ aquaculture for nutritional purposes							0	0
	Wild plants (terrestrial and aquatic, including fungi, algae) used for nutrition or materials							0	0
	Wild animals (terrestrial and aquatic) used for nutrition, direct use, or processing							30	26
	Seeds, spores and other plant materials collected for maintaining or establishing a population							0	0
	Animal material collected for the purposes of maintaining or establishing a population							0	0
	Surface and marine water for detritus, material use, and energy							0	0
	Ground (and subsurface) water for detritus							0	0
	Mineral substances used for nutritional or material purposes							1	1
	Non-mineral resources used for nutritional or material purposes, or solar energy							1	1
	Total Provisioning Ecosystem Services	3	0	1	0	24	2	32	
Regulation & Maintenance	Bioremediation and filtration/sequestration/storage/accommodation by micro-organisms, algae, plants, and animals							8	8
	Sediment reduction, noise attenuation and visual screening							0	0
	Regulation of erosion and water flows							9	9
	Maintenance of nursery populations and habitats, including dispersal functions							18	14
	Biological regulation of soil quality and structure							1	1
	Regulation of the chemical condition of salt waters by living processes							2	2
	Regulation of atmospheric, oceanic, and climate conditions							2	2
	Water quality regulation							7	7
	Mediation of resistance by abiotic structures or processes							0	0
	Abiotic regulation of mass, liquid, or gaseous flows							0	0
	Maintenance and regulation by inorganic natural chemical and physical processes							1	1
	Other food, larval and gamete dispersal by physical processes							0	0
	Total Regulation & Maintenance Ecosystem Services	10	0	20	11	14	2	78	
Cultural	Characteristics of living systems that enable nature-based interactions that support health and well-being							11	10
	Characteristics of living systems that hold scientific, educational, cultural, and aesthetic value							10	8
	Elements of living systems that enable symbolic, spiritual, and place-based cultural value							2	1
	Elements of living systems that enable contemporary or inter-generational values							7	7
	Natural, abiotic characteristics of nature that enable active or passive physical and experiential interactions							6	6
	Natural, abiotic characteristics of nature that enable intellectual interactions							0	0
	Natural, abiotic characteristics or features of nature that have either an existence, option or bequest value							1	1
	Total Cultural Ecosystem Services	5	1	30	1	8	0	37	
Total occurrences		18	1	48	12	46	4	122	
Documents per threat		9	1	25	6	23	4	12	

THREATS

Of the six threat categories considered, most frequently reported in the literature were human disturbances and overharvesting, which were similar in occurrence (48 and 46 occurrences, respectively). Following these were catchment impacts and invasives (18 and 12). The least recorded threats, with less than 10 occurrences throughout the literature each, were climate change and pollution. Twelve documents did not identify any threats. Notably, those threats which were recorded earliest (i.e. human disturbance and overharvesting) had the most occurrences, while those more recently documented (i.e. pollution and climate change) had the least (Figure 3). Only three documents addressed multiple threats, and all six primary threats were represented, although with uneven frequency.

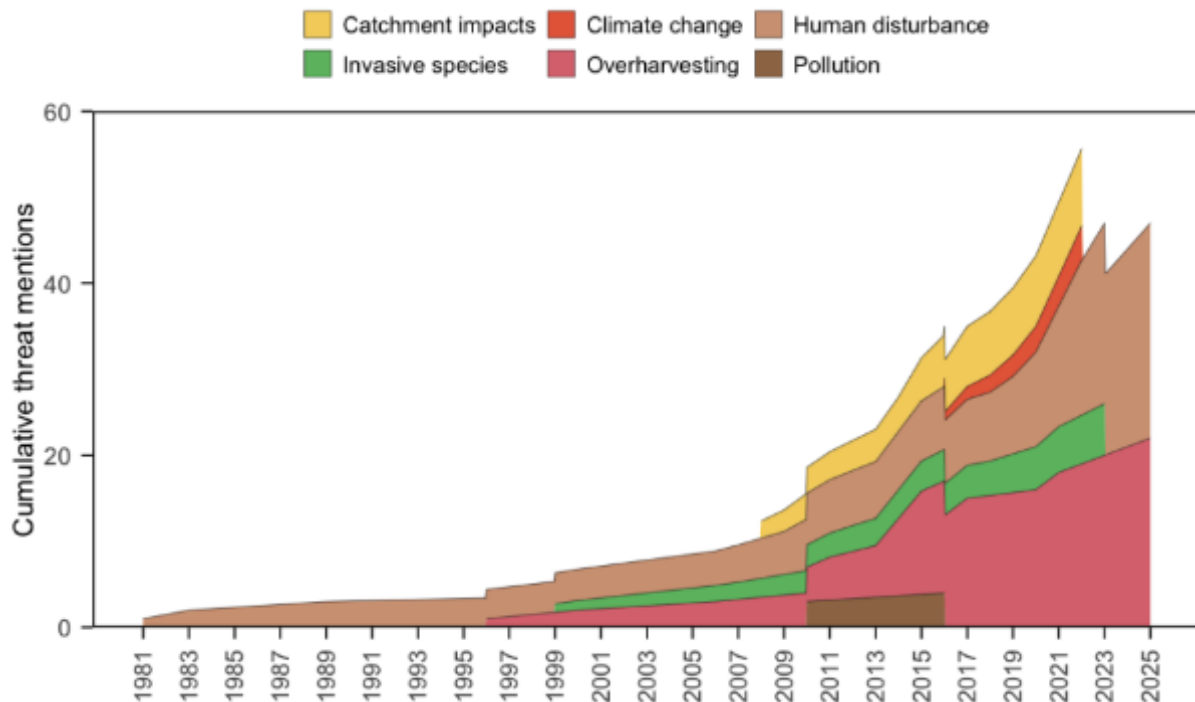


Figure 3. Cumulative mentions of threats compiled from 80 unique documents relevant to the ocean beach system within the Coorong, Lower Lakes and Murray Mouth (CLLMM) region between 1981 to 2025. Only clearly identified threat categories were included; records where threats were unspecified were excluded.

ECOSYSTEM SERVICE-THREAT LINKAGES

The ecosystem service sections and primary threat pairings included in the literature showed distinct imbalances (Table 1; Figure 4). Provisioning services were predominantly linked to overharvesting (24 occurrences, 75%), with relatively minor connections to catchment impacts, human disturbance, and pollution (each with ≤ 3 occurrences, or $\leq 10\%$). Climate change and invasive species were not linked to provisioning services in any of the reviewed documents. Regulation and maintenance services displayed the broadest spread across threats, though most occurrences were still concentrated on human disturbance (28 occurrences, 36%) and overharvesting (14 occurrences, 18%), with fewer links to invasive species, catchment impacts, climate change, and pollution (all $< 15\%$). Cultural services were similarly dominated by associations with human disturbance (19 occurrences, 51%), although overharvesting also featured notably (8 occurrences, 22%). Other threats, including catchment impacts, climate change, and invasive species, were comparatively infrequent (all $< 15\%$). No associations were documented between cultural services and pollution. In addition, several studies identified threats without documenting associated services, which were captured in the “unidentified” ecosystem service category, and were most often linked to unspecified threats.



Figure 4: Links between ecosystem service sections (provisioning, regulation and maintenance, and cultural) and threats identified in the reviewed literature on ocean beaches of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. The width of flows represents the relative frequency of associations recorded across 80 unique documents.

DISCUSSION

Diverse ecosystems, including ocean beaches, are vital providers of ecosystem services, yet recognising which services are prioritised and their perceived threats requires synthesising dispersed knowledge. Here, we brought together evidence from a range of sources to examine how ecosystem services provided by ocean beaches are characterised, and how different threats are linked to those services. We focus on ocean beach ecosystems, which have historically received limited attention compared to other coastal ecosystems such as coral reefs, seagrass meadows, and mangroves. Our review of ocean beaches in the CLLMM revealed that certain ecosystem services have been strongly emphasised, particularly those with the potential for immediate economic or ecological visibility. This emphasis translated into a strong focus on provisioning services, particularly wild animals used for nutrition (i.e., fisheries), and on regulation and maintenance services, most often through nursery habitats. Correspondingly, the threats most frequently documented were overharvesting and human disturbance from direct physical use of beaches such as recreational off-road driving. Future research could usefully broaden this scope to include services and threats that have so far received limited consideration, such as symbolic cultural values and the emerging influence of global pressures, such as climate change, on the capacity of beaches to buffer extreme events. Applying similar approaches in other understudied regions could help consolidate dispersed knowledge and generate comparable insights.

PROVISIONING SERVICES

Among the ecosystem services that ocean beaches provide, provisioning services are the material goods obtained from ecosystems, including food, freshwater, and other resources that support human livelihoods and well-being. In the CLLMM region, provisioning services were almost exclusively represented by food from wild animals such as pipi (*L. deltoides*) and mulloway (*A. japonicus*), which underpin local fisheries. These services were frequently reported in the literature, underscoring their importance as both recreational and commercial fisheries (King, 1985; McLachlan et al., 1996; Ferguson et al., 2014; Status of Australian Fish Stocks, 2023; Durante et al.,

2025), as they contribute significantly to local livelihoods while also supporting interstate and global export markets (Australian Trade and Investment Commission, 2025).

The main threat identified to the provisioning services provided by ocean beach fisheries in the CLLMM region is overharvesting, which can reduce stocks of key species, limiting their availability for both commercial and recreational use. Overexploitation can also alter population dynamics, weakening resilience to environmental variability, and compounding the impacts of other stressors. Other threats to fishery provisioning were rarely considered despite their potential impacts. For example, human disturbance associated with off-road vehicles on beaches can cause substantial mortality of intertidal infauna (e.g. pipi) through crushing impacts (Schlacher et al., 2008). At broader spatial scales, alterations to estuarine flow can disrupt the delivery of nutrients that underpin coastal productivity (Loneragan, 1999; Ferguson et al., 2008). Excessive or poorly timed flows arising from altered flow regimes, such as those influenced by the River Murray barrages, can act as a form of pollution by transporting nutrients from upstream agriculture and degrading water quality (Carpenter et al., 1998). Climate change introduces additional risks to fisheries through process such as ocean warming, marine heatwaves, ocean acidification, and reduced estuarine flows, contributing to shifts in species distributions, declines in productivity, and heightened vulnerability to overexploitation. These changes ultimately affect provisioning to people and their associated health and wellbeing (Pörtner & Peck, 2010; Hobday et al., 2016; Gillanders et al., 2011; IPCC, 2022; Falkenberg et al., 2020). Despite these multiple pathways of impact, many non-harvest threats to fisheries in the CLLMM were weakly represented in the reviewed literature. While fisheries are central to local economies and livelihoods, other potential provisioning services, such as wild plants, water resources, and renewable energy, were not identified in the literature. Their absence likely reflects limited use or current lack of development in the CLLMM region, rather than irrelevance. Exploring their potential importance may be worthwhile, particularly as global disruptions associated with climate change destabilise resource systems and increase reliance on local sources of material goods (Springmann et al., 2016).

REGULATION AND MAINTENANCE SERVICES

Regulation and maintenance services play a critical role in sustaining ecosystem structure and function, supporting processes such as habitat maintenance, nutrient cycling, and buffering against environmental extremes. In the CLLMM region, the reviewed literature most frequently focussed on nursery habitats for key species. As many species depend on these habitats during vulnerable life stages, disturbance or degradation of nursery areas can have disproportionate effects on population dynamics and ecosystem functioning.

Human disturbance emerged as the most frequently recorded threat, largely associated with impacts on shorebirds. Activities such as off-road driving are known to negatively affect shorebirds on ocean beaches globally (Schlacher et al., 2013; 2025) and evidence from the CLLMM region indicates that these disturbances can alter foraging and breeding behaviour and cause direct mortality (Buick & Paton, 1989; Jones et al., 2015). Overharvesting was the second most frequently identified threat, particularly in relation to fishery species whose life cycles depend on these habitats, such as mullet which rely on the surf zone at the Murray Mouth as a critical spawning and nursery ground (Ferguson et al., 2014). The sustainability of these species

is tightly linked to the protection of habitats that support reproduction and early life stages (Beck et al., 2001).

Many other regulating processes, however, received comparatively little attention, despite their role in sustaining the physical and ecological functioning of ocean beach ecosystems. Services such as erosion control, water flow regulation, and mediation of runoff and base flows are critical given the strong influence of river discharge and catchment inputs on beach morphology and productivity (Brauman et al., 2007), yet these processes were rarely linked explicitly to ocean beaches in the CLLMM region. Regulating services that buffer extreme events (e.g., storms, floods, and marine heatwaves) are becoming increasingly important under climate change, as they maintain shoreline integrity and support ecosystem resilience which directly shape the benefits ocean beaches provide to society (Defeo et al., 2009; Everard et al., 2010; Barbier et al., 2011). For example, the CLLMM ocean beach–dune system is undergoing long-term geomorphic change, with foredunes retreating landward in response to sediment dynamics and sea-level rise (DaSilva et al., 2024). Projected sea-level rise under climate change is expected to further amplify coastal retreat and alter shoreline configuration across sandy coastlines globally (Odériz et al., 2022). These geomorphic shifts directly influence beach width, sediment budgets, habitat availability, and the resilience of ecological communities (Defeo et al., 2009). The limited recognition of these functions highlights a critical gap: greater emphasis is needed on regulating services that are fundamental to the long-term sustainability of ocean beach systems.

CULTURAL SERVICES

Cultural services are the non-material benefits people obtain from ecosystems, including recreational, aesthetic, spiritual, and educational values that contribute to quality of life and community identity. Cultural services of ocean beaches are particularly important across Australia, where beaches are central to national identity, everyday recreation, and community life (Harvey & Caton, 2003). A growing body of evidence highlights the importance of nature-based interactions for human health and well-being, with regular engagement linked to psychological restoration, physical activity, and social cohesion (Martin et al., 2016). Yet, despite their significance, cultural services only accounted for ~25% of documented occurrences in our review of the CLLMM ocean beaches.

Human disturbance emerged as the dominant threat to cultural services, but this was recorded primarily in documents highlighting the cultural significance of shorebirds. Recreational activities such as off-road driving and beach visitation disrupt shorebird breeding and foraging, undermining both ecological values and diminishing the cultural benefits people derive from observing and engaging with these species. Other threats with substantial implications for cultural services were seldom represented in the reviewed literature. Globally, climate change is eroding cultural values on coasts, such as the loss of coastal heritage sites to sea-level rise (Reimann et al., 2018). Similarly, catchment impacts can diminish water quality and alter beach conditions, reducing their suitability for recreation, tourism, and cultural connection (Schuhmann et al., 2019; Furey et al., 2022). Yet, for the CLLMM region, the extent to which these pressures are reshaping ocean-beach ecosystems and their services remains poorly understood.

Spiritual and symbolic values, especially those tied to First Nations peoples' connections to Land and Sea Country, had limited representation in the reviewed

literature. This represents a critical gap. First Nations knowledge and custodianship are deeply embedded in the CLLMM region, where beaches and coasts hold profound cultural, spiritual, and historical significance (Ngarrindjeri Nation Yarluyar-Ruwe Plan, 2007). While these enduring connections to Country are well established, the literature rarely made explicit links to the services provided by ocean beaches themselves. The absence of cultural framing is particularly evident in relation to the overharvesting of pipis, which are not only a key fishery species but also a traditional food for First Nations peoples (Clarke, 2002). Their importance extends beyond sustenance: pipis are central to cultural practices and community gatherings, as reflected in extensive shell middens across the Coorong and Murray Mouth (Clarke, 1994). Connections such as these are integral to cultural identity and wellbeing, and their omission highlights the need to better recognise and incorporate First Nations perspectives alongside other cultural services.

A LOOK FORWARD: OPPORTUNITIES AND CHALLENGES

Syntheses such as this not only consolidate existing knowledge but also reveal where understanding remains limited. A major gap identified by this review concerns the limited attention given to the impacts of multiple, interacting threats. Ecosystems are seldom affected by a single driver in isolation; rather, change often arises from the convergence of pressures that interact in complex and potentially amplifying ways (Halpern et al., 2008; Crain et al., 2008; Folke et al., 2010). The ongoing marine harmful algal bloom (HAB) in South Australia illustrates this dynamic. Since March 2025, the HAB has affected ~20,000 km² of coastal waters and has been associated with mortality across more than 550 marine taxa (Government of South Australia, 2025; Murray et al., 2025). A dedicated community-led iNaturalist project has logged over 110,000 observations of deceased marine vertebrates and macroinvertebrates, illustrating the spatial extent and taxonomic breadth of the event (SA Marine Mortality Events 2025 - 2026 iNaturalist). The HAB has been associated with a combination of environmental conditions, including elevated sea surface temperatures linked to marine heatwaves, and increased nutrient inputs from catchment runoff and coastal upwellings (Government of South Australia, 2025), highlighting how interacting climatic and catchment processes may converge to generate large-scale ecological disruption. Beyond widespread beach closures and extensive ecological disruption, the event has also had substantial economic impacts on coastal industries. Media reporting indicated that one major South Australian abalone producer estimated revenue losses of ~AU\$5 million (Lance, 2025). In addition, Tourism Industry Council South Australia reported that 99% of surveyed tourism businesses had experienced income losses, with an average decline of approximately AU\$52,000 per business and some exceeding AU\$100,000 (Tourism Industry Council South Australia, 2025).

Beyond ecological and economic consequences, extreme events can also undermine the cultural services of coastal “blue spaces” (White et al., 2010). The restorative and psychological values people derive from spending time by the ocean are tightly coupled to environmental health, with beaches especially valued for their recreational opportunities. Impacts extend beyond leisure, as growing evidence suggests that access to healthy coastal environments supports psychological well-being, physical activity, reduces stress, and contributes to community identity (White et al., 2013; Pichler et al., 2025). As the recent HAB illustrates, when ecosystem decline severs these connections, recreation can turn into a sense of exclusion and loss associated with profound psychological and physical distress (Le Busque et al. 2026). With climate change expected to increase the frequency and severity of extreme

events such as marine heatwaves and HABs, the risk of culture service disruption is likely to intensify (UNFCCC non-economic losses report, 2024). Yet in this review, we found that for the CLLMM, cultural services were rarely documented and linked to these threats, suggesting their potential loss may remain undocumented and unrecognised.

The disruption of cultural services by events such as HABs illustrates a broader point: patterns of ecosystem service provision are dynamic, shifting with the convergence of multiple stressors. The patterns identified in this review will likely change in response to emerging events and the intensifying impacts of climate change. Cumulative pressures resulting in events such as HABs illustrate how interacting threats can rapidly reconfigure both ecological functions and cultural services, and similar events are expected to become more frequent in the future. This increasing instability underscores the need for research and monitoring frameworks that move beyond isolated threats to anticipate how multiple drivers converge, and how the balance of ecosystem services at risk may change over time. By adopting more adaptive approaches that integrate ecological, cultural, and social dimensions, management can better prepare for the uncertainties ahead and support the long-term resilience of ocean beach ecosystems.

CONCLUSION

This review demonstrates how reviewing and synthesising existing knowledge can enhance insight to the services provided by, and threats to, ecosystems that have been under-represented in the literature. Here, we demonstrate this potential through a synthesis of ecosystem services and their threats represented in the literature on ocean beaches of the CLLMM region. Our review shows that research has tended to emphasise the most visible categories, such as fisheries and recreation, while other functions remain underexplored. Yet this unevenness also points to clear opportunities. By extending attention to less visible but still valuable services, such as shoreline protection, nutrient regulation, and cultural connections, future research can better capture the full value of ocean beaches. Similarly, recognising emerging and cumulative threats, particularly under a changing climate, offers a chance to anticipate, rather than simply react to, ecological disruption. Taking a holistic view of both services and threats will not only fill knowledge gaps but also strengthen management capacity to support resilient ecosystems and communities. In this way, the challenges identified using such approaches, both for ocean beach ecosystems and other understudied systems, can be reframed as a pathway towards more inclusive and adaptive conservation of ecosystems and the services on which we depend.

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Appendix B Social survey



This survey relates to the ocean beaches in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region, encompassing the 60-km Young Husband Peninsula and the 15-km Goolwa Beach (i.e. the two long ocean beaches either side of the Murray Mouth, collectively running between Middleton Point and Cape Jaffa)

This confidential survey will take approximately 10-15 minutes to complete. You choose to answer all or just some questions. You are under no obligation to complete the survey and can withdraw at any time, but we greatly appreciate your time if you can participate. You must be 18 years or older to participate. A participant information sheet with further information is available upon request.

☐

Please tick here if you consent to be involved in the research.



This study is being conducted by the University of South Australia in association with the Coorong and Lower Lakes Murray Mouth (CLLMM) Research Centre. This project has been approved by UniSA Human Ethics Committee. Protocol# 207119

1) Which of the following activities do you engage in, within the Coorong, Lower Lakes and Murray Mouth (CLLMM) region?

Land based activities:

☐ Socialising with family and friends

☐ Horse riding

☐ Motorbike riding

- | | | |
|---|--------------------------------------|---|
| ☐ Four wheel driving | ☐ Walking | ☐ ATV/Quad bike riding |
| ☐ Mountain bike riding (including e-bikes) | ☐ Dog walking | ☐ Birdwatching |
| ☐ Photography | | |

Water based activities:

- | | | |
|--------------------------------------|----------------------------------|-----------------------------------|
| ☐ Jet Skiing | ☐ Fishing | ☐ Swimming |
| ☐ Kitesurfing | ☐ Surfing | ☐ Cockling |

(Note – items were randomised in electronic version)

If you have another activity that is not listed in our options, please specify it here:

2) What do you value most when visiting ocean beaches in the CLLMM region? (tick one that you value most)

- ☐ Conservation/nature protection
- ☐ Scenery/aesthetics
- ☐ Spending time with family/friends

- ☐ Challenge/adventure
- ☐ Opportunity for solitude

3) What do you generally consider to be your primary motivation for visiting these beaches? (tick all that apply)

- ☐ To build new skills
- ☐ To help reduce stress or built-up tension
- ☐ To spend time with family and friends
- ☐ To teach/lead others
- ☐ To engage in a particular activity
- ☐ To help protect the environment
- ☐ To enjoy the outdoors (e.g. sounds and smells of nature)
- ☐ To enjoy the scenery

4) How frequently do you access ocean beaches in the CLLMM region? (tick one)

- ☐ Frequently throughout the whole year (>6 times)
- ☐ Frequently during summer (>6 times)
- ☐ Frequently during times other than summer (>6 times)
- ☐ About 3-6 times a year.
- ☐

About twice a year

☐

About once a year

☐

Less than once a year

5) Please indicate which of the following categories you consider best describes your understanding of ocean beaches and coastal environments:



1

2

3

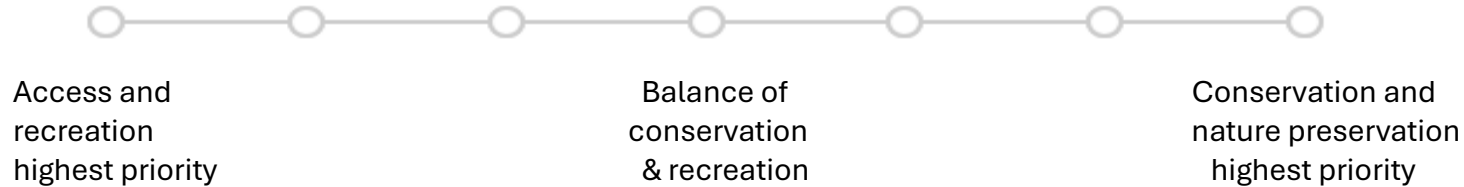
4

5

6) Please indicate how strongly you agree or disagree with each of the statements below (leave blank if you don't know):

	1	2	3	4	5
As dynamic environments ocean beaches can bounce back quickly from disturbances or impacts	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
Ocean beaches are environmentally sensitive areas	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
People using beaches responsibly cause minimal damage to the environment	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree

7) Please indicate where on the spectrum below your overall value system lies in relation to the protection of ocean beaches in the CLLMM region:



8) What do you consider to be the three biggest threats to beaches in this region? Place a “1” in the box you believe is the biggest threat, place a “2” in the box you think is the second biggest threat, and a “3” in the box you believe is the next biggest threat:

- ☐ Climate change
- ☐ Pollution
- ☐ Beach driving
- ☐ Invasive species
- ☐ Human disturbance
- ☐ Overharvesting
- ☐ Catchment impacts
- ☐ Other (please specify): _____

9) Do you usually drive (or sit in a car that someone else is driving) on the beach when you visit a beach in the CLLMM region?

☐ Yes☐ No

10) With respect to use of beaches, including driving on beaches, please indicate how strongly you agree/ disagree with each statement below (leave blank if you don't know):

I am concerned about long-term environmental damage to beaches caused by vehicles	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
I think closure to all people in some areas of the study site are necessary	☐ Strongly disagree	☐ Disagree ☐	☐ Neither agree nor disagree	☐ Agree ☐	☐ Strongly agree
I think closures to vehicles in some areas of beach are necessary	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
I think temporal restrictions (based on time of year) on people are needed in some areas	☐ Strongly disagree	☐ Disagree ☐	☐ Neither agree nor disagree	☐ Agree ☐	☐ Strongly agree
I think temporal restrictions on vehicles (based on time of year) are needed in some areas.	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
I support limits to the number of vehicles on the beach at one time	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
I support a permit system that rewards responsible driving with greater access	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree

I support a permit system that penalizes irresponsible driving	☐ Strongly disagree	☐ Disagree	☐ Neither agree nor disagree	☐ Agree	☐ Strongly agree
I think greater attention to ecological restoration of this area is needed	☐ Strongly disagree	☐ Disagree ☐	☐ Neither agree nor disagree	☐ Agree ☐	☐ Strongly agree

11) How likely do you think climate change will significantly impact beaches in this region, where 1 = Not at all, 4 = Unsure, 7 = Very likely

Within 1 year



Within 5 years



Within 10 years



Within 30 years



12) Thinking about the harmful algal bloom that has affected South Australia over the last year, please indicate your level of agreement with the following statements related to how your beach use since the beginning of the bloom, where 1 = Strongly disagree, 4 = Neutral and 7 = Strongly agree (leave blank if statement doesn't apply)

1) I have stopped going to the beach myself

A horizontal scale bar with a light gray background and rounded ends. It has vertical tick marks at the far left and right, labeled '1' and '7' respectively. There are four unlabeled tick marks between them, dividing the scale into five equal segments.

2) I have stopped taking my family to the beach

A horizontal scale bar with a light gray background and rounded ends. It has vertical tick marks at the far left and right, labeled '1' and '7' respectively. There are four unlabeled tick marks between them, dividing the scale into five equal segments.

3) I have stopped taking my dog to the beach

A horizontal scale bar with a light gray background and rounded ends. It has vertical tick marks at the far left and right, labeled '1' and '7' respectively. There are four unlabeled tick marks between them, dividing the scale into five equal segments.

4) I have reduced the time I spend on the beach and/or changed what I do there

A horizontal scale bar with a light gray background and rounded ends. It has vertical tick marks at the far left and right, labeled '1' and '7' respectively. There are four unlabeled tick marks between them, dividing the scale into five equal segments.

5) I have reduced the amount of seafood I consume

A horizontal scale bar with a light gray background and rounded ends. It has vertical tick marks at the far left and right, labeled '1' and '7' respectively. There are four unlabeled tick marks between them, dividing the scale into five equal segments.

6) I have changed the way I interact with coastal environments in general

1 7

7) I have involved myself in activities to help monitor the effects of or to promote recovery from the bloom

1 7

8) I expect those in charge to do more to help protect beaches and the coastal environment

1 7

13) Now just a few questions about you:

a) Who do you typically visit beaches in this region with?

☐

Alone

☐

Partner

☐

Family

☐

Group of Friends

☐

Family and Friends

☐

Organised Group

b) What is the postcode of your primary residence?

c) How do you identify?

☐

Female

☐

Male

☐

Non Binary

☐

Prefer not to answer

☐

Other

d) In what year were you born? _____

14) Finally, we'd like you to map places within the Coorong, Lower Lakes and Murray Mouth (CLLMM) area that you consider:

- ☒ Special places (use green stickers)
- ☐ Your most frequented locations (use white stickers)
- ☐ Impacts you've seen that affect the way you use or experience this area (use orange stickers)
- ☐ Environmental issues are occurring (use red stickers)

Please put your stickers on the maps on the following pages – you have enough stickers to map up to three of each type of place (. You can place a single sticker in the middle of an area you'd like to map/highlight OR if there is a broader area you'd like to map you can use two stickers, one either end of the area of beach you want to highlight and maybe draw arrows on the stickers to indicate the area in between. Feel free to write on any other information you want to explain your choices onto the maps as well.

Additionally, is there anything you would like us to know about:

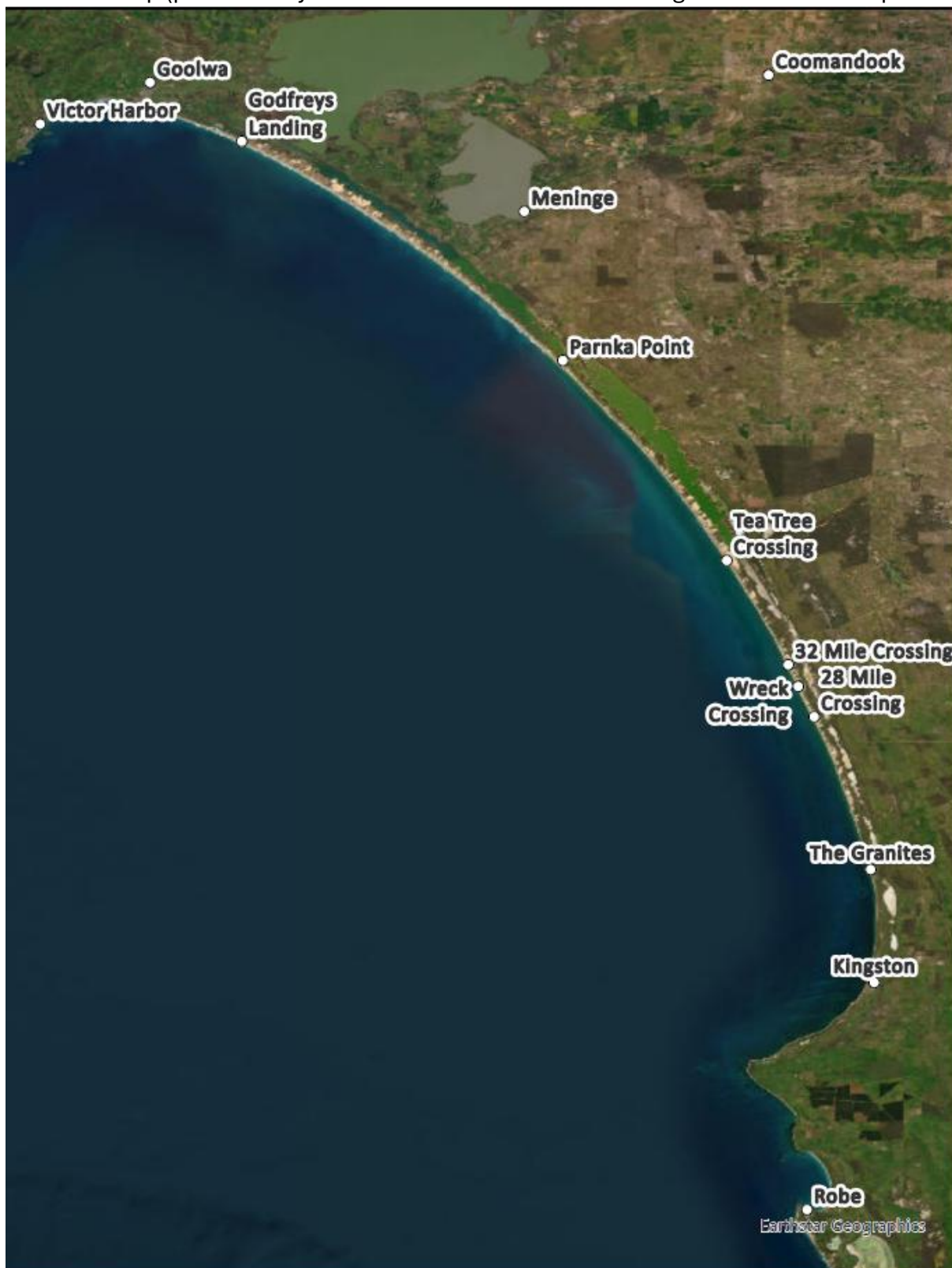
A) Your special places (e.g. what makes them special?)

B) Your most frequented locations (e.g. why do you go to these places the most, when and how often do you go?)

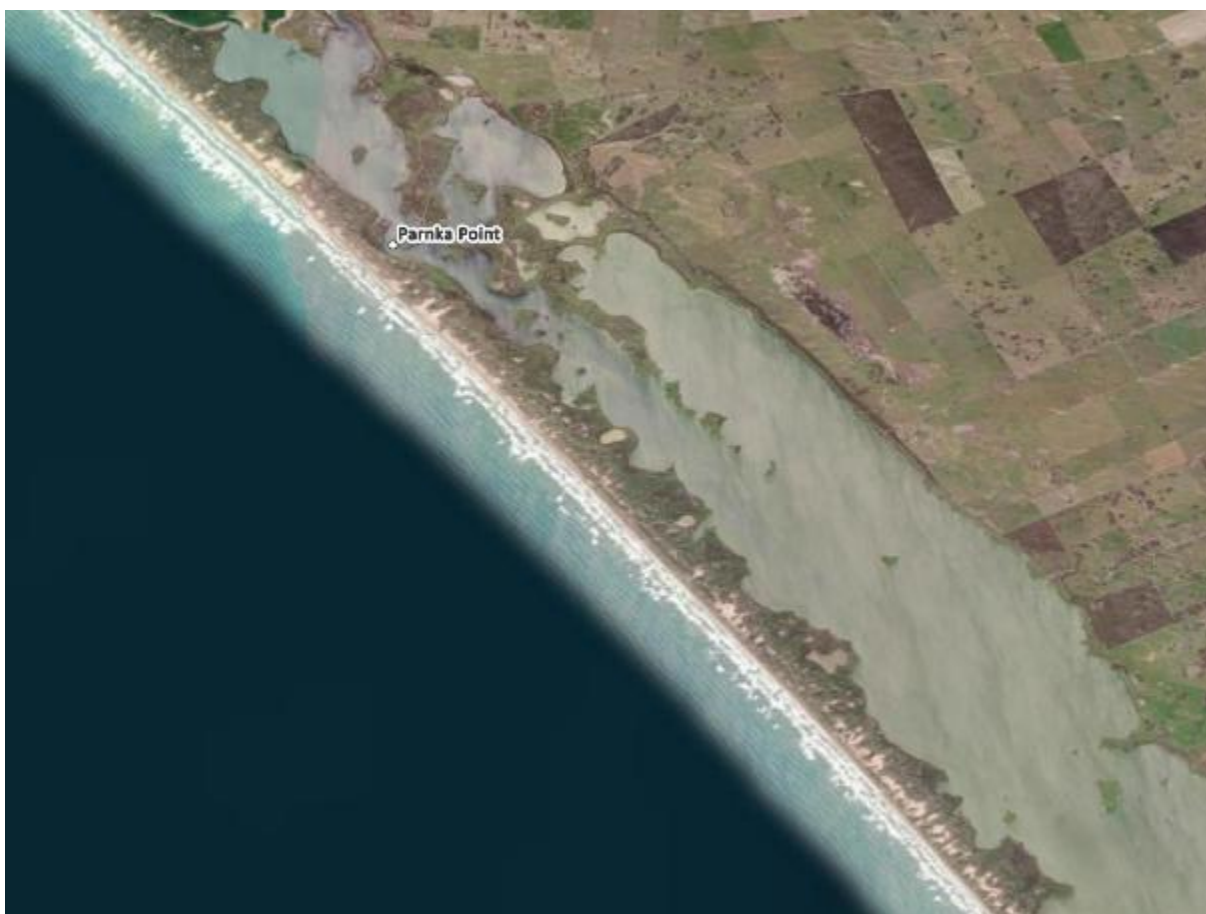
C) Impacts that affect the way you use or experience this place (e.g. what impacts have you seen and how are these affecting the way you use or value the beaches?)

D) Environmental issues (e.g. what impacts have you seen, what are causing these, and how might these be prevented or solved?)

Overview map (please add your stickers here or in the following more detailed maps.

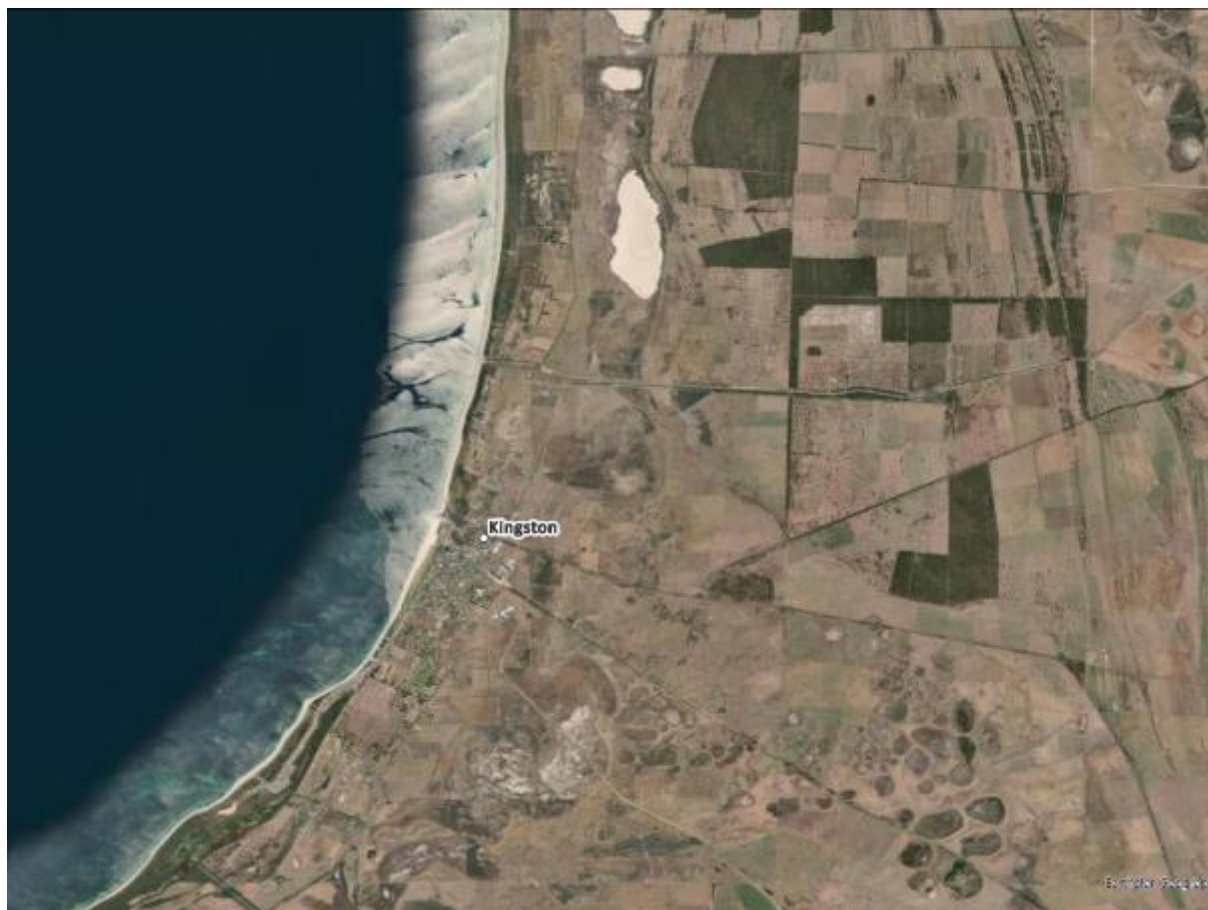












Thank you for completing the survey!

If you would like to be involved in further aspects of the study, please complete the contact details form and place in the box provided, or give it to our research team member.

**For further information,
please contact Delene Weber (delene.weber@unisa.edu.au)**

Appendix C Interview script

General Rapport Building Questions:

If we could start with a little about yourself. Could you tell me a little about your background?
Build rapport here, briefly self-disclose as an example if needed. Collect information on their:

- History in area
- Current Work
- Family
- Community involvement

Value Section:

Great thank you. Now if it's OK, I'd like to ask you some more questions about your experiences with the beaches in the study area.

1. What is it that you like about the beaches in the area generally?
2. How do you spend your time on the beaches in the area?
3. What things do you think are most important for you when you visit the beach?
4. What things limit your enjoyment of the beach do you think?
5. What would you like to see done to improve your experience of the beach?
6. What is your favourite memory of the coast? - Why?

Threats Section:

1. What problems do you feel negatively affect the beaches in this area?
2. Have you noticed any changes in the environment of the beaches in this area?
- 8.
3. What do you know about invasive species?
4. In what ways do you think invasive species have impacted the beaches in this area (please be specific)?
5. How big of a risk do you think invasive species present to the future of beaches in this area? Why?
6. What do you know about the water flow in this area?
7. In what ways do you think water flow has impacted the beaches in this area (please be specific)?
8. How big of a risk do you think water flow presents to the future of beaches in this area? Why?
- 9.
9. What do you know about overharvesting of certain species in this area?
10. In what ways do you think overharvesting of certain species has impacted the beaches in this area (please be specific, which species)?

11. How big of a risk do you think overharvesting of certain species presents to the future of beaches in this area? Why?
12. What do you know about the concept of climate change?
13. In what ways do you think climate change has impacted the beaches in this area (please be specific)?
14. How big of a risk do you think climate change presents to the future of beaches in this area? Why?
15. In what ways do you think human behaviours have impacted the beaches in this area (please be specific, which type of behaviours)?
16. How big of a risk do you think human behaviours present to the future of beaches in this area? Why?

Beach Driving Section.

1. Have you driven (or been a passenger in a car) on a beach in the area in the past 2 years? Yes/No

[If no]

2. What impact, if any, do you think driving on the sand has on the beach?

[If yes]

3. How long have you been driving on the beach for?
4. Is it something you used to do when you were growing up?
5. What led you to start actively beach driving? Could you describe how it came about?
6. How do you feel after a day of having headed out driving on the beach?
7. What impact, if any, do you think driving on the sand has on the beach?

Concluding questions.

Is there anything else you want to share about how you feel about the beaches in this area?

Appendix D Stakeholders of the CLLMM region

Stakeholder groups involved in the Coorong, Lower Lakes and Murray Mouth (CLLMM) region. Stakeholder types include: Government agencies and local councils, which are responsible for planning, regulation, and environmental management at state and local levels; Conservation and environmental organisations (not-for-profit), which focus on biodiversity conservation, restoration, and advocacy; Community and volunteer groups, which are locally driven and often involved in stewardship, monitoring, and on-ground activities; Tourism and recreation industry, which includes businesses providing nature-based tourism and recreational services; Commercial and industry stakeholders, which rely directly on coastal resources for economic activities; Recreational and sporting groups, which represent organised recreational use of coastal environments; and Research and academic institutions, which contribute scientific knowledge and research.

Table A2. Stakeholder Organisations in the Coorong, Lower Lakes and Murray Mouth (CLLMM) Region.

ORGANISATION	GEOGRAPHIC REGION	STAKEHOLDER TYPE
Alexandrina Council	Alexandrina	Government agency
BioR	CLLMM	Not-for-profit
BirdLife Australia	National	Not-for-profit
BirdLife Australia	South Australia	Not-for-profit
Birds SA	South Australia	Not-for-profit
Coastal Protection Board	South Australia	Government agency
Coorong District Council	Coorong	Government agency
Encounter Bay Right Whale Study	South Australia	Community and volunteer
Friends of Shorebirds SE	South-East SA	Community and volunteer
Friends of the Coorong	Coorong National Park	Community and volunteer
Goolwa to Wellington Local Action Plan Association	Lower Lakes, Upper Coorong	Community and volunteer
Hindmarsh Island Landcare	Hindmarsh Island	Community and volunteer
Kingston SE Surf Fishing Contest	Coorong	Recreational and sporting
Landscape Board	Murraylands & Riverland	Government agency
Landscape Board	Limestone Coast	Government agency
Landscape Board	Hills & Fleurieu	Government agency
Nature Glenelg Trust	South East SA, Coorong	Not-for-profit
Ocean Living Surf School	Goolwa, Middleton	Tourism & recreation Industry
OzFish Coorong	Coorong	Not-for-profit
OzFish Limestone Coast	Limestone Coast	Not-for-profit
PipiCo	Goolwa	Commercial industry
RecFish SA	South Australia	Not-for-profit

SA National Parks and Wildlife Service	South Australia	Government agency
SA Shorebirds Foundation	South Australia	Not-for-profit
SA Water	South Australia	Government agency
SA Whale Centre	South Australia	Tourism & recreation industry
Spirit of the Coorong	CLLMM	Tourism & recreation industry
Surf & Sun	Goolwa, Middleton	Tourism & recreation industry
Surf Life Saving (Goolwa)	Goolwa	Recreational and sporting
University of Adelaide	CLLMM	Research and academic institution
Victor Harbour Dolphin Watch	Victor harbour	Community and volunteer

Appendix E Documents and associated metadata of the CLLMM

Table A3. List of documents and associated metadata that contain information about the ocean beach system of the Coorong, Lower Lakes and Murray Mouth (CLLMM) region.

Author	Title	Year	Document type	Focus	Threat
Auricht, H., Clarke, K. D., Lewis, M. M., Mosley, L. M.	Have droughts and increased water extraction from the Murray River (Australia) reduced coastal ocean productivity	2017	Journal article	Water quality & productivity	Catchment impacts
Auricht, H., Mosley, L., Lewis, M., Clarke, K.	Mapping the long-term influence of river discharge on coastal ocean chlorophyll- <i>a</i>	2022	Journal article	River discharge and primary productivity	Catchment impacts
Baker, A.N.	Status, Relationships, and Distribution of Mesoplodon Bowdoini Andrews, 1908 (Cetacea: Ziphiidae)	2006	Journal article	Cetacean	Unspecified
BirdLife Australia	BirdLife Australia's Submission to the Parliament of South Australia Natural Resources Committee inquiry into the use of off-road vehicles.	2020	Inquiry	Shorebird	Human disturbance
Bourman, R.P., Murray-Wallace, C.V., Harvey, N.	Coastal landscapes of South Australia [chapters 4 & 5]	2016	Book	Geomorphology	Climate change
Buick, A. M., Paton, D. C.	Impact of off-road vehicles on the nesting success of Hooded Plovers Charadrius rubricollis in the Coorong region of South Australia	1989	Journal article	Shorebird	Human disturbance
Charlton, C., O'Shannessy, B., Moller, L., McCauley, R.	Scientific Background Scoping Paper: Enhancing protection of whales in coastal waters of South Australia	2023	Technical Report	Cetacean	Human disturbance
Colombelli-Négre, D., Nur, D., Auricht, H. C. C., Clarke, K. D., Mosley, L. M., Dann, P.	Combined Effects of Hydrological Drought and Reduced Food Availability on the Decline of the Little Penguins in South Australia	2022	Journal article	Seabird	Catchment impacts
Colombelli-Négre, D., Nur, D., Auricht, H. C. C., Clarke, K.	Combined Effects of Hydrological Drought and Reduced Food Availability on the Decline of the Little	2022	Journal article	Seabird	Climate change

D., Mosley, L. M., Dann, P.	Penguins in South Australia					
Corbett, E., Rifai, S. W., Miot da Silva, G., Hesp, P. A.	Temporal and Spatial Distribution of 2022–2023 River Murray Major Flood Sediment Plume	2025	Journal article	Water quality	Unspecified	
Department for Environment and Heritage	Managing Salinity in the Coorong – pumping hypersaline water out of the Southern Lagoon. Technical Feasibility Assessment	2010	Report	Salinity	Catchment impacts	
Department for Environment, Water and Natural Resources	Upper South East Marine Park Management Plan 2012	2012	Management plan	Management	Unspecified	
Department for Environment, Water and Natural Resources	Encounter Marine Park Management Plan 2012	2012	Management plan	Management	Unspecified	
Durante, L. M., Bailleul, F., Beckmann, C. L.	On-site survey of recreational fishing for Pipi in Goolwa, South Australia 2020-21	2022	Report	Fishery	Overharvesting	
Durante, L. M., Beckmann, C., Bailleul, F., Ferguson, G.	Existing datasets uncover complex interactions driving catches of a data-poor recreational fishery in South Australia	2024	Journal article	Fishery	Overharvesting	
Earl, J.	Assessment of the South Australian Lakes and Coorong Fishery in (2018/19)	2020	Report	Fishery	Overharvesting	
Earl, J.	Fishery statistics and performance indicators for the South Australian lakes and Coorong fishery	2017	Report	Fishery	Overharvesting	
Earl, J.	Fishery statistics for the South Australian Lakes and Coorong Fishery 2014/15.	2016	Report	Fishery	Overharvesting	
Earl, J.	Fishery statistics for the South Australian Lakes and Coorong Fishery (1984/85-2013/14).	2015	Report	Fishery	Overharvesting	
Earl, J., Ward, T. M.	Mulloway (Argyrosomus japonicus) Stock Assessment Report (2013/14).	2014	Report	Fishery	Overharvesting	
Edwards, D. S., Vinall, D. R., Corrick, A. J., McKirdy, D. M.	Natural bitumen stranding on the ocean beaches of Southern Australia: a historical and geospatial review	2016	Journal article	Pollution	Pollution	

Ekanayake, K., Cullen, M.	Report on the 2024 Biennial Hooded Plover Population Count	2025	Report	Shorebird	Human disturbance
Ekanayake, K., Cullen, M.	Report on the 2022 Biennial Hooded Plover Population Count	2023	Report	Shorebird	Human disturbance
Ferguson, G. J.	Assessment of the South Australian Pigi (Donax deltoides) Fishery in 2016/17.	2017	Report	Fishery	Overharvesting
Ferguson, G. J.	Pigi (Donax deltoides) Fishery	2013	Report	Fishery	Overharvesting
Ferguson, G. J., Hooper, G., Mayfield, S.	Temporal and spatial variability in the life- history of the surf clam Donax deltoides: Influences of density dependent processes	2021	Journal article	Fishery	Overharvesting
Ferguson, G. J., Ward, T. M.	Mullocky (Argyrosomus japonicus) Fishery	2011	Report	Fishery	Overharvesting
Ferguson, G. J., Ward, T. M., Gorman, D.	Recovery of a Surf Clam Donax deltoides Population in Southern Australia: Successful Outcomes of Fishery- Independent Surveys	2015	Journal article	Fishery	Overharvesting
Ferguson, G. J., Ward, T. M., Ivey, A., Barnes, T.	Life history of Argyrosomus japonicus, a large sciaenid at the southern part of its global distribution: Implications for fisheries management	2014	Journal article	Fishery	Catchment impacts
Ferguson, G. J., Ward, T. M., Ivey, A., Barnes, T.	Life history of Argyrosomus japonicus, a large sciaenid at the southern part of its global distribution: Implications for fisheries management	2014	Journal article	Fishery	Overharvesting
Ferguson, G. J., Hooper, G.E.	Pigi (Latona deltoides) Fishery (2025)	2025	Report	Fishery	Overharvesting
Ferguson, G. J., Hooper, G.E.	Pigi (Donax deltoides) Fishery 2020/21.	2021	Report	Fishery	Overharvesting
Ferguson, G., Mayfield, S.	The South Australian Goolwa Cockle (Donax deltoides) Fishery (2006)	2006	Report	Fishery	Overharvesting
Ferguson, G.J., Ward, T.M., Geddes, M.C.	Do recent age structures and historical catches of mullocky, Argyrosomus japonicus (Sciaenidae), reflect freshwater inflows in the remnant estuary of the Murray River, South Australia?	2008	Journal article	Fishery	Catchment impacts
Friends of Shorebirds SE	Protecting Hooded Plovers by Controlling Beach Weeds Project	2023	Report	Shorebird	Invasive species

	summary and Coastal Weed Control Plan.				
Furbank, D., Mead, R., Maguire, G.	Monitoring Hooded Plovers on the Adelaide coast and Fleurieu Peninsula: A summary of breeding success for the 2022-23 season	2024	Report	Shorebird	Human disturbance
Gilbertson, D.D.	The Impacts of Off-Road Vehicles in the Coorong Dune and Lake Complex of South Australia	1983	Book	Geomorphology	Human disturbance
Gilbertson, D.D.	The impact of past and present land use on a major coastal barrier system	1981	Journal article	Geomorphology	Human disturbance
Gorman, D., Ferguson, G., Mathews, C., Ward, T.	Inter-tidal infauna of the Younghusband Peninsula: assessing the potential impacts of discharge of hypersaline water	2010	Report	Fishery	Pollution
Hesp, P. A., DaSilva, M., Miot da Silva, G., Bruce, D., Keane, R.	Review and direct evidence of transgressive aeolian sand sheet and dunefield initiation	2022	Journal article	Geomorphology	Climate change
Hilton, M., Harvey, N., James, K.	The impact and management of exotic dune grasses near the mouth of the Murray River, South Australia	2007	Journal article	Dune vegetation	Invasive species
Izzo, C., Manetti, D., Doubleday, Z.A., Gillanders, B.M.	Calibrating the element composition of Donax deltoides shells as a palaeo-salinity proxy	2017	Journal article	Fishery	Catchment impacts
James, K.F.	Gaining New Ground: Thinopyrum junceiforme, A Model of Success Along the South Eastern Australian Coastline	2012	Thesis	Dune vegetation	Invasive species
Jones, G.K.,	Changes in distribution and abundance of Australian pied and sooty oystercatchers on highly disturbed beaches of the south-eastern fleurieu Peninsula, South Australia	2015	Journal article	Shorebird	Catchment impacts
Jones, G.K.,	Changes in distribution and abundance of Australian pied and sooty oystercatchers on highly disturbed beaches of the south-eastern fleurieu Peninsula, South Australia	2015	Journal article	Shorebird	Human disturbance
Jones, G.K.,	Changes in distribution and abundance of Australian pied and sooty	2015	Journal article	Shorebird	Overharvesting

	oystercatchers on highly disturbed beaches of the south-eastern fleurieu Peninsula, South Australia				
Joury, M. R. F., James, N. P., James, C.	Nearshore cool-water carbonate sedimentation and provenance of Holocene calcareous strandline dunes, southeastern Australia	2018	Journal article	Geomorphology	Unspecified
Kemper, C. M., Steele-Collins, E., Al-Humaidhi, A., Segawa Fellowes, T., Marsh, O., Charlton, C.	Encounter Bay, South Australia, an important aggregation and nursery area for the southern right whale, Eubalaena australis (Balaenidae: Cetacea)	2022	Journal article	Cetacean	Human disturbance
Kemper, C.M.	Osteological variation and taxonomic affinities of bottlenose dolphins, Tursiops spp., from South Australia	2021	Journal article	Cetacean	Unspecified
Lester, R. E., Fairweather, P. G.	Synthesising potential impacts of the proposed South Lagoon Salinity Reduction Scheme on the Encounter Bay receiving marine environment	2010	Report	Salinity	Pollution
McLachlan, A., Dugan, J. E., Defeo, O., Ansell, A. D., Hubbard, D. M., Jaramillo, E., Penchaszadeh, P. E.	Beach clam fisheries	1996	Journal article	Fishery	Overharvesting
Moulton, M.A., Hesp, P.A., Miot da Silva, G., Bouchez, C., Lavy, M., Fernandez, G.B.	Changes in vegetation cover on the Youngusband Peninsula transgressive dunefields (Australia) 1949–2017	2018	Journal article	Dune vegetation	Invasive species
Moulton, M.A.B.	Drivers of coastal dune dynamics on the Youngusband Peninsula, South Australia	2020	Thesis	Geomorphology	Invasive species
Murray-Jones, S., Steffe, A.S.	A comparison between the commercial and recreational fisheries of the surf clam, Donax deltoides	2000	Journal article	Fishery	Overharvesting
Murray-Wallace, C.V.	Holocene Coastal Sedimentary Environments of the Coorong Coastal Plain, Southern Australia. In: Quaternary History of the	2018	Book chapter	Geomorphology	Unspecified

Coorong Coastal Plain,
Southern Australia.

Ngarrindjeri Tendi, Ngarrindjeri Heritage Committee, Ngarrindjeri Native Title Management Committee	Ngarrindjeri Nation Yarlurwar-Ruwe Plan	2006	Management Plan	First Nations	Human disturbance
Nieblas, A. E., Sloyan, B. M., Hobday, A. J., Coleman, R., Richardson, A. J.	Variability of biological production in low wind-forced regional upwelling systems: A case study off southeastern Australia	2009	Journal article	Upwelling	Unspecified
Opperman, A.	A biological survey of the South Australian coastal dune and clifftop vegetation 1996-1998	1999	Report	Dune vegetation	Invasive species
Paton, D.C.	At the End of the River: The Coorong and Lower Lakes: Chapter 2 - The coorong beach: A high energy coastline	2010	Book	Shorebird	Human disturbance
Pavey, C.R.	The occurrence of the Pygmy Right Whale <i>Caperea marginata</i> (Cetacea: Neobalaenidae), along the Australian coast	1992	Journal article	Cetacean	Unspecified
Primary Industries and Regions South Australia	South Australian Beach-Cast Seagrass and Marine Algae Fishery Assessment	2014	Report	Fishery	Overharvesting
Ramsdale, T.M.	Ecological impacts of vehicles on the sandy beaches of southern Adelaide, South Australia	2009	Thesis	Macrofauna & meiofauna	Human disturbance
Roetman, J., Mead, R., Maguire, G., Bartley, K.	Monitoring Hooded Plovers on the Adelaide coast and Fleurieu Peninsula: A summary of breeding success for the 2023-24 season	2025	Report	Shorebird	Human disturbance
SA Murray Darling Basin NRM Board	Preliminary Hydrodynamic Modelling for Coorong Temporary Saline Discharge	2010	Report	Salinity	Pollution
Sanchez, S., Cullen, M., Maguire, G.S.	Fairy Tern census in south-eastern Australia in 2023/2024	2024	Report	Shorebird	Human disturbance
Sarakinis, K. G., Earl, J.	Assessment of the South Australian Lakes and Coorong Fishery in 2022/23.	2024	Report	Fishery	Overharvesting

Shaughnessy, P. D., Kemper, C. M., Ling, J. K.	Records of vagrant phocid seals (family Phocidae) in South Australia	2012	Journal article	Pinniped	Unspecified
Shaughnessy, P. D., Tomo, I., Gibbs, S. E., Kemper, C. M., Stemmer, D.	Records of leopard seals <i>Hydrurga leptonyx</i> ashore in South Australia	2023	Journal article	Pinniped	Unspecified
Short, A.D.,	Australian beach systems: Are they at risk to climate change?	2022	Journal article	Geomorphology	Climate change
Short, A.D.,	Australian beach systems—nature and distribution.	2006	Journal article	Geomorphology	Unspecified
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 8. March, 2023	2023	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 6. March, 2022	2022	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 7. September, 2022	2022	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 4. March, 2021	2021	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 5. August, 2021	2021	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 3. September, 2020	2020	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 2. August, 2019	2019	Newsletter	Shorebird	Human disturbance
South Australian Shorebirds Foundation	Team oystercatcher newsletter: No. 1. August, 2018	2018	Newsletter	Shorebird	Human disturbance
Stephens, E., Mead, R., Maguire, G.	Monitoring Hooded Plovers on the Adelaide coast and Fleurieu Peninsula: A summary of breeding success for the 2020/2021 season	2021	Report	Shorebird	Human disturbance
Vanderzon, E.	Investigating the impacts of human activities on oystercatcher presence and foraging behaviour along a multi-use recreational sandy beach ecosystem	2022	Thesis	Shorebird	Human disturbance
Wainwright, P., Christie, M.	Wader surveys at the Coorong and SE coastal lakes, South Australia	2008	Conference proceedings	Shorebird	Catchment impacts

Ward, T., Ferguson, G., Payne, N., Gorman, D.	Effectiveness of fishery-independent surveys for monitoring the stock status of pipi (<i>Donax deltoides</i>) on the Youngusband Peninsula, South Australia	2010	Report	Fishery	Overharvesting
Western, M., Hesp, P., Bourman, R.	Coastal adaption study	2019	Technical Report	Geomorphology	Climate Change
Wright, L. D., Short, A. D.	Morphodynamic variability of surf zones and beaches	1984	Journal article	Geomorphology	Unspecified

