Marine and Coastal

National Environmental Science Program

FINAL REPORT

Project 1.5: Scoping Study

October 2022

Scoping for an Australian Wetland Inventory: Identify knowledge gaps and solutions for extent mapping of Australian marine and coastal wetlands

Rachael Brock, Jasmine Rasmussen, Fernanda Adame, Christopher Brown, Rod Connolly

Griffith UNIVERSITY
Queensland, Australia

Milestone number: 6

Research Plan number: RP2021

Please address inquiries to: Rod Connolly
r.connolly@griffith.edu.au

Preferred citation

Brock RJ, Rasmussen J, Adame MF, Brown CJ, Connolly RM (2022) *Identifying knowledge gaps and solutions for extent mapping of Australian marine and coastal wetlands, Project 1.5 Scoping study.* Report to the National Environmental Science Program, Marine and Coastal Hub. Griffith University.

Copyright

Acknowledgement

This work was undertaken for the Marine and Coastal Hub, a collaborative partnership supported through funding from the Australian Government's National Environmental Science Program (NESP).

NESP Marine and Coastal Hub partners

The Australian Institute of Marine Science, Bioplatforms Australia, Bureau of Meteorology, Charles Darwin University, Central Queensland University, CSIRO, Deakin University, Edith Cowan University, Flinders University, Geoscience Australia, Griffith University, Integrated Marine Observing System, James Cook University, Macquarie University, Murdoch University, Museums Victoria, NSW Department of Planning and Environment (Environment, Energy and Science Group), NSW Department of Primary Industries, South Australian Research and Development Institute, The University of Adelaide, University of Melbourne, The University of Queensland, University of New South Wales, University of Tasmania, University of Technology Sydney, The University of Sydney, University of Western Australia, The University of Wollongong.

Disclaimer

Cover images: Global Wetlands Project, Griffith University

This report is available on the NESP Marine and Coastal Hub website:
www.nespmarinecoastal.edu.au

Table of Contents

List of figures

List of tables

Executive summary

Coastal wetlands support a striking diversity of life and provide a multitude of ecosystem services. In Australia, coastal wetlands protect our shorelines, improve water quality, support healthy fisheries, promote tourism, store carbon, and hold special cultural values, supporting our people and our economy. However, like many wetlands around the world, Australian wetlands continue to be threatened, degraded, and lost due to development, climate change, and anthropogenic stressors.

It is widely accepted that the first step in management of wetlands is development of an inventory. Australia is one of two nations with advanced economies that lacks a national wetland inventory, hampering our ability to protect these valuable ecosystems and fulfil many important national and international reporting requirements. To rectify this, the Australian government announced the development of an Australian Wetland inventory (AWI). This report provides a consolidated overview assessing coastal wetland mapping to determine future research and mapping priorities for development of this part of the national inventory. The investigating team assessed five key topics of interest to the Commonwealth Department of Climate Change, Energy, the Environment and Water which are a critical part of the coastal wetland inventory: seagrasses, saltmarshes, intertidal macroalgae, shorebird habitat, and blue carbon mapping. Mangroves are also discussed because of their significance to blue carbon, however as they have recently been mapped on a national scale were not a focus in the report.

A combination of literature assessments and interviews with 73 key end-users and industry experts generated 25 recommendations across the five areas of interest. The recommendations are summarised below in three sections. First, we present those recommendations deemed the key recommendation. These stood out due to their high levels of urgency, consistent demand from end-users, and for their potential as discrete projects. In addition, conversations around research and mapping priorities invariably led to discussions revealing fundamental practices that were echoed throughout the project meetings and literature, regardless of the habitat being investigated. These concepts are summarised below under *Themes*, and whilst they aren't designed to be directly implemented as projects, they provide key guidelines sought after by end-users which are elaborated upon in the report. Finally, we include a table outlining each individual recommendation provided for the topics investigated which are justified and expanded upon on in specific sections of the report. Implementing the recommendations will help to develop a consistent and complete Australian coastal wetland inventory that fulfils the needs of its end-users.

Key recommendations

OVERALL STRATEGY: Host a project that develops a national approach to mapping and classifying key attributes of coastal wetlands. One of the biggest challenges of developing the national wetland inventory is fragmented, disparate, and inconsistent datasets and approaches. Discussions with end-users revealed the need to organise a project where the key attributes for habitats/ecosystems and mapping approaches could be agreed on among the states to support a coordinating approach to mapping coastal wetlands on a national scale. The Queensland attribute-based classification system and mapping method for intertidal and subtidal ecosystems was regularly used as an example of a well-developed approach to mapping coastal systems by end-users in interviews. This is an example of a detailed framework that is consistent with, and extends, existing national frameworks to be used as the basis for a national approach. A project facilitating this discussion and making decisions regarding key attributes agreed on by all states would be the first step in developing a wetland inventory that can be expanded to a national scale. This would need to be complemented with a mapping method. Based on previous applications of the Queensland Intertidal and Subtidal Ecosystem Classification Scheme, priority attributes for classification, typology, mapping, and inventory include benthic depth, tidal inundation, substrate consolidation, substrate grain size, substrate composition, energy magnitude, terrain morphology, and structural macrobiota.

SEAGRASS: Improve capacity for mapping subtidal seagrass to fill notable inventory gaps in deep waters across Australia and in turbid waters in northern Australia. Improved methods for mapping seagrass extent and condition are needed, particularly for application in deep waters and shallower turbid waters. Deep seagrass meadows are suspected to be widespread in Australian waters and potentially valuable in delivering ecosystem benefits but are currently poorly mapped in all states. In the Great Barrier Reef World Heritage Area, the distribution of deep seagrass is predicted based on bathymetry but requires validation. For much of the rest of Australia, and notably in South Australia and Tasmania, records are patchy and outdated. Seagrass distributions are also poorly mapped in turbid waters, notably in northern Australia, and in estuaries along the majority of the Australian coastline. More cost-effective, rapid mapping methods are needed to fully capture the national seagrass resource, and support temporal surveys for trend analysis. Literature analysis and expert interviews point to two technological developments for solutions to this challenge: (1) improvements in remote sensing, and (2) the collection of vast amounts of imagery using underwater vehicles and drones with imagery processed automatically using computer vision software.

SALTMARSH: Identify and actively manage retreat of coastal saltmarsh and encroachment of mangroves. Coastal saltmarsh retreat due to sea level rise, subsequent mangrove encroachment and the lack of ability to move landward due to development and infrastructure present notable threats to saltmarsh extent. NSW Department of Planning, Industry and the Environment have recently produced some excellent maps modelling the future of saltmarsh and mangrove extent under different sea level rise scenarios in 110 of their 180 estuaries, which can support active management of this threat from several angles. Firstly, mapping of saltmarsh extent and relevant attributes could determine regions that are less likely to experience mangrove encroachment and flag them for protection. For example, encroachment is most likely in marshes adjacent to tidal creeks, and so conservation efforts should be targeted at these regions as they are less likely to experience losses with SLR. Similarly, maps can identify barriers to retreat, to actively remove barriers (such as work done by the Victoria Saltmarsh Protection Tender), or zone land for future saltmarsh expansion. Maps including the elevation profile could be used to determine whether adjusting the elevation of adjacent land could support saltmarsh expansion landward, another management opportunity. Provided saltmarsh extent maps are first developed with sufficient details of key attributes, expanding the modelling produced by NSW Department of Planning, Industry and the Environment to the rest of Australia would support saltmarsh conservation.

INTERTIDAL MACROALGAE: Widespread mapping of intertidal macroalgae needs to be conducted. Macroalgae are important primary producers and play a major role in carbon cycling, but there is very limited mapping of intertidal macroalgae distribution currently. Some regions have included subtidal macroalgae in mapping efforts, but distribution in the intertidal space is rarely documented, and could be mapped using remote sensing if appropriate training data sets are developed. Options should be explored to map intertidal macroalgae in conjunction with key attributes and qualifiers relevant to the intertidal zone including substrate consolidation, terrain morphology, coverage, and macroalgae species. Imaging methods should include unmanned aerial vehicle (UAV) technology, capable of discriminating between different macroalgae species, or a selection of Sentinel-2 or Landsat images taken during the low tide from current archives, noting that Landsat's 30 m x 30 m resolution may be too coarse to identify macroalgae in regions where it occupies narrow strips. The few existing maps of macroalgal distribution, such as the maps produced in Central Queensland, could potentially be used to inform a training data set.

SHOREBIRDS: Produce maps that integrate existing habitat zones and threats to shorebird habitat, including sea level rise, mangrove encroachment, and development. There are many threats facing coastal shorebirds in Australia, most notably being habitat degradation and loss. Shorebird habitat extent has been relatively well mapped in Australia by Birdlife Australia, however low-elevation sandy beaches, mudflats and saltmarshes providing critical habitat to shorebirds and are at risk from rising sea levels. Understanding the impacts of SLR and interactions with existing infrastructure and future development are important for prioritising future conservation and development actions. This could be addressed by including key habitat attributes such as tidal inundation, terrain morphology, infauna utilisation, substrate grain size, and substrate composition, in mapping efforts. Developing these maps with clear attributes will support better predictive models of the impacts of climate change to shorebird habitat, and support identification of regions that should be prioritised for protection or rehabilitation.

BLUE CARBON: Maps need to include different habitats to demonstrate connectivity across the seascape and should be integrated with national products. The sequestration capacity and co-benefits produced by a blue carbon assessment or restoration project vary depending on adjacent habitats. Rather than assessing habitats independently, blue carbon mapping requires a seascape approach, encompassing all habitats below the highest astronomical tide. Excellent work has been done already in Australia, however blue carbon predictions can only be as accurate as the habitat maps provided. Development of these products should always consider integration with national mapping products, include jurisdictional boundaries and pressures or barriers to implementation, and may be required on finer scales to support restoration projects. Specific habitat attributes in addition to structural macrobiota presence and qualifiers of biomass or cover have also been identified that support blue carbon work, including substrate composition (organic categories), tidal inundation (inundation / emersion periods), and terrain morphology. Detailed mapping at relevant locations should be developed with the goal of eventually expanding this to the national scale.

Themes identified

1. **Research should focus on mapping habitat values and condition as well as habitat nature and extent.** Key values and habitat condition are important metrics for land managers, have implications for blue carbon, assist in restoration projects, and can identify habitat loss during early stages. These were consistently called for by end-users.

2. **There is strong demand for trend mapping.** Static mapping can provide an excellent baseline, but to monitor and protect wetlands trend mapping is needed, both in historic and current formats, and predictive models. Trend mapping was called for in all interviews conducted.

3. **Allocate resources to projects producing high quality ground truthing data to provide necessary data for improvements in remote sensing.** Widespread mapping using remote sensing imagery is possible for many unmapped habitats if additional training data is collected. A lack of training data is the major bottleneck to using remote sensing projects to identify many habitats.

4. **Small-scale maps are often preferred by land managers and could be used to inform coarser scale maps.** Many end-users requested detailed, smaller scale mapping products as these offer them greater utility than broadscale mapping. Scales of 1:5000 and 1:25000 were mentioned as ideal and minimum resolutions, respectively, and development of a tiered scaling system based on map purpose and habitat attributes was proposed.

5. **Data collected needs to become more discoverable and accessible, and managed by a data curation team.** Large stores of data have been collected but are not shared due to the work involved in data curation. Resources need to be allocated to this field to ensure that all project information is findable, accessible, interoperable, and reusable (FAIR).

6. **High-end satellite imagery is prohibitively expensive for many mapping projects and brokering a deal through government leaders with image providers could reduce barriers to use.** Other than a lack of training data sets, the lack of access to very high-quality satellite imagery is the other major barrier to implementing widescale remote sensing. Current costs for very high-quality satellite imagery are prohibitive, and partnerships with image providers could make this more affordable.

7. **Disparate data needs to be integrated into useful formats.** One challenge of collating and curating data is the lack of consistency, however consistent methods of data collection are not always suitable. Research into the best methods for integrating disparate data (i.e. polygons and point data) into formats able to be interrogated would benefit data curators and users, in conjunction with classifying data consistently based on biophysical attributes.

8. **Investment in improvements in aerial and underwater drones will support more affordable mapping and ground truthing data.** Use of drones consistently came up in interviews, both for mapping directly and for collecting imagery for ground truthing data sets. Continued investment in this field will be required in future projects.

9. **Mapping outputs need to clearly demonstrate accuracy.** Confidence bounds in mapping products need to be clearly displayed to identify the accuracy of assessments. This helps to determine whether changes in distribution are genuine or mere artefacts of mapping error. Mapping error can propagate through application targeting models (i.e. blue carbon calculations). End-users suggested that error is displayed both as an overall accuracy and with confidence level maps.

10. **More mapping is required of Ramsar and non-Ramsar sites.** Ramsar site mapping was often mentioned by end-users, particularly Parks Australia, and are of special interest. However, many adjacent wetlands to Ramsar sites may hold similar values but can be overlooked in the shadow of the nearby listed wetland. Increased resource allocation to unlisted wetlands adjacent to Ramsar sites provide an additional opportunity for mapping and monitoring efforts.

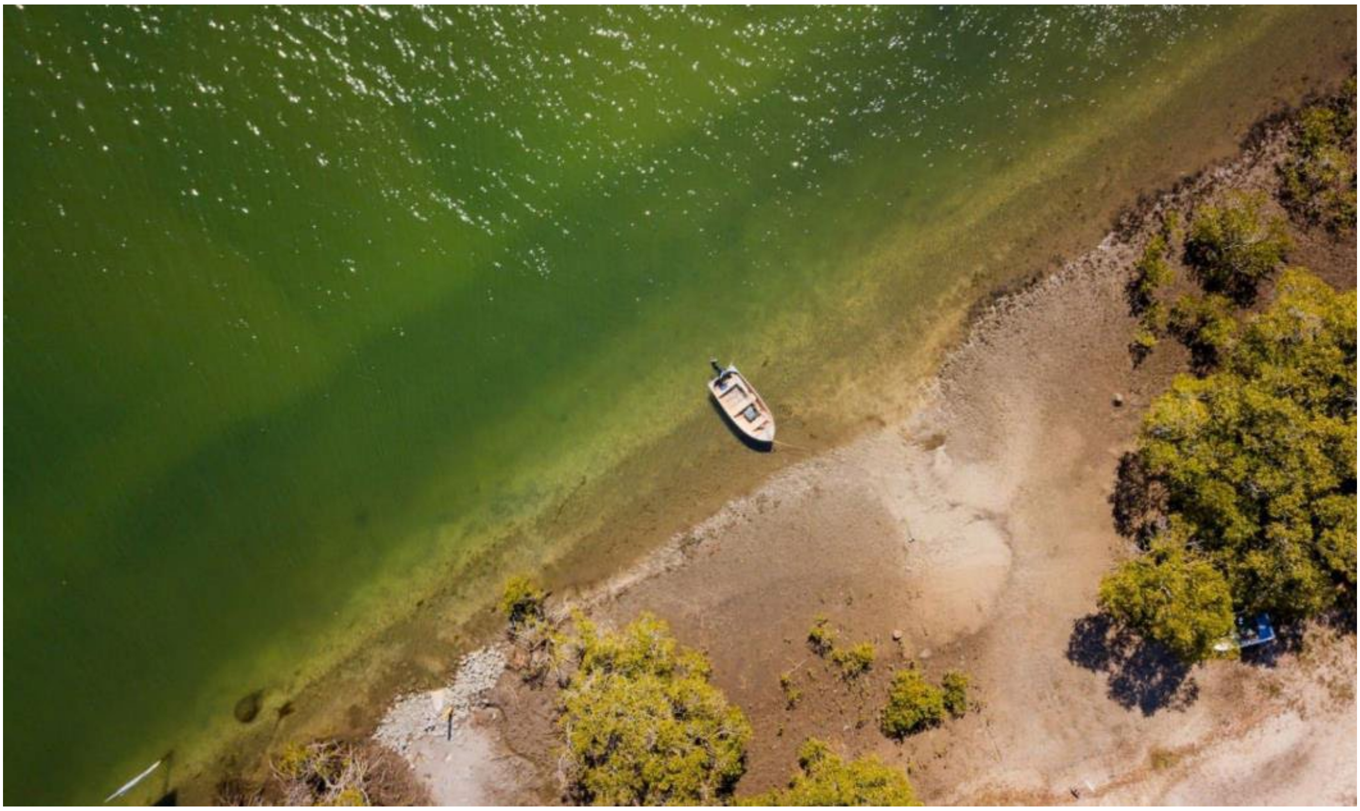


Figure 1: Coastal wetland ecosystems in the clear waters of eastern Moreton Bay, Queensland.

Specific recommendations

Table 1: Specific recommendations produced through interviews for each of the five topics addressed. Further information and justification for the recommended projects included in each topic's relevant section.

Seagrass	Saltmarsh	Intertidal Macroalgae	Shorebirds	Blue Carbon
1. Map deep seagrasses. 2. Map subtidal seagrasses Australia-wide, with notable gaps in northern Australia and parts of Western Australia 3. Develop a consistent method for classification of seagrass meadow characteristics, particularly meadow condition, transience, and species or structural composition, to be included in national maps. 4. Increased use of rapid underwater imaging technology and automated image processing to increase mapping coverage at decreased costs. 5. Strategically select regions for seagrass mapping using fauna species distribution models, knowledge of Traditional Custodians, and bathymetry.	1. Promote access to high quality satellite imagery for more accurate saltmarsh mapping. 2. Produce maps with clear differentiation of saltmarsh and mangroves for management of mangrove encroachment and blue carbon resources. 3. Improve the technology for mapping saltmarsh using unmanned aerial vehicles (UAVs). 4. Include habitat condition and species composition in saltmarsh maps.	1. Produce high quality maps of intertidal macroalgae in Australia. 2. Invest in remote sensing methods to simultaneously map macroalgae extent, dominant species, and sediment composition of the intertidal space. 3. Map historical macroalgae extent using satellite image archive. 4. Identify any climate change induced distribution shifts for macroalgal species and establish the ecological impacts of these contractions.	1. Develop predictive maps demonstrating the impacts of sea level rise, mangrove encroachment, development, and climate change on shorebird habitat to determine opportunities for mitigation. 2. Improve maps of the shorebird habitat, with emphasis on tidal mudflats and understudied regions. 3. Map the supratidal clay pans used by shorebirds in high tides as shorebird habitat. 4. Monitor prey density and availability at key shorebird sites.	1. Produce and integrate maps of blue carbon habitats below the highest astronomical tide into one resource. 2. Produce historical maps of blue carbon systems, including maps of pre-clearance vegetation. 3. Field verification for blue carbon stock maps, including strategic sampling in various geomorphological settings 4. Co-benefits need to be carefully measured and mapped to understand full value of restoration projects 5. Models of climate change induced landward migration of coastal ecosystems, including artificial barriers, are needed to assess changes in blue carbon stocks and sequestration due to sea level rise 6. Supratidal forests need to be first defined and then mapped.

1. Introduction

Coastal wetlands are ecosystem service powerhouses, delivering economic, biological, and cultural services valued at up to AU$272,000/ha/yr (Costanza et al. 2014). Serving as the junction where land meets the sea, they support a striking diversity of life, and provide the habitat that allows coexistence of terrestrial and marine biota offering provisioning, regulating, and supporting ecosystem services. These vital ecosystems and their unique array of fauna and flora regulate water quality, filter anthropogenic pollutants, and provide coastal protection from waves and extreme weather events. In addition to these ecosystem services, Australian wetlands are of cultural significance to Indigenous and Torres Strait Islanders, while supporting recreation, industry, and tourism. However, coastal wetlands continue to be threatened, degraded, and lost (Hu et al. 2017, Serrano et al. 2019). This is of particular importance in Australia, where 85% of the population lives within 50 km of our 35,000 km coastline (Clark & Johnston, 2016; Geoscience Australia, 2018), creating conflicts between development and the environment (Lee et al. 2006). This continues to add pressure to wetlands, with incremental, seemingly modest losses, leading to large cumulative impacts.

Australia is one of the two nations with advanced economies that lack a national wetland inventory, limiting our ability to monitor and protect our wetlands. It is widely accepted that developing a national wetland inventory is a prerequisite tool for effective conservation and management (Dugan et al. 1990, Finlayson & van der Valk 1995, Finlayson et al. 1999, Ramsar Convention 2002, Kingsford et al. 2005, Davidson et al. 2018), and as we embark on the UN decade of ecosystem restoration this has never been more apparent. Under the Ramsar convention and as part of the UN sustainable development goals, Australia is required to report on our wetland extent and health (Ramsar Convention Secretariat 2016), and as a nation, has also pledged to restore 60 million hectares of wetlands by 2030 (Sewell et al. 2020). To support these goals, the Australian government announced the development of an Australian Wetland Inventory (AWI). This report will therefore provide a consolidated overview assessing coastal wetland mapping on regional scales to determine future research and mapping priorities to develop an AWI.

Figure 2: Waves wash over the rocky reef in Pennington Bay on Kangaroo Island, South Australia

1.1 Purpose of this study

The management of human impacts on marine and coastal wetlands in Australia is hampered by the lack of a consolidated, comprehensive, and current wetland inventory. Coastal wetland extent and distribution at present is only partially mapped and classified, with different methodologies and resolutions for sections of coastline in different jurisdictions. Gaps in existing mapping and classification prevent rigorous analyses of historical changes in extent, and predictive modelling of potential future changes in distribution. They also make it difficult to provide practical, on-ground management advice to avoid or minimise impacts on wetlands from proposed new developments and activities, and to place an economic value on coastal systems using environmental accounting. There is a need to develop capacity and integration across all wetland mapping in Australia, and this project helps to achieve that for marine and coastal wetlands.

This report identifies knowledge and mapping gaps for marine and coastal wetlands and provides solution pathways to filling those gaps. This was achieved by analysing how end-user needs intersect with mapping methods and capacity through a review of the literature, and virtual workshops with industry experts in wetland mapping. A wetland inventory for Australia and its external territories is currently being collated using the Australian National Aquatic Ecosystem (ANAE) classifications up to the “Level 3 – system” criteria (refer to Auricht (2022) for inventory status). This scoping project builds on that work by assessing the mapping status and needs of different habitats within the marine and estuarine system class, classified using the ANAE’s structural macrobiota subcategory. Further information on the ANAE classification system is included in Appendix A.

There are six types of structural macrobiota listed in the ANAE structural macrobiota classification: mangroves, coral, filter-feeders, seagrass, saltmarsh, and macroalgae. In this report, we focus on the latter three due to limited mapping in these categories (Roelfsema et al. 2013, York et al. 2017, Serrano et al. 2019). Mangroves have recently been mapped on a national scale using Landsat imagery (Lymburner et al. 2020), and strategic allocation of resources to seagrass, saltmarsh, and intertidal macroalgae ecosystems would assist in filling mapping gaps for a comprehensive AWI. Note that in this report the focus is on intertidal macroalgae, as subtidal macroalgae ecosystems are covered in the NESP Marine and Coastal Hub project 1.09 Quantifying the ecosystem services of the Great Southern Reef.

In addition, habitat mapping to support blue carbon projects and shorebird monitoring were assessed. These two wetland applications were selected based on their reliance on the habitats assessed, a demonstrated need for additional research and mapping, and a strong interest by the Commonwealth Department of Climate Change, Energy, the Environment and Water (DCCEEW). Within these two wetland application topics all six types of structural macrobiota are considered, however the focus of the report remains on seagrass, saltmarsh, and intertidal macroalgae.

Figure 3: Sunrise over the mangroves watched by an eastern great egret.

1.2 Importance of developing an Australian Wetland Inventory

To fulfil legislative and compliance requirements

As a signatory on the Ramsar Convention, Australia is required to support “the conservation and wise use of all wetlands through local and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world” (Ramsar, 1971). The current 2016-2024 strategic plan requires all signatories to have started, completed, or updated a national wetland inventory, with 47% already having a complete inventory as of 2016 (Ramsar Convention Secretariat 2016).

In addition, developing an AWI would support the United Nations (UN) Sustainable Development Goals (SDGs), which among other goals require Australia to:

> ***6.6*** *– Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes*
> ***11.4*** *– Protect and safeguard the world’s cultural and natural heritage*
> ***14.5*** *– Conserve at least 10% of coastal and marine areas*
> ***15.1*** *– Ensure conservation, restoration, and sustainable use of terrestrial and inland freshwater ecosystems.*

Within SDG 6.6 is goal 6.6.1, which requires Australia to report on change in wetland extent over time. Due to lack of current mapping and ongoing monitoring this is not currently possible, and Australia did not report on this target in the UN’s most recent data drive. Developing an AWI would not only benefit land managers, but also help fulfil these important legislative requirements.

Monitoring and conservation

The development of an inventory of maps is considered the first step for any land conservation program (Dugan et al. 1990, Finlayson & van der Valk 1995, Finlayson et al. 1999, Ramsar Convertion 2002, Kingsford et al. 2005, Davidson et al. 2018). By mapping wetlands, land managers can establish baseline monitoring on changes in wetland extent and degradation and compare these results across regions to assess different threats, successes, and priority zones for conservation. The lack of frequent mapping and monitoring is a major restriction preventing more active management of wetlands threats in Australia.

Proper valuation of ecosystem services

Coastal wetlands produce up to AU$272,000 in value through ecosystem services per hectare each year (Costanza et al. 2014). These ecosystem services need to be considered when assessing society’s net benefit from future developments. Recently, the ecosystem services provided by Geographe Bay were quantified in Australia’s first Ocean Accounting Project (Box 1.2.1) allowing park managers to make informed decisions regarding the marine park to optimise the net benefit from management interventions. In addition to determining social net benefit, coastal wetland ecosystem services can be integrated into the economy to promote sustainable development. For example, Australia recently introduced a Blue Carbon Method to the Emissions Reduction Fund, providing emission abatements for suitable blue carbon projects through tidal restoration. This is an excellent opportunity to restore wetlands, sequester carbon, and enhance ecosystem benefits, but to accurately include these services in a national accounting and emission targets it is important to know the extent of this resource.

Box 1.2.1: Case study: Geographe Marine Park, Parks Australia

Geographe Bay is known for its turquoise waters, sweeping white sandy beaches, diverse marine life, and recently as the location for the Australian Government's first ocean environmental accounting project. Using the new environmental value assessment under the National Strategy and Action Plan for Environmental-Economic Accounting (EEA), this pilot project demonstrated how ocean accounting can be used in policy and planning. By assessing the extent of different habitats present (seagrass, rocky reef, sandy bottom, macroalgae, etc.) and the services they provide, each of the habitats were valued under the nationally consistent EEA framework. This analysis continues to assist park managers, Parks Australia, to make informed interventions related to the Marine Park.

The success of this pilot project revealed that this method could be extended nationwide, if supported by quality mapping of ecosystem extent and condition. Different metrics were selected for valuing ecosystem services that have the potential to be used on a national scale. For example, seagrass ecosystem productivity was valued based on seagrass density, fish diversity, fish abundance, and fish biomass. Using these metrics, and the known human activities in the region, experts could estimate carbon sequestered, fish nursery productivity, value of recreational and commercial fishing, and coastal protection, to develop an estimated dollar value per year of contributions to the community.

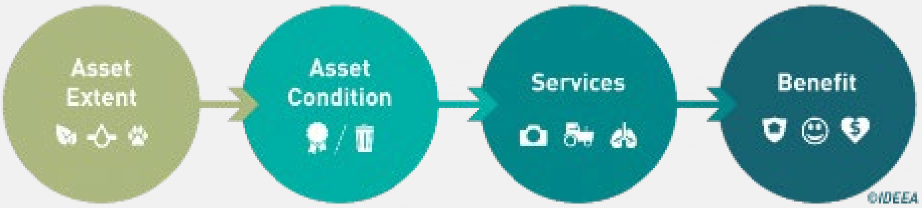


Figure 4: The core ecosystem accounting framework to developing benefit assessments used by the Institute for the Development of Environmental-Economic Accounting (IDEEA) in their ecosystem accounting of Geographe Bay.

This framework provides an excellent opportunity for Australian environmental accounting. The results, however, are only as reliable as the ecosystem extent maps. To accurately apply an accounting framework to marine systems it was recommended that mapping frequency and resolution be increased, and that specific local management issues of interest be considered in each region where the assessments take place. Targeted investment in data collection, capacity building, and research could support a rollout on a national scale.

Figure 5: Dusk at Geographe Bay, WA

Land use planning

Since European colonisation of Australia, an estimated 47-50% of saltmarsh, 52-78% of mangroves, and 20-26% of seagrass historic extent has been lost (Serrano et al. 2019), primarily to drainage and repurposing of the land for development and agriculture (Davis & Froend 1999). Wetlands also face threats from coastal squeeze from the combined threats of urban development and sea level rise (Borchert et al. 2018). This makes effective land use planning critical if these habitats are to be conserved. Land use planners can prepare for this threat using maps of current and predicted future wetland extent to design future developments in a way that will accommodate a changing landscape, and actively manage current barriers to wetland migration, if appropriate maps are developed.

Previous attempts at a wetland inventory

Australia has the benefit of the previously developed National Directory of Important Wetland Areas (DIWA). Whilst experts acknowledge DIWA is not a wetland inventory and is currently out of date, through documentation of nationally significant wetlands it provides very valuable linework laying the foundation for a national scale inventory. Criteria for listing within DIWA is included in Box 1.2.2. In addition, Seamap, Australia's first national marine benthic habitat typology map, provides a single resource synthesising national seabed mapping data into one spatial data product (Lucieer et al. 2019). This is an excellent resource to support FAIR[1] data sharing principles and encourages a consistent approach to seabed mapping according to a specific typology, which could be cross-walked into a nationally consistent attribute-based classification system when this system is developed. However, Seamap has remained relatively static since its release, and large data gaps in mapping remain as will be discussed in the following sections.

For maps to continue to be relevant, they need to be regularly updated (Finlayson & van der Valk 1995), with end-users recommending updates a minimum of every 5-10 years. Currently many of the wetland extent maps in Australia are outdated, often with records over 20 years old (e.g. SA Department for Environment and Water, 2018), and limited frequency of repeat monitoring is one of the major limitations of existing mapping along Australia's coastline.

Box 1.2.2: Directory of Important Wetlands in Australia (DIWA)

The DIWA database was first published in 1996 and updated in 2001. Since then, it has continued to include additional wetlands, with the most recent addition in 2019. A wetland may be considered nationally important if it meets at least one of the following criteria:

1. *"It is a good example of a wetland type occurring within a biogeographic region in Australia.*
2. *It is a wetland which plays an important ecological or hydrological role in the natural functioning of a major wetland system/complex.*
3. *It is a wetland which is important as the habitat for animal taxa at a vulnerable stage in their life cycles, or provides a refuge when adverse conditions such as drought prevail.*
4. *The wetland supports 1% or more of the national populations of any native plant or animal taxa.*
5. *The wetland supports native plant or animal taxa or communities which are considered endangered or vulnerable at the national level.*
6. *The wetland is of outstanding historical or cultural significance."*

(DAWE 2021)

[1] FAIR data sharing is data that is Findable, Accessible, Interoperable, and Repeatable

2. Methods

A workshop on developing an Australian Wetland Inventory was hosted by the Australian government in September 2021. This workshop included leading wetland scientists, end-users, and government officials throughout Australia. All attendees were offered the opportunity to be involved in the scoping project, and through this a list of experts and engagement expectations were developed. Open invitations were sent to attendees who requested involvement in the development of the project. Additional experts were contacted for involvement to ensure representation from all geographic jurisdictions in Australia, and inclusive of all major remote sensing and wetland mapping methodologies. Overall 103 people were consulted on the project, with 74 engaging in developing recommendations through bespoke workshops and meetings. For a full list of attendees and affiliations refer to Appendix C.

Prior to conducting the interviews, a review of the literature assessing the current state of wetland mapping and future research priorities was conducted. The literature analysis was made significantly more effective thanks to Chris Auricht's database of previous wetland mapping projects in Australia (Auricht 2022). Additional mapping products were collated using data.gov.au (Australian Government 2022), and research directed at each of the five key topics using databases and resources obtained from experts. The goal of this review was to generate a broad assessment summarising knowledge gaps whilst noting current mapping outputs that may have not been identified in previous database reviews.

Prior to the meetings, information packages were distributed to end-users and researchers, providing an overview of the project to maximise discussion time. Discussions and interviews were conducted online and typically ran for 60 – 90 minutes, with attendees encouraged to share any additional thoughts after the interview via email.

We used the information from interviews and the literature to develop recommendations for research that addressed gaps identified in each of the investigated topics and any specific recommendations for Australia's states and territories, including external territories, where interviewees expressed the same research needs as end users from managing mainland regions. We also collated a separate section on research themes, which included specific end-user and research needs that applied to the gathering of information for the inventory in general and did not specifically relate to one habitat or topic.

Figure 6: Brolgas in Wetlands near Walcott Inlet in the Kimberley Region of Western Australia. Photo by Philip Schubert.

3. Research priorities and recommendations

3.1 Key recommendations

For each of the five topics addressed in the report we identified several gaps and recommendations for required research. Here we select from those recommendations the most important, or key, recommendation for each topic, as well as one overall strategy. These recommendations stood out due to high levels of urgency, consistent demand from end-users, and for their nature as potential discrete projects.

Overall strategy

Host a project that develops a national approach to mapping and classifying key attributes of coastal wetlands. One of the biggest challenges of developing the national wetland inventory is fragmented, disparate, and inconsistent datasets and approaches. Discussions with end-users revealed the need to organise a project where the key attributes for habitats/ecosystems and mapping approaches could be agreed on among the states to support a coordinating approach to mapping coastal wetlands on a national scale. The Queensland attribute-based classification system and mapping method for intertidal and subtidal ecosystems was regularly used as an example of a well-developed approach to mapping coastal systems by end-users in interviews (Queensland Department of Environment and Heritage Protection 2017, Queensland Department of Environment and Science 2020b) and has been suggested as an example of a detailed framework that is consistent with, and extends, existing national frameworks to be used as the basis for a national approach. A project facilitating this discussion and making decisions regarding key attributes agreed on by all states would be the first step in developing a wetland inventory that can be expanded to a national scale. This would need to be complemented with a mapping method. Based on previous applications of the Queensland Intertidal and Subtidal Ecosystem Classification Scheme, priority attributes for classification, typology, mapping, and inventory include benthic depth, tidal inundation, substrate consolidation, substrate grain size, substrate composition, energy magnitude, terrain morphology and structural macrobiota (Queensland Department of Environment and Science, 2020b).

Seagrass

Improve capacity for mapping subtidal seagrass to fill notable inventory gaps in deep waters across Australia and in turbid waters in northern Australia. Improved methods for mapping seagrass extent and condition are needed, particularly for application in deep waters and shallower turbid waters. Deep seagrass meadows are suspected to be widespread in Australian waters and potentially valuable in delivering ecosystem benefits but are currently poorly mapped in all states. In the Great Barrier Reef World Heritage Area, the distribution of deep seagrass is predicted based on bathymetry but requires validation (Coles et al. 2009). For much of the rest of Australia, and notably in South Australia and Tasmania, records are patchy and outdated. Seagrass distributions are also poorly mapped in turbid waters, notably in northern Australia, and in estuaries along the majority of the Australian coastline (see Table 2 page 15). More cost-effective, rapid mapping methods are needed to fully capture the national seagrass resource, and support temporal surveys for trend analysis. Literature analysis and expert interviews point to two technological developments for solutions to this challenge: (1) improvements in remote sensing, and (2) the collection of vast amounts of imagery using underwater vehicles and drones with imagery processed automatically using computer vision software.

Saltmarsh

Identify and actively manage retreat of coastal saltmarsh and encroachment of mangroves. Coastal saltmarsh retreat due to sea level rise, subsequent mangrove encroachment and the lack of ability to move landward due to development and infrastructure present notable threats to saltmarsh extent. NSW Department of Planning, Industry and the Environment have recently produced some excellent maps modelling the future of saltmarsh and mangrove extent under different sea level rise scenarios in 110 of their 180 estuaries (Hughes et al. 2022) which can support active management of this threat from several angles. Firstly, mapping of saltmarsh extent and relevant attributes could determine regions that are less likely to experience mangrove encroachment and flag them for protection. For example, encroachment is most likely in marshes adjacent to tidal creeks, and so conservation efforts should be targeted at these regions as they are less likely to experience losses with SLR (Whitt et al. 2020). Similarly, maps can identify barriers to retreat, to actively remove barriers (such as work done by the Victoria Saltmarsh Protection Tender), or zone land for future saltmarsh expansion (Leo et al. 2019). Maps including the elevation profile could be used to determine whether adjusting the elevation of adjacent land could support saltmarsh expansion landward, another management opportunity (Stralberg et al. 2011, Leo et al. 2019, Prahalad & Kirkpatrick 2019). Provided saltmarsh extent maps are first developed with sufficient details of key attributes, expanding the modelling produced by NSW Department of Planning, Industry and the Environment to the rest of Australia would support saltmarsh conservation.

Intertidal macroalgae

Widespread mapping of intertidal macroalgae needs to be conducted. Macroalgae are important primary producers and play a major role in carbon cycling, but there is very limited mapping of intertidal macroalgae distribution currently. Some regions have included subtidal macroalgae in mapping efforts, but distribution in the intertidal space is rarely documented, and could be mapped using remote sensing if appropriate training data sets are developed. Options should be explored to map intertidal macroalgae in conjunction with key attributes and qualifiers relevant to the intertidal zone including substrate consolidation, terrain morphology, coverage, and macroalgae species. Imaging methods should include unmanned aerial vehicle (UAV) technology, capable of discriminating between different macroalgae species, or a selection of Sentinel-2 or Landsat images taken during the low tide from current archives, noting that Landsat’s 30 m x 30 m resolution may be too coarse to identify macroalgae in regions where it occupies narrow strips. The few existing maps of macroalgal distribution, such as the maps produced in Central Queensland, could potentially be used to inform a training data set.

Shorebirds

Produce maps that integrate existing habitat zones and threats to shorebird habitat, including sea level rise, mangrove encroachment, and development. There are many threats facing coastal shorebirds in Australia, most notably being habitat degradation and loss. Shorebird habitat extent has been relatively well mapped in Australia by Birdlife

Australia (Weller et al 2020), however low-elevation sandy beaches, mudflats and saltmarshes providing critical habitat to shorebirds and are at risk from rising sea levels. Understanding the impacts of SLR and interactions with existing infrastructure and future development are important for prioritising future conservation and development actions (Iwamura et al. 2013, Sims et al. 2013, Saintilan et al. 2019) and could be addressed by including key habitat attributes such as tidal inundation, terrain morphology, infauna utilisation, substrate grain size, substrate composition, in mapping efforts. Developing these maps with clear attributes will support better predictive models of the impacts of climate change to shorebird habitat, and support identification of regions that should be prioritised for protection or rehabilitation.

Blue carbon

Maps need to include different habitats to demonstrate connectivity across the seascape and should be integrated with national products. The sequestration capacity and co-benefits produced by a blue carbon assessment or restoration project vary depending on adjacent habitats. Rather than assessing habitats independently, blue carbon mapping requires a seascape approach, encompassing all habitats below the highest astronomical tide (HAT). Excellent work has been done already in Australia (e.g. Duarte de Paula Costa et al, 2021); however blue carbon predictions can only be as accurate as the habitat maps provided. Development of these products should always consider integration with national mapping products, include jurisdictional boundaries and pressures or barriers to implementation, and may be required on finer scales to support restoration projects. Specific habitat attributes in addition to structural macrobiota present and qualifiers of biomass or cover have also been identified that support blue carbon work, including substrate composition (e.g. organic categories), tidal inundation (e.g. inundation / emersion periods), and terrain morphology. Detailed mapping at relevant locations should be developed with the goal of eventually expanding this to the national scale.

Figure 7: A bed of Heterozostera nigricaulis in the clear waters of Southern Australia

3.2 Consistent themes

The focus of this report was to identify mapping gaps and future priorities for research, and these conversations invariably led to best practice discussions revealing fundamental practices and themes that were echoed throughout the project meetings and literature, regardless of the habitat being investigated. Whilst the below themes are not designed to be directly implemented as research projects, they provide the key attributes and practices sought by end-users and scientists to ensure that future projects are filling wetland extent mapping gaps.

Themes identified

1 **Research should focus on mapping habitat values and condition as well as presence.** Whilst habitat extent is important for reporting on SDGs and international requirements, knowledge of habitat condition provides an additional useful metric for environmental managers and is particularly important for Ramsar wetlands, Parks Australia, restoration of habitats, and for the Blue Carbon Method (Department of the Environment 2008, York et al. 2017, Ling et al. 2018). This can allow for early detection of at-risk habitats, identify links with habitat pressures, prioritise regions for conservation or carbon storage, and prevent wetland losses. There are many challenges with developing condition metrics however, and while nationally consistent approaches are required, the framework should be flexible to account for variation in different climatic zones and habitats and future innovation in monitoring techniques. Broadscale condition metrics may not always be representative of all habitats and should be tailored for species assemblages or bioregions. As an example, seagrass percentage cover could be a useful metric for persistent species like *Posidonia australis* but misleading for transient *Halophila* species. Instead, experts proposed that a research project be conducted to develop a list of condition metrics for specific climatic zones and species assemblages, that could then be ranked on a quantitative scale to compare between regions. This framework would guide practitioners to use specific indicators of condition for particular species assemblages in particular climate zones. National, standardised metrics to monitor habitat condition are required for environmental ecosystem accounting before it can be implemented on a national scale, and for consistent monitoring of blue carbon projects. For mangroves and saltmarsh, condition reporting will require the development of a nationally consistent typology as a geomorphological framework. Note that condition monitoring is separate to attribute based classification of ecosystems and would be an additional layer of information for the inventory.

2 **Allocate resources to projects producing high quality ground truthing data to provide necessary data for improvements in remote sensing.** High quality satellite imagery is available from multiple sources, and data from Sentinel-2 has the potential to identify species composition of flora, providing more detailed mapping across Australia and improving on existing Landsat data. However, the ability of remote sensing to classify imagery is limited by a lack of ground truthing information, collected either using traditional methods or high-quality image sources such as drones. Research projects that contribute to the collection of ground truthing data would allow for increased mapping accuracy inclusive of many habitat attributes (such as sediment composition, plant species, etc) supporting end-user needs and a comprehensive inventory.

3 **Data collected needs to become more discoverable and accessible, and managed by a data curation team.** There is a difference between having an inventory and having information, and currently there is an abundance of mapping information that has been collected in Australia yet is inaccessible due to time required to prepare and share data in a useful format. Researchers and end-users expressed a desire for data to be available under FAIR principles (Wilkinson et al. 2016, Ling et al. 2018). Natural resource extraction companies, multiple private agencies, and some land management organisations may collect but not share their

mapping data, as preparing data for publication can be time consuming. In addition to data availability, to promote continued use it needs to be curated by a dedicated team (United Nations Environment Programme 2020). Seamap Australia is an excellent example of data sharing in a typology format (Lucieer et al. 2019), and continued allocation of resources to data curation teams like Seamap Australia is a critical component of an inventory, particularly if these resources could incorporate an attribute based classification system. Similarly, Western Australia has recently started to tackle this issue by requiring biodiversity data from environmental assessments to be collected for aggregation and reuse as part of the Index of Biodiversity Surveys for Assessments (WABSI 2019). This requires environmental assessors to share both their final reports and the data used to draw those conclusions to WA's Biodiversity Information Office, with the vision to make data promptly and routinely available for all biodiversity experts. Through this experience, they found that accepting data in a variety of formats, rather than asking the data providers to use a specific format or provide certain data sets, was key to increasing compliance.

4 **Disparate data needs to be integrated into useful formats.** Following on from the previous theme, multiple papers have cited the need for consistent data collection across fields (Finlayson et al. 1999, York et al. 2017, Ling et al. 2018). Whilst consistent data collection should be strived for amongst all projects, and classification of wetlands (such as use of ANAE) should be kept consistent across the nation, methods of data collection are frequently tailored to project needs (Kilminster et al. 2015). Often it may not be practical or efficient for all projects to use the same methods, especially when considering different habitats. For example, some projects may require point data, and others polygon data, but there is a lack of understanding around how to integrate point and polygon data together effectively, and research in this field is required. Researchers called for a focus on supporting data curation teams to develop methods that integrate disparate data into a useful format accessible to end-users, and methods to cross-walk existing field methods and data into attribute-based classifications. DCCEEW's future National Wetlands Group could be one avenue where data integrability and data curation teams could be explored for the Australian Wetland Inventory.

5 **Mapping outputs need to clearly demonstrate accuracy.** Assessment of trends is limited by a lack of clearly demonstrated error bands within maps (Phinn et al. 2018). Inclusion of clearly defined error bands presents two clear benefits: (1) regions that require mapping could be prioritised based on the accuracy of the current mapping; (2) confidence intervals would allow for distinction between genuine changes in wetland extent, and artefacts of mapping error, when monitoring change over time. Clearly displayed error bounds for polygons, or at a minimum the percentage error of the mapping product, should be included in all mapping efforts, as well as quantifiers of attribute accuracy (such as data density).

6 **There is strong demand for trend mapping.** Monitoring to detect changes in wetland extent and health over time was called for in all the expert interviews. The applications for trend monitoring are broad, including scientific research, early identification of habitat range contractions, assessing the impacts of management decisions, or assessing success of rehabilitation projects. Current satellite data is regular enough to support annual or seasonal trend mapping, with Landsat Satellites 5-8 cycling every 16 days, and Sentinel Constellations every 5-6 days. One opportunity to support on-going trend mapping is development of a consistent and robust form of automated or semi-automated image classification, as lack of resources and inconsistency between mapping methods were regularly described as barriers to including temporal monitoring.

Semi-automated mapping of seagrass meadows using satellite imagery was recently conducted in southeast Queensland with 63% accuracy (Kovacs et al. 2022), capable of scaling on a national level. Research supporting increasing the accuracy of similar methods of automation, or other forms of trend mapping, would greatly support wetland researchers and managers, however development of these procedures should consider integration with an attribute-based mapping methodology to enhance integration of products.

7 **Small-scale maps are often preferred by land managers and could be used to inform national scale maps.** Whilst Australia requires a national inventory, several end-users requested that this inventory be comprised of sub-regions, each with a series of smaller-scale maps. Expert interviews revealed detailed maps with high accuracy allow end-users to capture small wetlands and changes in wetland extent, with an ideal scale of 1:5000 and a maximum scale of 1:25,000 recommended by NSW end-users to allow them to capture their small patches of wetlands (Ling et al. 2018). End-users in other states did not provide a desired scale but shared the same sentiment of a desire for local scale mapping, particularly when tackling restoration projects and assessing development applications which require finer detail in maps. Another suggestion was to develop tiered levels for locations to determine a regions mapping needs based on habitat attributes and the map's purpose, which can then determine the level of spatial representation required, as is recommended in the Queensland intertidal and subtidal classification scheme (Department of Environment and Heritage Protection Queensland, 2017, Department of Environment and Science, 2020).

8 **High-end satellite imagery is prohibitively expensive for many mapping projects and brokering a deal through government leaders with image providers could reduce barriers to use.** Arranging a deal with one or more of the higher quality image resources would allow mapping quality to drastically improve. Satellite imagery from Landsat and even Sentinel-2 can fail to detect small patches or strips of vegetation, or fragmented habitat, due to the large pixel size (Figure 8). For example, in NSW the Department of Primary Industries mapped saltmarsh extensively using drones as Sentinel-2 could not detect the narrow strips of vegetation, unlike higher quality satellite imagery. Current costs of high-end satellite imagery (e.g. Worldview II) are prohibitively expensive for many researchers, but a national agreement with image providers through federal or state partnerships was suggested as an option that could make image sourcing affordable. High-end satellite imagery also now has an additional benefit in being able to map seabed bathymetry (Roelfsema et al. 2020).

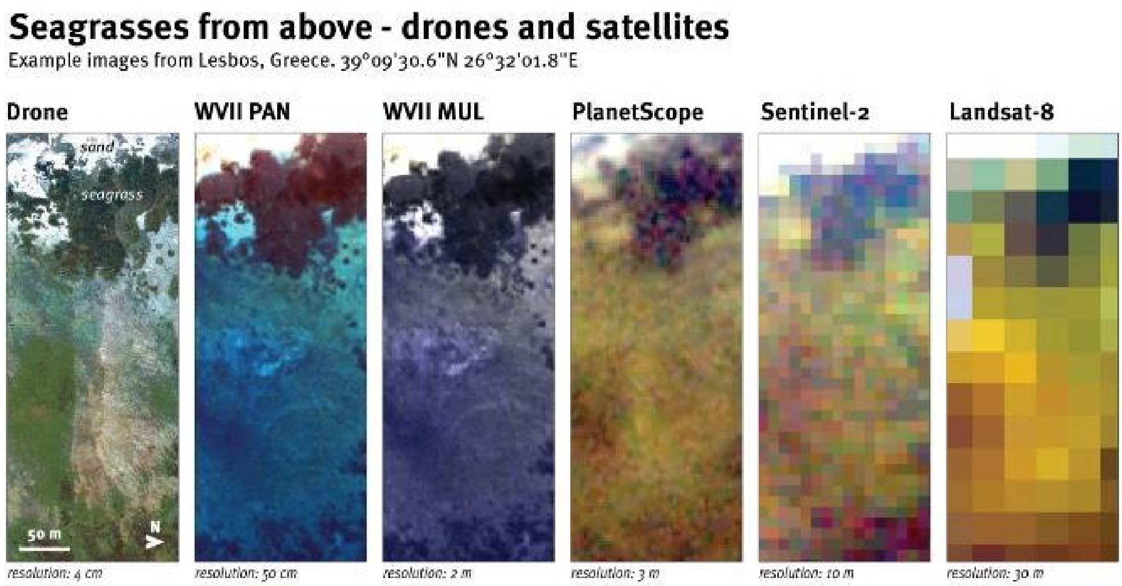
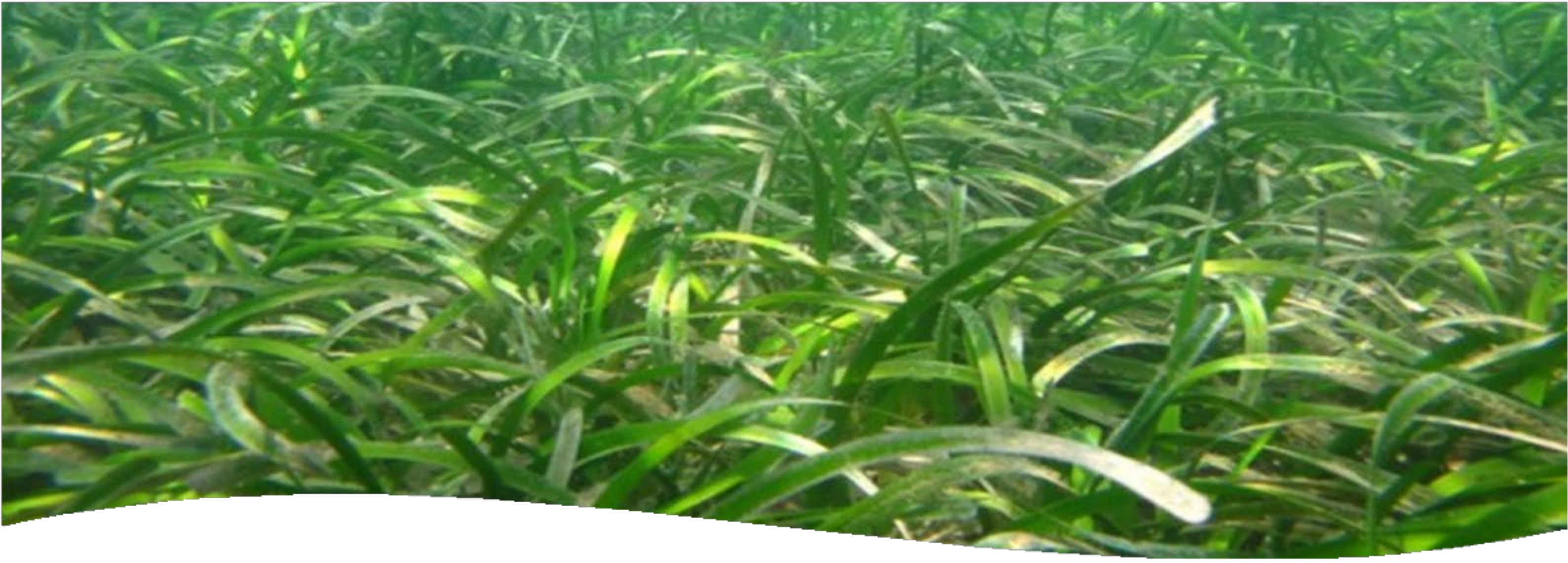


Figure 8: Example of remote sensing image resolution using drones, worldview II satellites, PlantetScope, Sentinel-2, and Landsat-8. Figure reproduced from United Nations Environment Programme (2020).

9 **Investment in improvements in aerial and underwater drones will support more affordable mapping and ground truthing data.** There is considerable discussion in the remote sensing forums around using UAVs to provide very-high image quality for mapping and ground truthing. UAVs have the benefit of rapid deployment, low costs, repeatability, and high-quality imagery (Klemas 2015, Ruwaimana et al. 2018, Díaz-Delgado et al. 2019, Navarro et al. 2020), and have proven successful as mappers of saltmarsh (Oldeland et al. 2021), intertidal macroalgae (Murfitt et al. 2017), and seagrass meadows (Duffy et al. 2018). Collation of drone imagery from citizen scientists is another avenue being pursued to access high quality imagery at low cost. For example, the organisation *GeoNadir* has developed a platform where drone imagery collected by citizen scientists can be integrated into one map (Joyce et al, 2022). Similarly, a recent study analysed erosion patterns in sandy beaches using drone footage collected by citizen scientists and found that imagery collected by citizen scientists was unbiased and resembled the accuracy of professional researchers, at reduced costs (Pucino et al. 2021). Whilst traditional field survey methods will need to continue to complement drone work in situations where they are unsuitable (e.g. mapping beneath canopy cover, no fly zones, etc), UAVs will be an increasingly important tool in the remote sensing arsenal (Rossiter et al. 2020, Sun et al. 2021). As advocated in the attribute-based typology mapping approach (Queensland Department of Environment and Science 2020b), there will be a need to account for differing data densities at varying scale, and attribute accuracy as well as spatial accuracy.

10 **More mapping is required of Ramsar and non-Ramsar sites.** In addition to continued mapping and monitoring of Ramsar wetlands, land managers generally agreed that non-Ramsar sites require a larger mapping focus and can be overlooked in the shadow of adjacent Ramsar wetlands. These sites often demonstrate valuable ecosystem services but lack monitoring and management for reasons such as limited resources and complexities with land ownership. As researchers and managers move towards a seascape model that incorporates connectivity among adjacent areas or habitats, increased focus on these non-Ramsar sites, particularly those already adjacent to regions with ongoing monitoring, should be considered.

Figure 9: Use of UAVs in remote imaging will substantially improve the quality and efficiency of wetland mapping efforts. Image by Bertrand Bouchez.



3.3 Seagrass

Seagrasses are marine flowering plants that form one of the most valuable coastal ecosystems, providing a host of ecosystem services. They sequester carbon 35 times faster than tropical rainforests (McLeod et al. 2011), whilst simultaneously providing nursery habitat for 20% of the world's 25 largest fisheries (UNEP 2020). They also form the first line of defence against coastal erosion, purify water, cycle nutrients, and reduce marine pathogen incidence by up to 50% (Lamb Joleah et al. 2017). Australian waters are home to half of the world's seagrass species and almost one third of the known seagrass area (McKenzie et al. 2020).

Globally seagrasses continue to suffer losses in many places, although analysis of overall trends in global seagrass cover is hampered by lack of reliable habitat maps (Dunic et al. 2021). Australian seagrasses are not exempt from these declines (Connolly et al. 2018), with losses in temperate waters tracking global averages (Waycott et al. 2009), and major losses occurring in tropical waters due to an array of threats including agricultural and industrial runoff, coastal developments, and climate change (Grech et al. 2012, McKenna et al. 2015). *Posidonia australis* seagrass meadows of the Manning-Hawkesbury ecoregion are currently listed as endangered under the EPBC act (Department of the Environment 2015), and if seagrass declines continue, not only will valuable ecosystem services be lost, but carbon stored in seagrass sediments could be eroded and released, turning a valuable carbon sink into a carbon source (Macreadie et al. 2014). Effective maps are imperative to ongoing monitoring and protection of Australian seagrasses.

Through an analysis of the literature supported by Chris Auricht's database (Auricht 2022), and consultation with seagrass experts across Australia, a summary of the current state of seagrass mapping on a state-by-state basis in included in Table 2. From this summary, there are clear regional gaps, and a lack of knowledge surrounding deep-water[2] seagrasses presence, excluding NSW where deep-water seagrasses are known to be absent (Jordan et al. 2010). Much of the mapping is limited by sporadic and site-specific temporal data, and a lack of an integrated data set, which limits policy makers ability to support conservation. The recent publication of eAtlas (Carter et al. 2020) is an example of effectively combining 35 years of spatial data along the Great Barrier Reef with consistency, however even in this excellent resource there are gaps, particularly for deep seagrass.

There are many challenges to developing a comprehensive seagrass inventory for Australia, most notably the difficulties associated with mapping habitats through water. Seagrasses exist in the intertidal and subtidal zone, making water clarity and depth a major barrier to mapping via remote sensing. Surface reflectance through water, surface disruption through wave action, poor clarity through turbidity, and limited light penetration through depth limits the applications for remote sensing (Phinn et al. 2018). Seagrasses have been documented as deep as 88m, limiting the

[2] Deep-water seagrass is defined in varying ways in seagrass literature; for the purpose of this report, deep-water refers to 25 m and deeper

capabilities of aerial remote sensing and requiring alternative methods of mapping. One option is modelling seagrass habitat using bathymetry to predict locations to inspect more closely for seagrass presence. This modelling has been produced for the Great Barrier Reef, however further ground truthing of the model's predictions is required (Coles et al. 2009). Furthermore, detailed bathymetric data for Australia is patchily distributed and often low resolution. A lack of available bathymetry sufficient for seagrass models was brought to our attention in multiple discussions, noting that the best bathymetry is available along the coasts of NSW and SA. Finally, developing seagrass maps is limited by a lack of a national approach for mapping and research, making integration of data across different states complex.

Several current research projects are underway addressing the knowledge gaps. For example, James Cook University (JCU) is producing a similar spatial synthesis of existing data to eAtlas for the Torres Strait and Gulf of Carpentaria. JCU are also conducting seagrass mapping in West Cape York, Limmen Marine Park, and Yanyuwa Sea Country in the Gulf of Carpentaria. Recent state-wide benthic habitat assessments have been conducted in Victoria under the Combine Biotope Classification Scheme, with new records from 2019 now available (Edmunds et al, 2021).

Experts in interviews expressed a need for additional resources to map seagrass meadows that have been predicted to be present, either through modelling or through presence of animal species that rely on seagrass. This lack of resources is particularly true for deep seagrasses, which are more difficult to monitor using remote sensing than shallower meadows. Beyond conducting additional mapping, experts recommended research using other forms of remote sensing, most notably automated analysis of imagery collected using unmanned underwater vehicles (Figure 9). With some refinement of existing technology, this will allow collection and automated analysis of underwater imagery that is consistently collected, provides a permanent record, addresses challenges associated with aerial monitoring such as surface reflectance and turbidity, and has the added benefit of increased safety, particularly in northern Australia where crocodiles pose a hazard.

Figure 10: Remotely operated vehicles can safely collect high-definition underwater imagery which is processed automatically using computer vision to extract seagrass data. Pictured: Underwater drone collecting imagery of seagrass in southeast Queensland.

Table 2: Current mapping coverage for seagrasses by state/territory. Mapping products produced in the last 30 years were considered in the analysis.

State	Subclass	Presence	Species Data	Temporal Trends
NSW	Intertidal	Excellent	Good	Fair - with pockets of excellent mapping
	Subtidal	Good	Good	Fair - with pockets of excellent mapping
	Deep	*Absent*	*Absent*	*Absent*
NT	Intertidal	Good - with pockets of excellent mapping	Good - with pockets of excellent mapping	Poor
	Subtidal	Poor	Poor	Poor
	Deep	Poor	Poor	Poor
QLD	Intertidal	Good - with pockets of excellent mapping	Good - with pockets of excellent mapping	Fair - with pockets of excellent mapping
	Subtidal	Good - with pockets of excellent mapping	Good - with pockets of excellent mapping	Fair - with pockets of excellent mapping
	Deep	Poor	Poor	Poor
SA	Intertidal	Good - with pockets of excellent mapping	Poor	Fair
	Subtidal	Good - with pockets of excellent mapping	Poor	Fair
	Deep	Poor	Poor	Poor
TAS	Intertidal	Good	Poor	Poor
	Subtidal	Fair	Poor	Poor
	Deep	Poor	Poor	Poor
VIC	Intertidal	Excellent	Good	Fair - with pockets of excellent mapping
	Subtidal	Excellent	Good	Fair - with pockets of excellent mapping
	Deep	Poor	Poor	Poor
WA - North	Intertidal	Fair	Poor	Poor
	Subtidal	Fair	Poor	Poor
	Deep	Poor	Poor	Poor
WA - South	Intertidal	Good	Poor	Fair
	Subtidal	Good	Poor	Fair
	Deep	Poor	Poor	Poor
Criteria	Excellent Mapping is available across 80% the state in a downloadable format or in interactive mapping products online	Good Mapping covers more than 50% of the state and is available online.	Fair There are patches of well mapped regions available online.	Poor There is limited to no data readily available online.

3.3.1 Seagrass Research Recommendations

1 **Map deep seagrasses.** There is very limited mapping of deep seagrasses anywhere in Australia. There is recent renewed interest in deep seagrasses due to their potential to store carbon and other ecosystem services they provide (Mazarrasa et al. 2018, York et al. 2018), and their suspected widespread distribution. In Queensland, deep seagrass distribution has been modelled with 74% accuracy on the Great Barrier Reef using bathymetry and sediment composition data (Coles et al. 2009), however the need for further field verification remains. Large areas of deep seagrass near Flinders Island in Bass Strait have also been identified but not yet properly mapped (Alan Jordan, pers. comm.). The need for mapping of deep seagrass was identified in all states except NSW, which has been searched with none evident. The lack of mapping is partially due to limited resources, and partially due to difficulties in mapping, as water clarity and depth can restrict the applicability of satellite imagery (Phinn et al. 2018). Technological refinement of maps involving a combination of remote sensing and the use of underwater drones with automated image analysis offers the potential to cost effectively map very large areas.

2 **Map subtidal seagrasses Australia-wide, with notable gaps in northern Australia and parts of Western Australia.** Both the literature and the focus group meetings identified large regions with minimal seagrass mapping in northern Australia, including parts of WA, the NT, and QLD (York et al. 2017). Whilst increasing the accuracy of existing maps is required, there still are many locations where seagrass is believed to be present, but mapping has not occurred. Additional resource allocation to these zones would facilitate a more complete inventory. Specific locations recommended for mapping during expert interviews are included in Appendix B.

3 **Develop a consistent method for classification of seagrass meadow characteristics, particularly transience, species or structural composition, and meadow condition, to be included in national maps.** Seagrasses can be persistent or transient, and whilst current mapping practices are adept at monitoring persistent meadows, there are limited guidelines as to how to monitor and record the presence of transient meadows, and more consistency is needed (York et al. 2017, UNEP 2020). Possible solutions identified through expert interviews include using remote sensing to characterise what percentage of the year an area is classified as 'seagrass', and classifying meadows as transient, persistent, or opportunistic during the mapping process. Knowledge of the persistence of a species is a critical metric for managers, to separate natural fluctuations from effects due to stressors. For example, certain species groups have predictable traits (including transience) and declines in one species group may be unusual, and indicative of meadow health, yet declines in another species group may be typical for that type of seagrass. An attribute-based approach would provide the foundations for defining such characteristics. Similarly, standardised condition monitoring metrics need to be developed so that this can be conducted in an accurate, consistent, and repeatable way (York et al. 2017, UNEP 2020). Certain bio-indicators can provide early warning signs for declines in seagrass health (McMahon et al. 2013), and declines in water quality causing seagrass stress have been successfully detected by remote sensing (Petus et al. 2014). The selection of appropriate indicators is critical to accurate monitoring, as implementing inaccurate indicators would provide misleading information. Research to determine the most appropriate methods of measuring these meadow characteristics, preferably in a consistent, national methodology aligning with the international work by the Scientific Committee on Oceanic Research (SCOR) working group Coordinated Global Research Assessment of Seagrass System (C-GRASS), is required before these attributes can be monitored (Duffy et al 2022).

4 **Increased use of rapid underwater imaging technology and automated image processing to increase mapping coverage at decreased costs.** Remote sensing through water has some unique challenges. In addition to cloud cover, accurate mapping requires suitable water clarity, low surface reflectance, high spatial resolution of imagery, and calm waters, making some regions difficult or impossible to map using aerial imagery. These challenges are often overcome with data collection by towed divers or snorkellers but can also be addressed using automated benthic habitat mapping with underwater vehicles. Underwater drones have been used for benthic mapping with automated image analysis in Europe, with the benefits of ease of use and low cost (Gauci et al. 2020). Similarly, underwater drones have been used for mapping seagrass in southern Queensland using cloud-based computer vision to automatically detect seagrass presence and density (Figure 10, Global Wetlands Project 2021) This technology can provide vast amounts of data on seagrass cover quickly, cheaply, safely, and can generate considerable calibration and validation data. Automated analysis of drone footage increases reproducibility from sequential visits and decreases costs per unit area mapped (Roelfsema et al. 2013), and could collect important attribute based information, which could be used to identify relationships between key attributes and other image data collected.

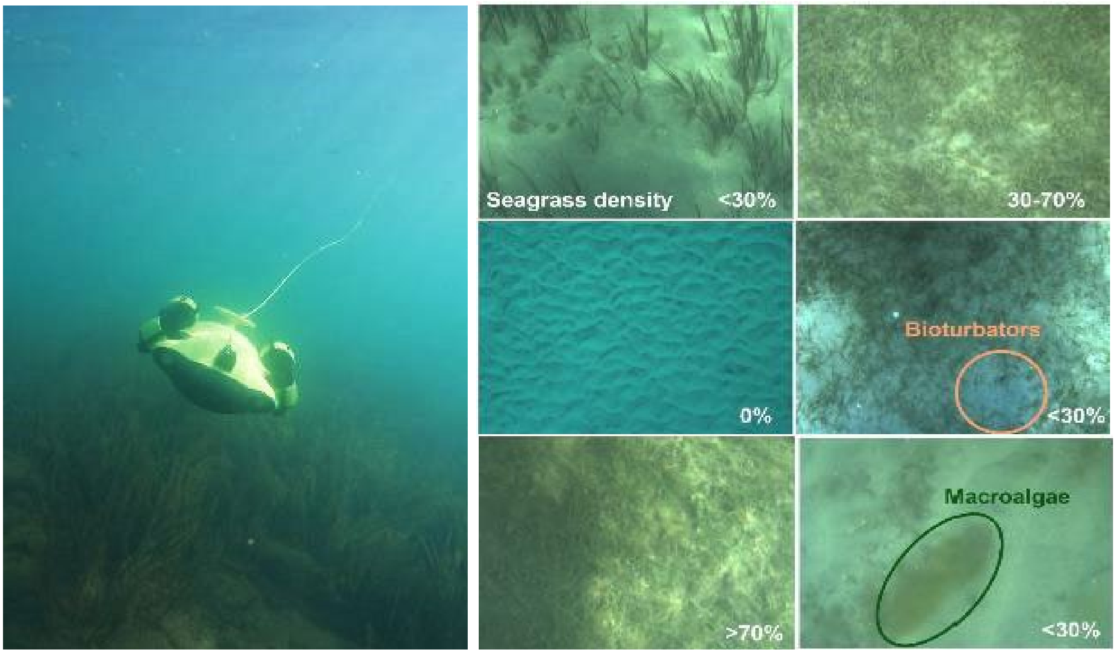


Figure 11: Automated monitoring using underwater drones (left) and computer vision technology (right) reduces the costs and risks and increases the accuracy of seagrass mapping. Photo by Ryan Pearson, The Global Wetlands Project, 2022.

5 **Strategically select regions for seagrass mapping using fauna species distribution models, knowledge of Traditional Custodians, and bathymetry.** Once existing maps from various institutes have been integrated together, the gaps in seagrass mapping can be strategically filled using existing information. Knowledge of Indigenous Australians has been used to successfully guide mapping efforts in the Northern Territory and far north QLD (Roelofs et al. 2005). Similarly, maps of fauna presence can be used to inform habitat presence. For example, both dugong (*Dugong dugon)* and green sea turtle *(Chelonia mydas)* tracking was used to detect seagrass meadows in northern Australia (Hays et al. 2018). In addition to informing mapping efforts, these meadows could be considered of higher priority to map as they provide important habitat for these protected species (York et al. 2017). Finally, bathymetric data can be used to inform likely seagrass presence as has been done in the Great Barrier Reef (e.g. Coles et al, 2009), and other attributes potentially interacting with bathymetry to explain seagrass distribution can be explored e.g. water clarity, energy magnitude involving current speed/benthic shear stress). As researchers continue to explore and map previously undocumented areas, this knowledge could be used as a starting point to strategically fill mapping gaps.

3.4 Saltmarsh

Saltmarshes are saline coastal ecosystems characterised by vegetation that experience episodic inundation by sea water. They generally occupy the upper intertidal zone between the average sea level and highest astronomic tide; however, they can occur in the supratidal zone where inundation occurs on weather assisted tides (e.g. storm surges). Saltmarsh vegetation ranges from grasses and herbs to rushes, sedges, shrubs, and samphire. The most floristically diverse saltmarshes are found in the temperate southern regions of Australia, with less diversity found in northern regions (Saintilan et al. 2009, Rogers et al. 2016).

Saltmarshes provide an array of ecosystem services. They provide valuable habitat for fauna, including shorebirds, as well as stabilising soils, providing coastal protection and erosion control. They also purify water through denitrification and nutrient retention (Więski et al. 2010), and sequester carbon in their soils (Lovelock et al. 2014, Macreadie et al. 2017).

Subtropical and temperate coastal saltmarshes are currently listed as a threatened ecological community under the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act),* due to continued detrimental change, amongst other criteria (DAWE 2013). Many saltmarshes have been drained or lost due to urban, industrial, and agricultural land use. Along the Victorian coastline between 5-20% of coastal saltmarsh has been lost since European settlement, with urban areas such as Port Philip Bay experiencing losses of up to 50% (Sinclair & Boon 2012). A similar pattern has been reported in NSW, with regional losses up to 100% in Weeney Bay, 92% for Careel Bay, and 67% for the Hunter River estuary, attributed to a combination of land reclamation, harvesting, and climate-changed induced losses (Saintilan & Williams 2000). Rising sea levels are also causing mangroves to migrate inland, encroaching on saltmarsh habitat which has limited room to retreat, due to artificial barriers restricting habitat migration to higher ground (Saintilan et al. 2014, Whitt et al. 2020). Accurate maps of saltmarsh presence and possible migration zones are therefore required for appropriate land use planning.

Saltmarsh extent can be complex to record by remote sensing due to small patch sizes, similar spectral results to pasture and other neighbouring land-uses, and interference by adjacent canopy-forming species (Kelleway et al. 2009). Saltmarshes have been well mapped using remote sensing in some states (e.g. Tasmania (Prahalad & Kirkpatrick 2019)) whilst mapping in other states has demonstrated higher error attributed to small patches and similar image spectra to pastureland (e.g. NSW (Navarro et al. 2021)).

Saltmarshes are currently being mapped on a national scale by a team at James Cook University led by Nick Murray using Landsat remote sensing. Upon completion, the researchers intend to share the map with Geoscience Australia for regular updating. Dr. Murray and his team also note that the map could be updated with higher quality imagery if available, allowing for more accurate mapping inclusive of small patches of saltmarsh that may not be detectable with Landsat's current resolution.

Interviews with experts and an assessment of the literature revealed two clear themes of research to support a national inventory of saltmarsh habitat. Firstly, saltmarsh mapping with its small patch sizes and similar spectral results to pastureland requires higher quality satellite imagery if this is to be achieved by remote sensing. Secondly, to support threat management and restoration, changes in saltmarsh extent over time need to be made available, both historically and modelled as predictive threats.

Table 3: Current mapping coverage for saltmarshes by state/territory. Mapping products produced in the last 30 years were considered in the analysis.

State	Presence	Species Data	Temporal Trends
NSW	Excellent	Poor	Fair
NT	Good	Poor	Poor
QLD	Good – with pockets of excellent mapping	Fair – with pockets of excellent mapping	Poor
SA	Good – However data is 20+ years old	Fair – with pockets of excellent mapping	Poor
TAS	Excellent	Good	Poor
VIC	Good – with pockets of excellent mapping	Fair – with pockets of excellent mapping	Good
WA - North	Fair	Poor	Poor
WA- South	Good	Poor	Poor

Criteria

Excellent	Good	Fair	Poor
Mapping is available across 80% the state coastline in an interactive, open-access format (polygons) supported by point data. Mangroves and saltmarsh are clearly distinguished.	Mapping covers more than 50% of the state coastline and is available online. Mangroves and saltmarsh are sometimes distinguished.	There are patches of well mapped regions that are available online. Mangroves and saltmarsh are not distinguished.	There is limited to no data available in an interactive, open-access format.

3.4.1 Saltmarsh research recommendations

1 **Promote access to high quality satellite imagery for more accurate saltmarsh mapping.** Australian saltmarsh patches can be large, but they also can be very small or in narrow strips (Kelleway et al. 2007). Most current mapping uses Landsat data, which uses 30 m x 30 m pixels. Whilst this makes it an excellent resource for broadscale mapping, the large pixels are unable to detect small patches. Sentinel-2 imagery with its 10 m spatial resolution is an improvement but is still unable to capture some small strips of vegetation. For example, end-users in NSW, expressed that Sentinel-2 satellite image quality was too coarse to accurately map fragmented patches of saltmarsh. Developing agreements to provide affordable access to higher quality satellite imagery would significantly benefit the accuracy and extent of saltmarsh mapping and would allow for better temporal monitoring. Satellite data can be used in conjunction with attribute-based inventory mapping, e.g. tidal inundation periods, to explore relationships between fine-scale elevation models (LiDAR) and high resolution imagery (drones).

2 **Produce maps with clear differentiation of saltmarsh and mangroves for management of mangrove encroachment and blue carbon resources.** Saltmarshes and mangroves are often found in adjacent habitats and can have some overlap, with saltmarsh obscured by mangrove canopy. This can make developing clear boundaries between saltmarsh and mangrove habitats difficult yet knowing the boundaries of each ecosystem has important implications for blue carbon calculations and monitoring mangrove encroachment (Saintilan et al. 2014, Whitt et al. 2020). Suggestions from end-users involved including a ‘boundary zone’ on maps where mangroves and saltmarsh are likely to occupy the same region, and including key attributes that influence vegetation such as tidal inundation and terrain morphology in mapping efforts. By mapping current and projected saltmarsh habitats under varying climate conditions (e.g. Hughes et al. 2022) urban barriers to landward migration can be identified and removed (such as work done by the Victoria Saltmarsh Protection Tender). Maps demonstrating elevation profile could be used to conserve suitable adjacent land for saltmarsh expansion and determine whether adjusting the elevation of seemingly unsuitable land could support saltmarsh expansion (Stralberg et al. 2011, Leo et al. 2019, Prahalad & Kirkpatrick 2019).

3 **Improve the technology for mapping saltmarsh using unmanned aerial vehicles (UAVs).** Traditional field survey methods are highly accurate but can be costly and time consuming. UAVs or drones provide a low cost and high-quality alternative for saltmarsh mapping and ground truthing. For example, a single drone can survey up to 7,500 ha within a 90-minute flight, providing very high image quality of <5 cm pixels (Quantum-Systems 2022). UAVs have the added benefit of reducing site impact (e.g. trampling), and the ability to do repeated standardised surveys (Oldeland et al. 2021). UAV surveys can be used either to develop maps in locations where satellite imagery is not available or is too coarse, and to collect training and validating data for satellite imagery, which image quality suitable to estimate several key attributes, such as sediment grain size (Gray et al. 2018). UAVs are currently being used by NSW DPI to validate some existing mapping of saltmarsh habitats, and multispectral UAV imagery is being trialled for monitoring saltmarsh loss and recovery in NSW (Tim Glasby, pers comm.). Further research developing mapping methods with drones, automated image processing, and increasing the battery life and data storage capacity could help develop this tool in the mapping inventory (Rossiter et al. 2020).

4 **Include habitat condition and species composition in saltmarsh maps.** Habitat condition is an important metric for managers of the coastal estate, and research to determine what metrics should be measured to monitor condition are required. One metric

that consistently was mentioned to monitor changes habitat health was saltmarsh species composition. Attribute-based classification approaches typically distinguish different saltmarsh structural macrobiota categories whose species composition are linked to patterns in tidal inundation and are potentially linked to regional attributes (e.g. freshwater source and volume, tidal range), which will be affected by climate change. Understanding transitions between salt couch/ herb grasslands, succulents, sedge and 'bare' (with or without microphytobenthos) that are elevation specific will inform saltmarsh condition and trends under climate change, and affect multiple species that rely on these habitats (Burford et al, 2019, 2020, Benfer et al., 2014, Department of Environment and Resource Management, 2010). There have been notable climate induced shifts in saltmarsh species distribution in recent decades, including both landward and poleward migrations. These range shifts require on-going monitoring, particularly as sea level rise and urbanisation continue to reduce the possible inhabitable area for marshes. Shifts in species composition towards invasive species can have flow on effects to other parts of the ecosystem. For example, *Spartina anglica* is an invasive saltmarsh grass that can alter macrofaunal communities and reduce shorebird usage (Simpson, 1996, Cutajar et al., 2012). As saltmarsh is a threatened ecological community, knowledge of the dominant species is also an important metric for habitat health assessments and classification by the Threatened Species Division in DCCEEW. For a habitat to be classified as the saltmarsh ecological community, a minimum of 50% of the habitat must be covered by native saltmarshes, and knowledge of the species assemblage can aid in identification of the ecological community. As was shown in Table 3, species composition is currently not included in many maps, and this species composition, along with attributes that help determine which species are likely to occupy a region, would be excellent metrics to collect in future mapping efforts.

Figure 12: Coastal saltmarsh in Burmagui, NSW. Photo by Jackie Mile

3.5 Intertidal macroalgae

Macroalgae are generally found attached to hard substrata such as reef and boulders (Diaz-Pulido & McCook 2008). They are important primary producers, providing food and habitat for many fish and invertebrates (Harley et al. 2012, Rossiter et al. 2020). They also play a major role in carbon cycling in coastal waters, where they can detach and become carbon sinks in adjacent regions, making further research into the sequestration capacity and knowledge of macroalgal extent important to blue carbon calculations (Macreadie et al. 2019). Macroalgae can function to either build reefs (such as crustose coralline algae), or degrade them (McCook 1999, Fabricius & De'ath 2001). Some macroalgae have also shown high sensitivity to chemical and physical stressors with increases in abundance of unattached macroalgae often an indicator of poor water quality or nutrient enrichment, which combined with their reef altering attributes makes them a useful taxon for monitoring habitat health (Howarth et al. 2019, D'Archino & Piazzi 2021).

Mapping intertidal macroalgae has many challenges. Firstly, there are the challenges associated with understanding the inundation extent and variability associated with the intertidal zone. Remote sensing imagery is sought during the low tide, however due to predetermined flight paths satellite passes do not always align with the tides, limiting the number of useful images captured. Whilst satellite imagery has proven successful for subtidal, canopy forming macroalgae (Cavanaugh et al. 2010, Casal et al. 2011), image obstruction by breaking waves and surface reflectance, combined with the coarse imagery from satellites, often restricts the utility of the satellite imagery favouring intertidal mapping via aerial surveys, or in recent years UAVs. Imagery collected using UAVs has proven successful internationally for monitoring and discriminating between common species of macroalgae with up to 95% accuracy (Rossiter et al. 2020), however other researchers have found understory species have been underestimated due to obscuration by the canopy (Murfitt et al. 2017, Tait et al. 2019). High quality imagery and attribute-based classification can also support the identification of consolidated substrate for the potential attachment of biota, and use multiple lines of evidence (i.e. elevation data and bathymetry) to predict macrobiota presence (Department of Environment and Heritage Protection, 2017, Queensland Department of Environment and Science 2020b). Mapping should also consider seasonal variability in macroalgal cover, as applications of attribute-based typology have identified seasonal variability as an important factor in determining macroalgal cover.

Australia has very limited intertidal macroalgae mapping along the coastline (Table 4). No state has a current complete map of intertidal macroalgae distribution. Researchers and end-users across Australia expressed a need for additional macroalgal mapping both in the subtidal and intertidal zone, but noted that the intertidal zone typically had less mapping than subtidal habitats. These comments were supported by the literature, where the focus has been on subtidal forests of canopy forming kelp (*Ecklonia radiata*) and endangered giant kelp (*Macrocystis pyrifera)*.

Top: Photograph of Neptune’s necklace (*Hormosira banksia*) by Ian Sanderson

Currently the NSW Department of Primary Industries is collecting bull kelp (*Durvillea potatorum*) presence data from Bermagui to Eden on the south coast of NSW to monitor future range contractions (Tom Davis, pers. comm), and ongoing monitoring projects occur in Victoria as part of the intertidal reef monitoring program (Pritchard et al. 2011). Parks Victoria are also currently working with Deakin university to produce extent maps for intertidal macroalgae, particularly *Hormosira banksia* (Neptune's necklace), as well as identifying temporal changes using both UAV and Sentinel-2 data. Macroalgal mapping along South Australia's coastline was completed in the 1990s as part of the state benthic mapping program. This dataset is an example of more comprehensive macroalgal mapping than the other states, but would also benefit from an update (SA Department for Environment and Water 2018). Wetlands*Info* curated intertidal mapping in Central Queensland using existing literature to produce the most detailed mapping in this field (Wetland*Info* 2021), but this process has not yet been extended to other regions in the state. Many end-users expressed praise for the attribute-based system developed for the Queensland intertidal space (Queensland Department of Environment and Science 2020b), and in meetings multiple end-users suggested that this system could be an excellent classification method to extend nationally.

Future priorities as indicated by interviews and literature focused on an increasing need for resource allocation to this space to support mapping projects, and inclusion of substrate attributes in addition to the structural macrobiota present when producing maps. Expert interviews also revealed the need for additional training data sets to allow accurate remote sensing, with the literature suggesting an emphasis on using new UAV technology to both map and collect ground truthing data in the intertidal zone (Tait et al. 2019, Rossiter et al. 2020).

Table 4: Current mapping coverage for intertidal macroalgae by state. Mapping products produced in the last 30 years were considered in the analysis.

State	Presence	Species Data	Temporal Trends
NSW	Poor	Poor	Poor
NT	Poor	Poor	Poor
QLD	Fair	Poor	Poor
SA	Good – however data is 20+ years old	Poor	Poor
TAS	Poor	Poor	Poor
VIC	Fair	Fair	Fair
WA - North	Poor	Poor	Poor
WA - South	Poor	Poor	Poor

Criteria

Excellent	Good	Fair	Poor
Mapping is available across 80% the state coastline in an interactive, open-access format (polygons) supported by point data.	Mapping covers more than 50% of the state coastline and is available online.	There are patches of well mapped regions that are available online.	There is limited to no data available in an interactive, open-access format.

3.5.1 Intertidal macroalgae research recommendations

1 **Produce high quality maps of intertidal macroalgae in Australia**. There is very limited mapping of macroalgae in the intertidal space across Australia. There are some sporadic regions that have mapped intertidal macroalgae well (e.g. Central Queensland, (Wetland*Info* 2021)), but no current state-wide maps exist. End-users called for extent mapping, supported by species composition or dominant species of macroalgae in each habitat. Changes in macroalgal species composition and distribution can be indicative of habitat health (Borowitzka 1972, McCormick & Cairns 1994) and useful in monitoring the effects of rising sea temperatures and need to be distinguished from seasonal and other cyclic changes in macroalgal extent.

2 **Invest in remote sensing methods to simultaneously map macroalgae extent and dominant species, as well as substrate consolidation, composition and grain size, along with similar attribute-based field training and validation datasets for the intertidal space.** Discussions with experts around intertidal macroalgae mapping also invariably lead to conversations around how to develop training data sets, and inclusion of substrate composition in mapping efforts in the intertidal space, as documentation of the different biophysical attributes can help to determine the ecosystem type and functions. As an example, the Department of Environment and Science, Queensland (2020), have developed an excellent list of 8 key attributes for intertidal and subtidal habitats providing important information for classification, typology, and mapping, which multiple interviewees expressed support for. Macroalgae extent, dominant species, and the substrate and sediment grain size as well as composition and other important attributes of the intertidal space have the potential to be mapped simultaneously using remote sensing if appropriate attribute-based training data sets are developed, but these data sets have not been created for the Australian coastline and can be costly. However, collection of multi-purpose field validation data inclusive of key attributes provides an opportunity to efficiently allocate resources. Existing small to medium scale maps of macroalgal distribution inclusive of sediment composition, such as the maps produced in Central Queensland (Queensland Department of Environment and Science 2020a), could potentially be used to inform a training data set to support remote sensing on large scales at low costs. Another possible avenue of collecting training data is using drones, combined with field validation to avoid error in species classification due to canopy forming algae, and could be supported by data collected by citizen scientists. Pursuing these alternate methods of producing high quality training data provide an opportunity to map these important habitats and their attributes at large scales.

3 **Map historical macroalgae extent using satellite image archive.** Australia has a Landsat image archive for the past 40 years curated by Geoscience Australia. This archive of imagery could be filtered for images at low tide, to develop a low tide mosaic of intertidal macroalgae coverage. Depending on the size of the resource, this may also be able to determine seasonal cycles of intertidal macroalgae distribution or be compared to historical museum and herbarium records to determine long term changes in extent. Although this imagery would be challenging to use to determine species composition and may be unable to determine small strips of macroalgae due to large pixel size, it would be an excellent resource to develop a baseline data set of macroalgae extent and could be updated with more high-quality imagery as it becomes available.

4 **Identify any climate change induced distribution shifts for macroalgal species and establish the ecological impacts of these contractions.** In Australia, intertidal macroalgae area are at their most diverse in cooler waters. A 2^{o} shift poleward in latitude in macroalgal distribution attributed to climate change has already been documented (Wernberg et al. 2011), with changes in Australian macroalgae extent predicted as sea surface temperatures increase (Diaz-Pulido et al. 2007). Understanding and predicting these changes is critical for natural resource managers, and to sustainability of coastal fisheries.

3.6 Shorebirds

Coastal shorebird sites of national and international significance have been mapped Australia-wide by Birdlife Australia (Weller et al. 2020), however further research is needed. Migratory shorebirds are recognised as a *Matter of National Environmental Significance* under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) (Australian Government 2000). As one of the final destinations for migratory shorebirds along the East Asian Flyway, suitable roosting and feeding habitat is critical to shorebird survival. Currently, coastal shorebird populations are declining faster than the rate of habitat loss, implying that there are multiple threats at play. There are 37 species of migratory shorebirds that use Australia's shores, 18 of which have demonstrated significant declines, and 7 that are listed as Threatened under the EPBC Act (Weller et al. 2020).

Shorebirds rely on many types of coastal wetlands including mudflats, saltmarshes, sandy beaches, and rocky coasts. The likelihood that migratory shorebirds will use a particular site is closely related to the area of intertidal habitat available, and the presence of high densities of benthic prey. Intertidal habitat exists between the high and low water marks, at the interface between terrestrial and marine environments. As these habitats often exist as narrow strips, they can be difficult to monitor and are at risk of loss (Dhanjal-Adams et al. 2016a, Hill et al. 2021). For example, in QLD, no agency is responsible for intertidal mapping in the state. There is a clear need for collaboration between land and marine managers to coordinate mapping of these zones.

Experts called for additional mapping related to shorebird threats which were generally related to habitat loss or degradation. Recognition of the importance of shorebird habitat sites can be lacking as the sites are disproportionally important to the birds compared to the amount of the year they are occupied. Rising sea levels are predicted to inundate between 23-40% of intertidal shorebird habitat along the East-Asian flyway (Iwamura et al. 2013), and saltmarshes continue to be threatened, with draining for development and encroachment by mangroves causing coastal squeeze (Whitt et al. 2020). Habitat quality is also of concern, with declines in prey species density documented in several shorebird habitats, attributed to changes in sediment composition, invasive species limiting benthic prey burrowing, climate change, development, and algal blooms, among other factors (Cutajar et al. 2012, Sutherland et al. 2012, Van Colen et al. 2014). Finally, threats within habitats include energetic losses due to flying to avoid off-leash dogs, feral animals, and other forms of disturbance (Schlacher et al. 2013, Dhanjal-Adams et al. 2016b, Stigner et al. 2016). These energetic losses can be costly when birds require time to refuel for large migrations, and the quality of stopover habitat can limit the population (Sheehy et al. 2011).

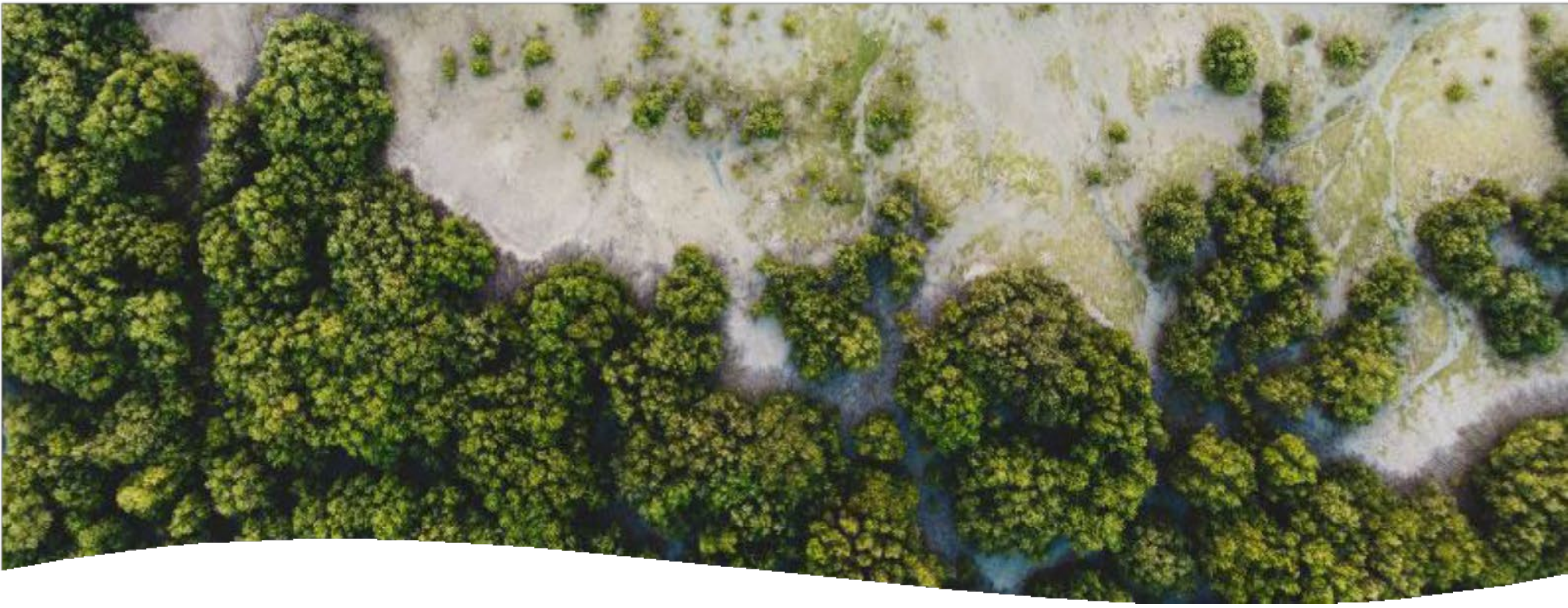
3.6.1 Shorebird research recommendations

1 **Develop predictive maps demonstrating the impacts of sea level rise, mangrove encroachment, development, and climate change on shorebird habitat to determine opportunities for mitigation.** Habitat management and restoration is key to supporting shorebird population recovery. Maps predicting the impacts of a changing climate and future development would allow conservationists to increase active management of shorebird habitat by identifying where significant losses are occurring, develop adaptive plans to stabilise those losses, facilitate retreat of the habitat, or support artificial wetland construction or restoration projects in adjacent regions. Artificial wetlands have shown high uptake by shorebirds in many instances (Bellio et al. 2009, Jackson et al. 2021) and mapping priority locations for placement of artificial or restored wetlands could assist land use planners and co-benefit mapping with other restoration initiatives such as blue carbon projects. This is particularly important in urban sites where retreat of habitat may not be possible.

2 **Improve maps of the shorebird habitat, with emphasis on mapping shorebird use of tidal mudflats and understudied regions.** There are many shorebird habitat types that require additional mapping focus. Tidal mudflats, whilst critical to shorebirds, are often overlooked in mapping efforts and do not clearly fall under land or marine jurisdictions. Geoscience Australia have recently published the intertidal extent model (ITEM) which demonstrates the relative time of exposure of intertidal habitat using Landsat data (Sagar et al 2017), but further mapping demonstrating the categorical type of each of these habitats is needed (sand, mudflat, rocky shore, etc). In addition, many remote intertidal regions have limited shorebird monitoring. This is a result of heavy reliance on citizen science contributions and shorebird habitats that exist in remote and difficult to reach locations. For example, Western Australia has the lowest proportion of shorebird habitat regions surveyed, whilst simultaneously having the highest number of roosting and feeding sites of the states. The Northern Territory with its sparsely populated regions has a similarly low proportion of surveys, attributed to a lack of infrastructure to allow access to habitats and limited availability of volunteers and citizen scientists who provide the majority of bird count data (Weller et al. 2020). Multiple researchers suggested the Gulf of Carpentaria as a focus for future research due to limited knowledge around this region. It was also recommended that maps demonstrate which portions of intertidal flats are used most by shorebirds, possibly by including a shorebird density metric, to help determine high priority conservation zones.

3 **Map the supratidal clay pans used by shorebirds in high tides as shorebird habitat.** Shorebird habitat is generally recognised based on consistent sightings of shorebirds in large numbers, however certain habitat zones, critical for shorebird survival, are used very infrequently such as during the highest astronomical tides, or extreme events. These zones often exist along in the high intertidal to supratidal zones, edged by mangroves, and face losses from rising sea levels and subsequent mangrove encroachment (such as in the Hunter Ramsar site). These sites are often excluded from shorebird habitat zoning, leaving them at risk of reclamation for development. Mapping and monitoring of these sites used during the HAT is required to ensure roosting and feeding sites are available during the entire tidal cycle. A combination of elevation-based highest astronomical tide models and an attribute-based approach to identifying structural macrobiota ‘bare’ areas could be used.

4 **Monitor prey density and availability at key shorebird sites.** Migratory shorebirds rely for food on benthic organisms, including worms, bivalves, crustaceans, and other macroinvertebrates. If the distribution of benthic organisms can be identified and monitored, it can inform and prioritise regions for management and protection (Wade & Hickey 2008). There is a known relationship between benthic organism concentrations and sediment grain size (Yates et al. 1993, Van Colen et al. 2014), which has been successfully detected using remote sensing, supported by ground truthing (Wade & Hickey 2008). However, prey densities can be negatively affected by infrastructure, development, and harvest by humans (Skilleter 2004), reducing shorebird foraging success (Shepherd & Boates 1999). Developing standards for recording and monitoring prey density in a habitat report card would be an excellent metric to determine which regions are providing critical feeding sites, and to investigate the impact of human pressures on prey.



3.7 Blue carbon

Policy makers and scientists are continuing to seek nature-based solutions to tackle climate change. Coastal vegetated ecosystems, also known as blue carbon systems, can provide a disproportionately large contribution towards mitigation of climate change through carbon sequestration (McLeod et al. 2011). Blue carbon systems can sequester carbon in their soils at a rate 30-50 times faster than terrestrial forests, trapping carbon for millennia (McLeod et al. 2011, Duarte et al. 2013).

Blue carbon systems are threatened by land-use change, and changes in nutrient inputs. Over 60% of coastal wetlands were estimated to have been lost during the 20th century, mainly attributed to drainage for alternate forms of land use, such as agriculture and development (Davidson 2014). Remaining coastal wetlands are faced with nutrient runoff from agricultural, commercial, and urban sources which can affect the ability of the system to capture and store carbon. This loss of both ecosystem functionality and above ground biomass not only limits carbon storage opportunities, but degraded systems can release carbon stored over millennia into the atmosphere (Lovelock et al. 2017).

Recently, the Clean Energy Regulator released Australia's first Blue Carbon Method, which creates the framework to allow blue carbon projects to be run within the Emissions Reduction Fund (Clean Energy Regulator 2022). Landowners can remove barriers to tidal flow, allowing re-entry of seawater and converting freshwater or drained wetlands into brackish or saline wetlands, which store carbon, produce a variety of ecosystem services, and have low greenhouse gas emissions. Australia holds an estimated 5-11% of global blue carbon stocks (Serrano et al. 2019, Kelleway et al. 2020, Young et al. 2021), however due to a lack of understanding of the quality and extent of these stocks, they are not currently included in our nationally determined contributions (NDCs) under the Paris Agreement. If blue carbon is being included as an emissions reduction opportunity within the ERF, it is critical that the nation develops a more accurate map of blue carbon stores and opportunities.

Current blue carbon mapping is limited by the quality of wetland habitat maps. Different types of structural macrobiota and plant communities can affect the ability of coastal wetlands to sequester blue carbon (Brown et al. 2016). Furthermore, information of the specific species present and condition of the habitat can affect blue carbon calculations, allowing for higher confidence estimations of blue carbon stores.

There are many exciting blue carbon projects currently underway in Australia. At present, the NSW government has commissioned a "first pass" prioritisation for blue carbon and associated co-benefits for the state through the Marine Estate Management Strategy. This project assesses potential sites for conservation and restoration through a combination of elevation datasets, land use mapping, and habitat mapping. Through this project the team have emphasised the importance of understanding land ownership and landowner attitudes to assess the permanence of a project.

3.7.1 Blue carbon research recommendations

1. **Produce and integrate maps of blue carbon habitats below the highest astronomical tide into one resource.** To fully understand and quantify the value of these coastal systems, an integrated seascape map of habitats needs to be developed (Macreadie et al. 2019). One of the major factors determining the blue carbon potential of a region is the habitat extent of blue carbon ecosystems (Rogers et al. 2019). Habitat extent maps are often only produced for one or two specific habitat types, and this lack of integration of habitats into one resource prevents accurate assessment of co-benefits, blue carbon potential, and may also be less useful for local managers.

2. **Produce historical maps of blue carbon systems, including maps of pre-clearance vegetation.** Historical maps of blue carbon habitats can be used to indicate areas that would support blue carbon restoration projects. This data may also give insights into potential threats to blue carbon ecosystems and allow analysis of historical responses to such threats. Many researchers and end-users have highlighted the need for this data when developing restoration projects.

3. **Field verification for blue carbon stock maps, including strategic sampling in various geomorphological settings.** Blue carbon science is a relatively new field of research, and current sediment sampling has been completed relatively ad-hoc based on immediate need. However, collection and analysis of sediment cores is expensive, and developing a database of core samples collected and corresponding environmental attributes could be used to strategically identify gaps in coring knowledge and direct further core collections cost-effectively. One method proposed in interviews involved using historical mangrove habitat mapping to determine the colonisation year of mangroves and completing coring at sites of different ages to determine the blue carbon potential relative to established time of mangroves for restoration projects. Similarly, this project could identify regional or habitat specific coring gaps (such as limited cores collected in northern Australia) to efficiently allocate resources across different habitats in Australia.

Figure 13: A young mangrove growing through the seagrass beds in Jawbone Sanctuary, Victoria.

4 **Co-benefits need to be carefully measured and mapped to understand full value of restoration projects.** Carbon capture is the main goal of blue carbon projects, but the list of co-benefits from restoration of tidal habitats is extensive. Quantifying the co-benefits raises public awareness and value to theses landscapes, and is a key goal of end-users to enhance uptake (Dittmann et al. 2019).

5 **Models of climate change induced landward migration of coastal ecosystems, including artificial barriers, are needed to assess changes in blue carbon stocks and sequestration due to sea level rise.** As discussed, landward migration of coastal systems, particularly mangrove encroachment into saltmarsh, will result in a changing landscape and affect blue carbon stocks. Developing models that predict this changing capacity will be an important next step in assessing the viability and suitability of blue carbon projects under the ERF (Lovelock et al. 2022). An important factor in developing such models is having accurate current and predicted digital elevation (DEM) models, including subsidence models, bathymetric modelling, and maps of coastal structures such as drains, ditches, and levees. The combined threat of subsidence and SLR will affect tidal flows, which could influence the suitability of a blue carbon project. Projects within the ERF span either 25 or 100 years (Clean Energy Regulator 2022), making understanding of long-term trends critical information prior to project commencement.

6 **Supratidal forests need to be first defined and then mapped.** Supratidal forests are excellent stores of carbon, and are currently included in the Blue Carbon Method, however national maps have not been produced, and different states in Australia have inconsistent definitions for supratidal forests. For maps to be used for blue carbon they need to be nationally consistent, requiring a nationally agreed definition for supratidal forests, and complete, requiring mapping of unmapped habitats, as for the supratidal forests in the northern Australia. Although some experts noted that producing maps of supratidal habitats such as Melaleuca forests may be difficult to achieve at a national level, development of state-wide maps using consistent nationally determined attribute-based classification schemes, would support integration of these forests into the AWI.

Figure 14: Aerial photograph of seagrass meadows in Shark Bay, Western Australia.

4. Conclusion

Developing an AWI is a critical first step to effective wetland conservation, management, and restoration. This report has outlined many of the key research priorities to support an AWI, such as mapping to fill knowledge gaps, research to support efficient filling of those gaps, and data management and processing practices that can harness existing knowledge and allow it to be shared more effectively. There are clearly large gaps in seagrass and intertidal macroalgae extent mapping across the nation, and a need to predict and monitor future threats to shorebird and saltmarsh habitat with climate change and development continuing to add pressure to these threatened species and ecosystems. End-users have also expressed the need to integrate data sets, both for blue carbon mapping, and to increase the utility of mapping resources. Developing methods to integrate disparate data and employing more consistent methods of data collection will allow us to strive for a national resource.

Within these many recommendations it is important to keep sight of the key strategy: *to develop a national approach to mapping key attributes of coastal wetlands.* Agreeing upon specific attributes and quantification methods will allow for the state maps to be combined in a national inventory. As with the development and implementation of the ANAE classification system, this will require a national cabinet of experts to determine what attribute data should be collected to support their end-user needs. This 'big picture' approach is a top priority to ensure that future mapping efforts can be integrated and interrogated on a national platform, and will remain relevant for future national applications such as ecosystem accounting frameworks.

We are eager to see these recommendations put into action through research projects and departmental action. Marine and coastal wetlands are one of Australia's most valuable biological resources, and progress towards an Australian Wetland Inventory is crucial for coastal wetland conservation and management.

Figure 15: Bull kelp holds fast to a rock in Recherche Bay, Tasmania.

5. Acknowledgements

The authors particularly thank Kathy Eyles for guidance throughout the project, and Chris Auricht for access to his databases of wetland mapping. As a Scoping project, it relied heavily on input from a very wide range of end-users, research experts, and other stakeholders, listed in Appendix C.

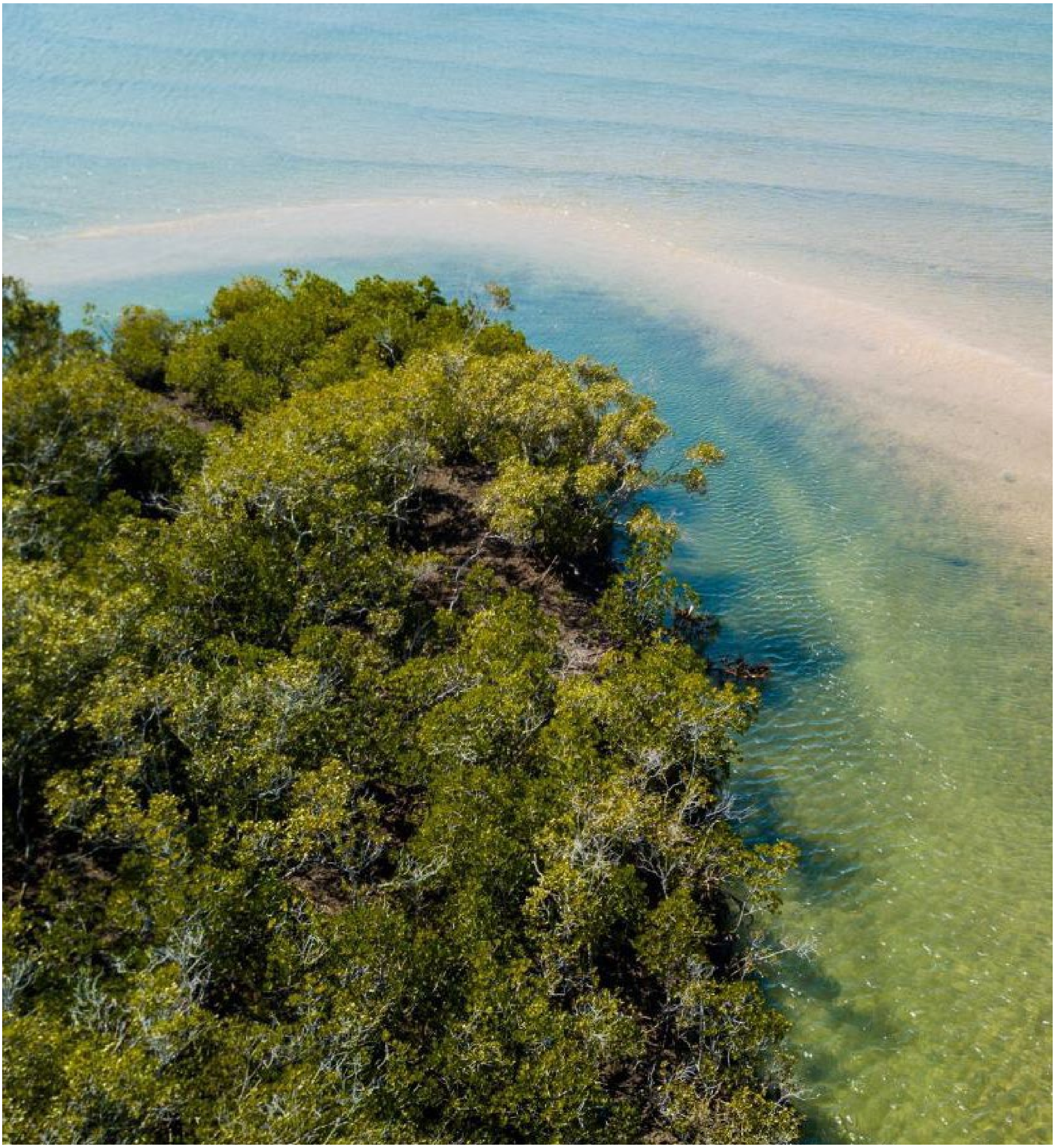


Figure 16: Mangroves along the waterline in Moreton Bay, Queensland

6. References

Asplund ME, Dahl M, Ismail RO, Arias-Ortiz A, Deyanova D, Franco JN, Hammar L, Hoamby AI, Linderholm HW, Lyimo LD, Perry D, Rasmusson LM, Ridgway SN, Salgado Gispert G, D'Agata S, Glass L, Mahafina JA, Ramahery V, Masque P, Björk M, Gullström M (2021) Dynamics and fate of blue carbon in a mangrove–seagrass seascape: influence of landscape configuration and land-use change. Landscape Ecology 36:1489-1509

Aquatic Ecosystems Task Group (2012) Aquatic ecosystems toolkit. Australian Government Department of Sustainability, Environment, Water, Population and Communities, Australia

Auricht C (2022) CEWO Aust Wetland Inventory Share-Point Site. Accessed 25/01/2022. https://auricht.com/awi/

Australian Government (2000) Environment Protection and Biodiversity Conservation Act 1999. Australian Government, Australia

Australian Government (2022) data.gov.au. Australian Government, Australia

Bellio MG, Kingsford RT, Kotagama SW (2009) Natural versus artificial- wetlands and their waterbirds in Sri Lanka. Biological Conservation 142:3076-3085

Benfer D, Baker AM, Ball T, Gynther I, Janetzki H, Fuller, S (2014_ Conservation genetics of the water mouse, Xeromys myoides Thomas, 1889. Aust. J. Zool. 62, 382. https://doi.org/10.1071/ZO14019

Borchert SM, Osland MJ, Enwright NM, Griffith KT (2018) Coastal wetland adaptation to sea level rise: Quantifying potential for landward migration and coastal squeeze. Journal of Applied Ecology 55:2876-2887

Borowitzka MA (1972) Intertidal algal species diversity and the effect of pollution. Marine and Freshwater Research 23:73-84

Brown DR, Conrad S, Akkerman K, Fairfax S, Fredericks J, Hanrio E, Sanders LM, Scott E, Skillington A, Tucker J, van Santen ML, Sanders CJ (2016) Seagrass, mangrove and saltmarsh sedimentary carbon stocks in an urban estuary; Coffs Harbour, Australia. Regional Studies in Marine Science 8:1-6

Burford M (2019) Links between Gulf rivers, coastal productivity & migratory shorebirds (project update). NESP Northern Australia Environmental Resources Hub project update 3.

Burford M, Faggotter SJ, Kenyon R (2020) Contribution of three rivers to floodplain and coastal productivity in the Gulf of Carpentaria: Component 1 final report. , Brisbane. Griffith University, Brisbane.

Carter A, Collier C, McKenna S, Rasheed M, Pitcher R, McKenzie L, Cole R (2020) Seagrass mapping synthesis: A resource for coastal management in the Great Barrier Reef (NESP TWQ Project 3.2.1 and 5.4, TropWATER, James Cook University). Accessed 10/10/2021. https://doi.org/10.25909/y1yk-9w85

Casal G, Sánchez-Carnero N, Sánchez-Rodríguez E, Freire J (2011) Remote sensing with SPOT-4 for mapping kelp forests in turbid waters on the south European Atlantic shelf. Estuarine, Coastal and Shelf Science 91:371-378

Cavanaugh KC, Siegel DA, Kinlan BP, Reed DC (2010) Scaling giant kelp field measurements to regional scales using satellite observations. Marine Ecology Progress Series 403:13-27

Clark GF, Johnston EL (2016) Coasts: Australia state of the environment 2016. Australian Government Department of the Environment and Energy, Canberra

Clean Energy Regulator (2022) Understanding your blue carbon project – simple method guide. Australia

Coles R, McKenzie L, De'ath G, Roelofs A, Lee Long W (2009) Spatial distribution of deepwater seagrass in the inter-reef lagoon of the Great Barrier Reef World Heritage Area. Marine Ecology Progress Series 392:57-68

Connolly RM, Jackson EL, Macreadie PI, Maxwell PS, O'Brien KR (2018) Seagrass Dynamics and Resilience. In: Larkum AWD, Kendrick GA, Ralph PJ (eds) Seagrasses of Australia: Structure, Ecology and Conservation. Springer International Publishing, Cham

Costanza R, de Groot R, Sutton P, van der Ploeg S, Anderson SJ, Kubiszewski I, Farber S, Turner RK (2014) Changes in the global value of ecosystem services. Global Environmental Change 26:152-158

Cutajar J, Shimeta J, Nugegoda D (2012) Impacts of the invasive grass Spartina anglica on benthic macrofaunal assemblages in a temperate Australian saltmarsh. Marine Ecology Progress Series 464:107-120

Edmunds, M, Flynn, A, Ferns, L (2021) Combined Biotope Classification Scheme (CBiCS): A New Marine Ecological Classification Scheme to Meet New Challenges. Victoria: The State of Victoria Department of Environment, Land, Water and Planning.

D'Archino R, Piazzi L (2021) Macroalgal assemblages as indicators of the ecological status of marine coastal systems: A review. Ecological Indicators 129:107835

Davidson NC (2014) How much wetland has the world lost? Long-term and recent trends in global wetland area. Marine and Freshwater Research 65:934-941

Davidson NC, Fluet-Chouinard E, Finlayson CM (2018) Global extent and distribution of wetlands: trends and issues. Marine and Freshwater Research 69:620-627

Davis JA, Froend R (1999) Loss and degradation of wetlands in southwestern Australia: underlying causes, consequences and solutions. Wetlands Ecology and Management 7:13-23

Department of Sustainability, Environment, Water, Population and Communities (2013). Conservation Advice for Subtropical and Temperate Coastal Saltmarsh. Canberra: Department of Sustainability, Environment, Water, Population and Communities. Available from: http://www.environment.gov.au/biodiversity/threatened/communities/pubs/118-conservation-advice.pdf.

DAWE (2021) Directory of Important Wetlands in Australia. Accessed 24/1/22. https://www.awe.gov.au/water/wetlands/australian-wetlands-database/directory-important-wetlands

Department of Environment and Heritage Protection Queensland (2017) Queensland Intertidal and Subtidal ecosystem classification scheme Version 1.0: Module 1—Introduction and implementation of intertidal and subtidal ecosystem classification. Queensland Wetlands Program. Queensland Government, Brisbane.

Department of the Environment (2015). Approved Conservation Advice (including listing advice) for Posidonia australis seagrass meadows of the Manning-Hawkesbury ecoregion ecological community. Canberra: Department of the Environment. Available from: http://www.environment.gov.au/biodiversity/threatened/communities/pubs/127-conservation-advice.pdf.

Department of the Environment and Resource Management (2010). National recovery plan for the water mouse (false water rat) Xeromys myoides - Report to the Department of the Environment, Water, Heritage and the Arts, Canberra. Brisbane, Queensland.

Department of the Environment, Heritage and the Arts, (2008) National Framework and Guidance for Describing the Ecological Character of Australia's Ramsar Wetlands. Module 2 of the National Guidelines for Ramsar Wetlands, Australia

Dhanjal-Adams KL, Hanson JO, Murray NJ, Phinn SR, Wingate VR, Mustin K, Lee JR, Allan JR, Cappadonna JL, Studds CE, Clemens R, Roelfsema CM, Fuller RA (2016a) The

distribution and protection of intertidal habitats in Australia. Emu - Austral Ornithology 116:208-214
Dhanjal-Adams KL, Mustin K, Possingham HP & Fuller RA (2016b) Optimizing disturbance management for wildlife protection: The enforcement allocation problem. Journal of Applied Ecology 53, 1215-1224.
Díaz-Delgado R, Cazacu C, Adamescu M (2019) Rapid Assessment of Ecological Integrity for LTER Wetland Sites by Using UAV Multispectral Mapping. Drones 3
Diaz-Pulido G, McCook L (2008) Macroalgae (Seaweeds). In: A. C (ed) The State of the Great Barrier Reef On-line. Great Barrier Reef Marine Park Authority, Townsville
Diaz-Pulido G, McCook LJ, Larkum AWD, Lotze HK, Raven JA, Schaffelke B, Smith JE, Steneck RS, Authority GBRMP (2007) Vulnerability of macroalgae of the Great Barrier Reef to climate change. Climate change and the Great Barrier Reef: a vulnerability assessment. The Great Barrier Reef Marine Park Authority, Queensland
Dittmann S, Mosley L, Jones AR, Clanahan M, Beaumont K, Gillanders BM (2019) Research agenda for blue carbon in South Australia. Technical Report Series No 19/31, South Australia
Duarte CM, Losada IJ, Hendriks IE, Mazarrasa I, Marbà N (2013) The role of coastal plant communities for climate change mitigation and adaptation. Nature Climate Change 3:961-968
Duarte de Paula Costa M, Lovelock CE, Waltham NJ, Young M, Adame MF, Bryant CV, Butler D, Green D, Rasheed MA, Salinas C, Serrano O, York PH, Whitt AA, & Macreadie PI (2021) Current and future carbon stocks in coastal wetlands within the Great Barrier Reef catchments. Global Change Biology, 27(14), 3257-3271.
Duffy JP, Pratt L, Anderson K, Land PE, Shutler JD (2018) Spatial assessment of intertidal seagrass meadows using optical imaging systems and a lightweight drone. Estuarine, Coastal and Shelf Science 200:169-180
Duffy JE, Weatherdon LV, Ambo-Rappe R, Cullen-Unsworth L, Fortes M, Marbà N, McKenzie L, Potouroglou M, Short F, Uku J, Connolly RM, de la Torre Castro M, Dierssen H, Duarte C, Fourqurean JW, Hessing-Lewis M, Muller-Karger F, Nakaoka M, Prathep A, Unsworth R (2022) Coordinated Global Research Assessment of Seagrass System (C-GRASS) Working Group. Accessed 23/2/2022. https://scor-int.org/group/158/
Dugan P, Dungan PJ, Nature IUfCo, Resources N (1990) Wetland Conservation: A Review of Current Issues and Required Action. IUCN
Dunic JC, Brown CJ, Connolly RM, Turschwell MP, Côté IM (2021) Long-term declines and recovery of meadow area across the world’s seagrass bioregions. Global Change Biology 27:4096-4109
Fabricius K, De'ath G (2001) Environmental factors associated with the spatial distribution of crustose coralline algae on the Great Barrier Reef. Coral Reefs 19:303-309
Finlayson CM, Davidson NC, Spiers AG, Stevenson NJ (1999) Global wetland inventory – current status and future priorities. Marine and Freshwater Research 50:717-727
Finlayson CM, van der Valk AG (1995) Wetland classification and inventory: A summary. In: Finlayson CM, van der Valk AG (eds) Classification and Inventory of the World’s Wetlands. Springer Netherlands, Dordrecht
Gauci A, Deidun A, Abela J, Cachia E, Dimech S Automatic Benthic Habitat Mapping using Inexpensive Underwater Drones. Proc IGARSS 2020 - 2020 IEEE International Geoscience and Remote Sensing Symposium
Global Wetlands Project (2021) Automated identification of benthic habitats. Report and provision of BenthicID software to Gold Coast Waterways Authority, Queensland.
Gray PC, Ridge JT, Poulin SK, Seymour AC, Schwantes AM, Swenson JJ, Johnston DW (2018) Integrating Drone Imagery into High Resolution Satellite Remote Sensing Assessments of Estuarine Environments. Remote Sensing 10:1257

Grech A, Chartrand K, Erftemeijer P, Fonseca M, McKenzie L, Rasheed M, Taylor H, Coles R (2012) A comparison of threats, vulnerabilities and management approaches in global seagrass bioregions. Environmental Research Letters - ENVIRON RES LETT 7

Harley CDG, Anderson KM, Demes KW, Jorve JP, Kordas RL, Coyle TA, Graham MH (2012) EFFECTS OF CLIMATE CHANGE ON GLOBAL SEAWEED COMMUNITIES. Journal of Phycology 48:1064-1078

Hays GC, Alcoverro T, Christianen MJA, Duarte CM, Hamann M, Macreadie PI, Marsh HD, Rasheed MA, Thums M, Unsworth RKF, York PH, Esteban N (2018) New Tools to Identify the Location of Seagrass Meadows: Marine Grazers as Habitat Indicators. Frontiers in Marine Science 5

Hill NK, Woodworth BK, Phinn SR, Murray NJ & Fuller RA (2021) Global protected-area coverage and human pressure on tidal flats. Conservation Biology 35, 933-943.

Howarth LM, Filgueira R, Jiang D, Koepke H, Frame MK, Buchwald C, Finnis S, Chopin T, Costanzo SD, Grant J (2019) Using macroalgal bioindicators to map nutrient plumes from fish farms and other sources at a bay-wide scale. Aquaculture Environment Interactions 11:671-684

Hu S, Niu Z, Chen Y, Li L, Zhang H (2017) Global wetlands: Potential distribution, wetland loss, and status. Science of The Total Environment 586:319-327

Huxham M, Whitlock D, Githaiga M, Dencer-Brown A (2018) Carbon in the Coastal Seascape: How Interactions Between Mangrove Forests, Seagrass Meadows and Tidal Marshes Influence Carbon Storage. Current Forestry Reports 4:101-110

Hyndes GA, Nagelkerken I, McLeod RJ, Connolly RM, Lavery PS, Vanderklift MA (2014) Mechanisms and ecological role of carbon transfer within coastal seascapes. Biological Reviews 89:232-254

Iwamura T, Possingham HP, Chadès I, Minton C, Murray NJ, Rogers DI, Treml EA, Fuller RA (2013) Migratory connectivity magnifies the consequences of habitat loss from sea-level rise for shorebird populations. Proceedings of the Royal Society B: Biological Sciences 280:20130325

Jackson MV, Woodworth BK, Bush R, Clemens RS, Fuller RA, Garnett ST, Lilleyman A, Maron M, Purnell C, Rogers DI, Amano T (2021) Widespread use of artificial habitats by shorebirds in Australia. Emu - Austral Ornithology 121:187-197

Jordan A, Davies P, Ingleton T, Foulsham E, Neilson J, Pritchard T (2010) Seabed habitat mapping of the continental shelf of NSW. NSW

Joyce K, Mead P, Li J, Crosby A, Tandukar N, Dhakal M, Blundell J, Maier S (2022) GeoNadir Data. Accessed 18/02/2022. https://data.geonadir.com/

Kelleway J, Williams R, Laegdsgaard P (2009) Mapping, assessment and monitoring of saltmarshes. Australian Saltmarsh Ecology CSIRO, Melbourne:211-229

Kelleway J, Williams RJ, Allen CB (2007) An assessment of a the saltmarsh of the Parramatta River and Sydney Harbour. NSW

Kelleway JJ, Serrano O, Baldock JA, Burgess R, Cannard T, Lavery PS, Lovelock CE, Macreadie PI, Masqué P, Newnham M, Saintilan N, Steven ADL (2020) A national approach to greenhouse gas abatement through blue carbon management. Global Environmental Change 63:102083

Kilminster K, McMahon K, Waycott M, Kendrick GA, Scanes P, McKenzie L, O'Brien KR, Lyons M, Ferguson A, Maxwell P, Glasby T, Udy J (2015) Unravelling complexity in seagrass systems for management: Australia as a microcosm. Science of The Total Environment 534:97-109

Kingsford RT, Dunn H, Love D, Nevill J, Stein J, Tait J (2005) Protecting Australia’s rivers, wetlands and estuaries of high conservation value. Canberra

Klemas VV (2015) Coastal and Environmental Remote Sensing from Unmanned Aerial Vehicles: An Overview. Journal of Coastal Research 31:1260-1267

Kovacs EM, Roelfsema C, Udy J, Baltais S, Lyons M, Phinn S (2022) Cloud Processing for Simultaneous Mapping of Seagrass Meadows in Optically Complex and Varied Water. Remote Sensing 14:609

Krause-Jensen D, Duarte CM (2016) Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9:737-742

Lamb Joleah B, van de Water Jeroen AJM, Bourne David G, Altier C, Hein Margaux Y, Fiorenza Evan A, Abu N, Jompa J, Harvell CD (2017) Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science 355:731-733

Lavery PS, Mateo M-Á, Serrano O, Rozaimi M (2013) Variability in the Carbon Storage of Seagrass Habitats and Its Implications for Global Estimates of Blue Carbon Ecosystem Service. PLOS ONE 8:e73748

Lee SY, Dunn RJK, Young RA, Connolly RM, Dale PER, Dehayr R, Lemckert CJ, McKinnon S, Powell B, Teasdale PR, Welsh DT (2006) Impact of urbanization on coastal wetland structure and function. Austral Ecology 31:149-163

Leo KL, Gillies CL, Fitzsimons JA, Hale LZ, Beck MW (2019) Coastal habitat squeeze: A review of adaptation solutions for saltmarsh, mangrove and beach habitats. Ocean & Coastal Management 175:180-190

Ling JE, Hughes MG, Powell M, Cowood AL (2018) Building a national wetland inventory: a review and roadmap to move forward. Wetlands Ecology and Management 26:805-827

Lovelock CE, Adame MF, Bennion V, Hayes M, O'Mara J, Reef R, Santini NS (2014) Contemporary Rates of Carbon Sequestration Through Vertical Accretion of Sediments in Mangrove Forests and Saltmarshes of South East Queensland, Australia. Estuaries and Coasts 37:763-771

Lovelock CE, Adame MF, Butler DW, Kelleway JJ, Dittmann S, Fest B, King KJ, Macreadie PI, Mitchell K, Newnham M, Ola A, Owers CJ, Welti N (2022) Modeled approaches to estimating blue carbon accumulation with mangrove restoration to support a blue carbon accounting method for Australia. Limnology and Oceanography n/a

Lovelock CE, Atwood T, Baldock J, Duarte CM, Hickey S, Lavery PS, Masque P, Macreadie PI, Ricart AM, Serrano O, Steven A (2017) Assessing the risk of carbon dioxide emissions from blue carbon ecosystems. Frontiers in Ecology and the Environment 15:257-265

Lucieer V, Barrett N, Butler C, Flukes E, Ierodiaconou D, Ingleton T, Jordan A, Monk J, Meeuwig J, Porter-Smith R, Smit N, Walsh P, Wright A, Johnson C (2019) A seafloor habitat map for the Australian continental shelf. Scientific Data 6:120

Lymburner L, Bunting P, Lucas R, Scarth P, Alam I, Phillips C, Ticehurst C, Held A (2020) Mapping the multi-decadal mangrove dynamics of the Australian coastline. Remote Sensing of Environment 238:111185

Macreadie PI, Anton A, Raven JA, Beaumont N, Connolly RM, Friess DA, Kelleway JJ, Kennedy H, Kuwae T, Lavery PS, Lovelock CE, Smale DA, Apostolaki ET, Atwood TB, Baldock J, Bianchi TS, Chmura GL, Eyre BD, Fourqurean JW, Hall-Spencer JM, Huxham M, Hendriks IE, Krause-Jensen D, Laffoley D, Luisetti T, Marbà N, Masque P, McGlathery KJ, Megonigal JP, Murdiyarso D, Russell BD, Santos R, Serrano O, Silliman BR, Watanabe K, Duarte CM (2019) The future of Blue Carbon science. Nature Communications 10:3998

Macreadie PI, Baird ME, Trevathan-Tackett SM, Larkum AWD, Ralph PJ (2014) Quantifying and modelling the carbon sequestration capacity of seagrass meadows – A critical assessment. Marine Pollution Bulletin 83:430-439

Macreadie PI, Ollivier QR, Kelleway JJ, Serrano O, Carnell PE, Ewers Lewis CJ, Atwood TB, Sanderman J, Baldock J, Connolly RM, Duarte CM, Lavery PS, Steven A, Lovelock CE (2017) Carbon sequestration by Australian tidal marshes. Scientific Reports 7:44071

Mazarrasa I, Samper-Villarreal J, Serrano O, Lavery PS, Lovelock CE, Marbà N, Duarte CM, Cortés J (2018) Habitat characteristics provide insights of carbon storage in seagrass meadows. Marine Pollution Bulletin 134:106-117

McCook LJ (1999) Macroalgae, nutrients and phase shifts on coral reefs: scientific issues and management consequences for the Great Barrier Reef. Coral Reefs 18:357-367

McCormick PV, Cairns J (1994) Algae as indicators of environmental change. Journal of Applied Phycology 6:509-526

McKenna S, Jarvis J, Sankey T, Reason C, Coles R, Rasheed M (2015) Declines of seagrasses in a tropical harbour, North Queensland, Australia, are not the result of a single event. Journal of Biosciences 40:389-398

McKenzie LJ, Nordlund LM, Jones BL, Cullen-Unsworth LC, Roelfsema C, Unsworth RK (2020) The global distribution of seagrass meadows. Environmental Research Letters 15:074041

McLeod E, Chmura GL, Bouillon S, Salm R, Björk M, Duarte CM, Lovelock CE, Schlesinger WH, Silliman BR (2011) A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. Front Ecol Environ 9:552-560

McMahon K, Collier C, Lavery PS (2013) Identifying robust bioindicators of light stress in seagrasses: A meta-analysis. Ecological Indicators 30:7-15

Murfitt SL, Allan BM, Bellgrove A, Rattray A, Young MA, Ierodiaconou D (2017) Applications of unmanned aerial vehicles in intertidal reef monitoring. Scientific Reports 7:10259

Navarro A, Young M, Allan B, Carnell P, Macreadie P, Ierodiaconou D (2020) The application of Unmanned Aerial Vehicles (UAVs) to estimate above-ground biomass of mangrove ecosystems. Remote Sensing of Environment 242:111747

Navarro A, Young M, Macreadie PI, Nicholson E, Ierodiaconou D (2021) Mangrove and Saltmarsh Distribution Mapping and Land Cover Change Assessment for South-Eastern Australia from 1991 to 2015. Remote Sensing 13

Hughes MG, Glasby TM, Hanslow DJ, West GJ, and Wen L (2022 submitted). Machine-learning classification method for predicting intertidal wetland migration under sea level rise. Frontiers in Environmental Science, in review.

Oldeland J, Revermann R, Luther-Mosebach J, Buttschardt T, Lehmann JRK (2021) New tools for old problems — comparing drone- and field-based assessments of a problematic plant species. Environmental Monitoring and Assessment 193:90

Petus C, Collier C, Devlin M, Rasheed M, McKenna S (2014) Using MODIS data for understanding changes in seagrass meadow health: A case study in the Great Barrier Reef (Australia). Marine Environmental Research 98:68-85

Phinn S, Roelfsema C, Kovacs E, Canto R, Lyons M, Saunders M, Maxwell P (2018) Mapping, Monitoring and Modelling Seagrass Using Remote Sensing Techniques. In: Larkum AWD, Kendrick GA, Ralph PJ (eds) Seagrasses of Australia: Structure, Ecology and Conservation. Springer International Publishing, Cham

Prahalad V, Kirkpatrick JB (2019) Saltmarsh conservation through inventory, biogeographic analysis and predictions of change: Case of Tasmania, south-eastern Australia. Aquatic Conservation: Marine and Freshwater Ecosystems 29:717-731

Pritchard K, Edmunds M, Stewart K, Davis S, Dickens L, Donnelly D (2011) Victorian Intertidal Reef Monitoring Program: the intertidal reef biota of central Victoria's marine protected areas. Book 70. Parks Vicotria, Melbourne

Pucino N, Kennedy DM, Carvalho RC, Allan B, Ierodiaconou D (2021) Citizen science for monitoring seasonal-scale beach erosion and behaviour with aerial drones. Scientific Reports 11:3935

Quantum-Systems (2022) Trinity F90Plus mapping drone. Accessed 13/1/22. https://www.quantum-systems.com/project/trinityf90plus-mapping-drone/

Queensland Department of Environment and Science (2020a) Layer: Intertidal subtidal mapping CQ. Wetland Maps. Wetland*Info*, Queensland, Australia

Queensland Department of Environment and Science (2020b) *Queensland Intertidal and Subtidal Ecosystem Classification Scheme Version 1.0: Module 4—A method for providing baseline mapping of intertidal and subtidal ecosystems in Queensland*. Queensland Wetlands Program. Queensland Government. Brisbane

Queensland Department of Environment and Heritage Protection (2017) *Queensland Intertidal and Subtidal ecosystem classification scheme Version 1.0: Module 1—Introduction and implementation of intertidal and subtidal ecosystem classification*. Queensland Wetlands Program. Queensland Government. Brisbane.

Ramsar Convention Secretariat (2016) The Fourth Ramsar Strategic Plan 2016–2024. Ramsar handbooks for the wise use of wetlands, 5th edition, vol 2, Gland, Switzerland

Ramsar Convertion (2002) Resolution VIII.6: a Ramsar framework for wetland inventory. Valencia, Spain

Roelfsema CM, Kovacs EM, Ortiz JC, Callaghan DP, Hock K, Mongin M, Johansen K, Mumby PJ, Wettle M, Ronan M, Lundgren P, Kennedy EV, Phinn SR (2020) Habitat maps to enhance monitoring and management of the Great Barrier Reef. Coral Reefs 39: 1039–1054

Roelfsema C, Kovacs EM, Saunders MI, Phinn S, Lyons M, Maxwell P (2013) Challenges of remote sensing for quantifying changes in large complex seagrass environments. Estuar Coast Shelf Sci 133:161-171

Roelofs A, Coles R, Smit N (2005) A survey of intertidal seagrass from Van Diemen Gulf to Castlereagh Bay, Northern Territory, and from Gove to Horn Island, Queensland.

Rogers K, Boon PI, Branigan S, Duke NC, Field CD, Fitzsimons JA, Kirkman H, Mackenzie JR, Saintilan N (2016) The state of legislation and policy protecting Australia's mangrove and salt marsh and their ecosystem services. Marine Policy 72:139-155

Rogers K, Macreadie PI, Kelleway JJ, Saintilan N (2019) Blue carbon in coastal landscapes: a spatial framework for assessment of stocks and additionality. Sustainability Science 14:453-467

Rossiter T, Furey T, McCarthy T, Stengel DB (2020) UAV-mounted hyperspectral mapping of intertidal macroalgae. Estuarine, Coastal and Shelf Science 242:106789

Ruwaimana M, Satyanarayana B, Otero V, M. Muslim A, Syafiq A M, Ibrahim S, Raymaekers D, Koedam N, Dahdouh-Guebas F (2018) The advantages of using drones over space-borne imagery in the mapping of mangrove forests. PLOS ONE 13:e0200288

SA Department for Environment and Water (2018) NatureMaps 3.2. Government of South Australia, South Australia

Sagar S, Roberts D, Bala B, and Lymburner L, (2017) Extracting the intertidal extent and topography of the Australian coastline from a 28 year time series of Landsat observations. Remote Sensing of Environment 195, 153–169.

Saintilan N, ProQuest E, Publishing C (2009) Australian saltmarsh ecology. CSIRO Pub, Collingwood, Vic

Saintilan N, Rogers K, Kelleway JJ, Ens E, Sloane DR (2019) Climate Change Impacts on the Coastal Wetlands of Australia. Wetlands 39:1145-1154

Saintilan N, Williams RJ (2000) The decline of saltmarsh in southeast Australia: Results of recent surveys. Wetlands (Australia) 18:49-54

Saintilan N, Wilson NC, Rogers K, Rajkaran A, Krauss KW (2014) Mangrove expansion and salt marsh decline at mangrove poleward limits. Global Change Biology 20:147-157

Schlacher TA, Weston MA, Lynn D, Connolly RM (2013) Setback Distances as a Conservation Tool in Wildlife-Human Interactions: Testing Their Efficacy for Birds Affected by Vehicles on Open-Coast Sandy Beaches. PLOS ONE 8:e71200

Serrano O, Lovelock CE, B. Atwood T, Macreadie PI, Canto R, Phinn S, Arias-Ortiz A, Bai L, Baldock J, Bedulli C, Carnell P, Connolly RM, Donaldson P, Esteban A, Ewers Lewis CJ, Eyre BD, Hayes MA, Horwitz P, Hutley LB, Kavazos CRJ, Kelleway JJ, Kendrick GA, Kilminster K, Lafratta A, Lee S, Lavery PS, Maher DT, Marbà N, Masque P, Mateo MA, Mount R, Ralph PJ, Roelfsema C, Rozaimi M, Ruhon R, Salinas C, Samper-Villarreal J, Sanderman J, J. Sanders C, Santos I, Sharples C, Steven ADL, Cannard T, Trevathan-Tackett SM, Duarte CM (2019) Australian vegetated coastal ecosystems as global hotspots for climate change mitigation. Nature Communications 10:4313

Sewell A, van der Esch S, Löwenhardt H (2020) Global Restoration Committments Database. Netherlands

Sheehy J, Taylor C, Norris R (2011) The importance of stopover habitat for developing effective conservation strategies for migratory animals. Journal of Ornithology 152:161-168

Shepherd PCF, Boates JS (1999) Effects of a Commercial Baitworm Harvest on Semipalmated Sandpipers and Their Prey in the Bay of Fundy Hemispheric Shorebird Reserve. Conservation Biology 13:347-356

Sims SA, Seavey JR, Curtin CG (2013) Room to move? Threatened shorebird habitat in the path of sea level rise—dynamic beaches, multiple users, and mixed ownership: a case study from Rhode Island, USA. Journal of Coastal Conservation 17:339-350

Sinclair SJ, Boon P Changes in the Area of Coastal Marsh in Victoria since the Mid 19th Century.

Simpson J (1996) Wading birds of Anderson Inlet and the work of the Victorian Wader Study Group. In*: How green is your mudflat? Proceedings of the Australasian conference on Spartina control.* Rash JE, Williamson RC, Taylor SG (eds). Department of Conservation and Natural Resources, Yarram, Victoria.

Skilleter G (2004) Assessment of the Impacts Associated with the Harvesting of Marine Benthic Invertebrates for Use as Bait by Recreational Anglers. Queensland

Stigner MG, Beyer HL, Klein CJ, & Fuller RA (2016) Reconciling recreational use and conservation values in a coastal protected area. Journal of Applied Ecology 53, 1206-1214.

Stralberg D, Brennan M, Callaway JC, Wood JK, Schile LM, Jongsomjit D, Kelly M, Parker VT, Crooks S (2011) Evaluating Tidal Marsh Sustainability in the Face of Sea-Level Rise: A Hybrid Modeling Approach Applied to San Francisco Bay. PLOS ONE 6:e27388

Sun Z, Wang X, Wang Z, Yang L, Xie Y, Huang Y (2021) UAVs as remote sensing platforms in plant ecology: review of applications and challenges. Journal of Plant Ecology 14:1003-1023

Sutherland WJ, Alves JA, Amano T, Chang CH, Davidson NC, Max Finlayson C, Gill JA, Gill Jr RE, González PM, Gunnarsson TG, Kleijn D, Spray CJ, Székely T, Thompson DBA (2012) A horizon scanning assessment of current and potential future threats to migratory shorebirds. Ibis 154:663-679

Tait L, Bind J, Charan-Dixon H, Hawes I, Pirker J, Schiel D (2019) Unmanned Aerial Vehicles (UAVs) for Monitoring Macroalgal Biodiversity: Comparison of RGB and Multispectral Imaging Sensors for Biodiversity Assessments. Remote Sensing 11

UNEP (2020) Out of the blue: The value of seagrasses to the environment and to people. Nairobi

Van Colen C, Verbelen D, Devos K, Agten L, Van Tomme J, Vincx M, Degraer S (2014) Sediment-benthos relationships as a tool to assist in conservation practices in a coastal lagoon subjected to sediment change. Biodiversity and Conservation 23:877-889

WABSI (2019) Digitally Transforming Environmental Assessment - Leveraging Digital Information to Streamline Environmental Assessment and Approvals. Western Australia

Wade S, Hickey R (2008) Mapping Migratory Wading Bird Feeding Habitats using Satellite Imagery and Field Data, Eighty-Mile Beach, Western Australia. Journal of Coastal Research 24

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA, Kenworthy WJ, Short FT, Williams SL (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences 106:12377

Weller, D., Kidd, L., Lee, C., Klose, S., Jaensch, R. and Driessen, J (2020) Directory of Important Habitat for Migratory Shorebirds in Australia. Prepared for Australian Government Department of Agriculture, Water and the Environment by BirdLife Australia, Melbourne.

Wernberg T, Russell BD, Moore PJ, Ling SD, Smale DA, Campbell A, Coleman MA, Steinberg PD, Kendrick GA, Connell SD (2011) Impacts of climate change in a global hotspot for temperate marine biodiversity and ocean warming. Journal of Experimental Marine Biology and Ecology 400:7-16

Wetland*Info* (2021) WetlandMaps Veriosn 5.1. Accessed 21/01/2022. https://wetlandinfo.des.qld.gov.au/wetlandmaps/

Whitt AA, Coleman R, Lovelock CE, Gillies C, Ierodiaconou D, Liyanapathirana M, Macreadie PI (2020) March of the mangroves: Drivers of encroachment into southern temperate saltmarsh. Estuarine, Coastal and Shelf Science 240:106776

Więski K, Guo H, Craft CB, Pennings SC (2010) Ecosystem Functions of Tidal Fresh, Brackish, and Salt Marshes on the Georgia Coast. Estuaries and Coasts 33:161-169

Wilkinson MD, Dumontier M, Aalbersberg IJ, Appleton G, Axton M, Baak A, Blomberg N, Boiten J-W, da Silva Santos LB, Bourne PE, Bouwman J, Brookes AJ, Clark T, Crosas M, Dillo I, Dumon O, Edmunds S, Evelo CT, Finkers R, Gonzalez-Beltran A, Gray AJG, Groth P, Goble C, Grethe JS, Heringa J, ’t Hoen PAC, Hooft R, Kuhn T, Kok R, Kok J, Lusher SJ, Martone ME, Mons A, Packer AL, Persson B, Rocca-Serra P, Roos M, van Schaik R, Sansone S-A, Schultes E, Sengstag T, Slater T, Strawn G, Swertz MA, Thompson M, van der Lei J, van Mulligen E, Velterop J, Waagmeester A, Wittenburg P, Wolstencroft K, Zhao J, Mons B (2016) The FAIR Guiding Principles for scientific data management and stewardship. Scientific Data 3:160018

Yates MG, Goss-Custard JD, McGrorty S, Lakhani KH, Durell SEALVD, Clarke RT, Rispin WE, Moy I, Yates T, Plant RA, Frost AJ (1993) Sediment Characteristics, Invertebrate Densities and Shorebird Densities on the Inner Banks of the Wash. Journal of Applied Ecology 30:599-614

York PH, Macreadie PI, Rasheed MA (2018) Blue Carbon stocks of Great Barrier Reef deep-water seagrasses. Biology Letters 14:20180529

York PH, Smith TM, Coles RG, McKenna SA, Connolly RM, Irving AD, Jackson EL, McMahon K, Runcie JW, Sherman CDH, Sullivan BK, Trevathan-Tackett SM, Brodersen KE, Carter AB, Ewers CJ, Lavery PS, Roelfsema CM, Sinclair EA, Strydom S, Tanner JE, van Dijk K-j, Warry FY, Waycott M, Whitehead S (2017) Identifying knowledge gaps in seagrass research and management: An Australian perspective. Marine Environmental Research 127:163-172

Young MA, Serrano O, Macreadie PI, Lovelock CE, Carnell P, Ierodiaconou D (2021) National scale predictions of contemporary and future blue carbon storage. Science of The Total Environment 800:149573

Appendix A

The Australian National Aquatic Ecosystem (ANAE) classification system provides a broadscale framework to classify wetlands. The structure (visually demonstrated below in Figure 17 and 9) uses a semi-hierarchical approach based on habitat attributes. This system is designed to be used on all projects involving aquatic ecosystem habitat classification in Australia.

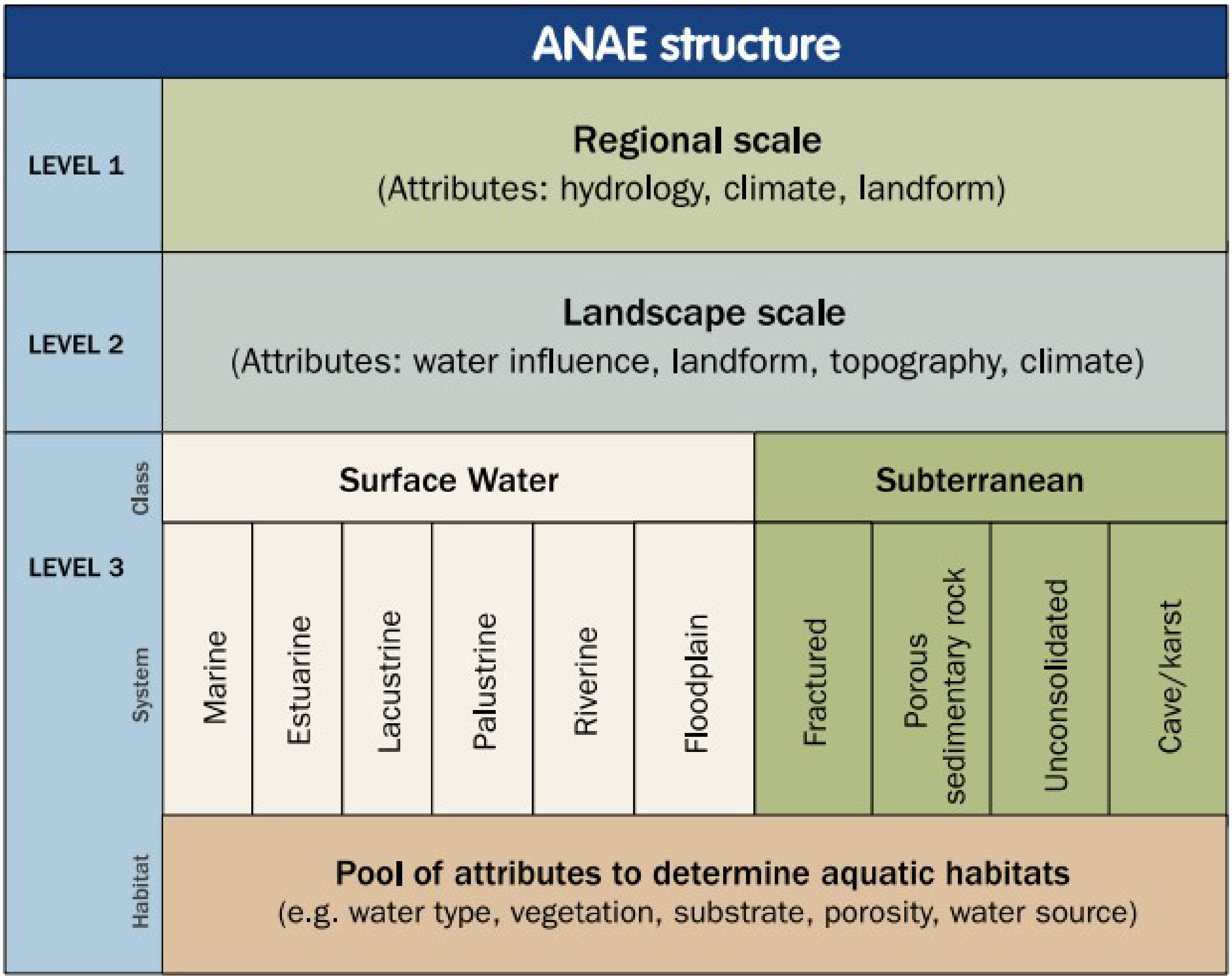


Figure 17: ANAE classification system. Reproduced from Aquatic Ecosystems Task Group (2012).

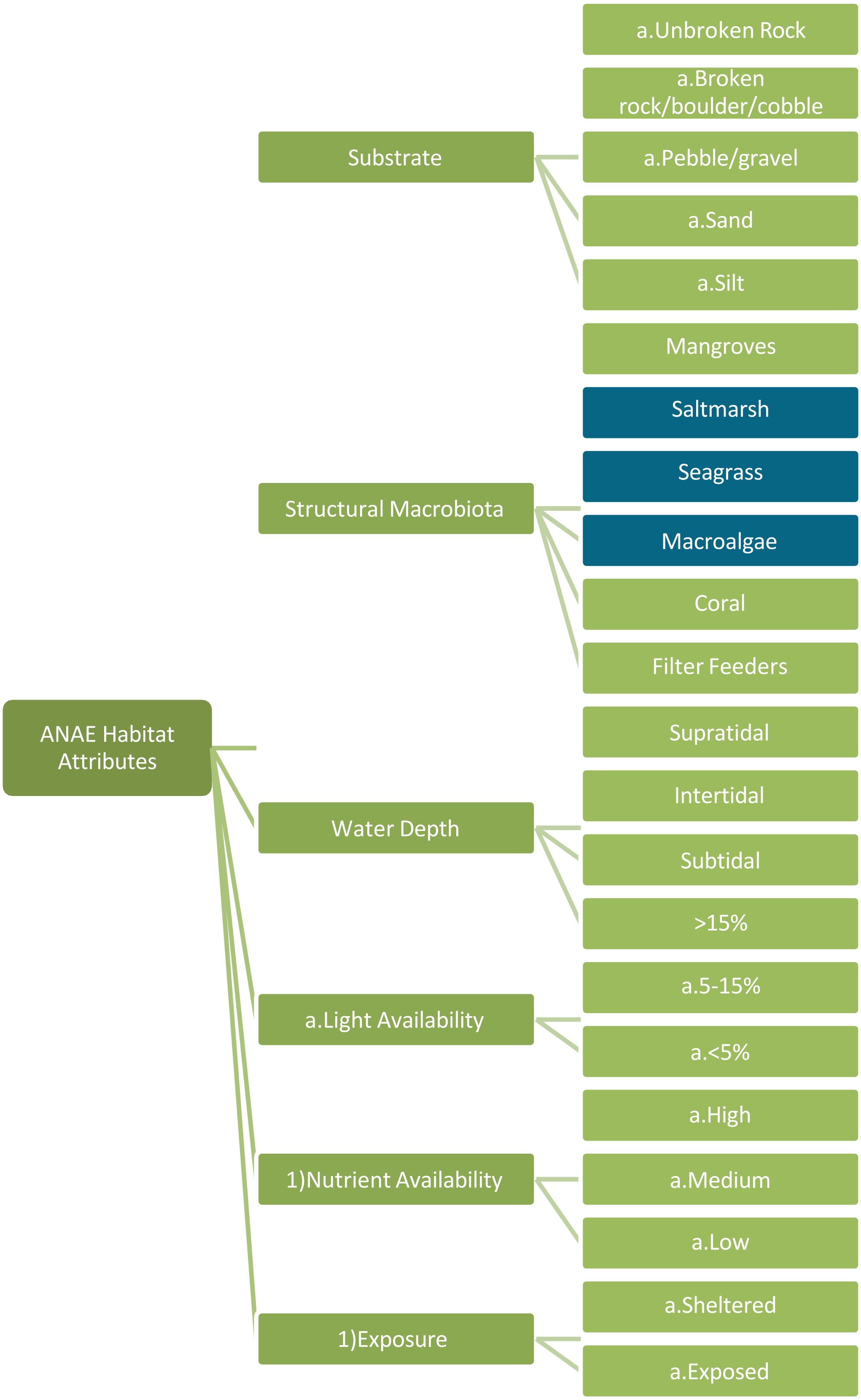


Figure 18: Pool of attributes used by the ANAE classification system to determine aquatic habitats. The attributes used as the basis of inclusion in this report are shaded blue.

Appendix B

During expert consultations several locations were suggested as focus zones for more mapping, which have been included in a list below. This list is a compilation of places mentioned over the course of interviews; it is not intended to provide a comprehensive guide for future mapping.

Table 5: Specific locations that experts suggested for additional mapping.
*Indicates the suggestion was noted but is outside of the scope of this report.

Category	Location	Justification
Algal flats	Northern WA	Conduct research understanding the significance of large supratidal algal flats in north Western Australia. These flats consist of cyanobacteria on muddy substrate and are poorly understood. Research investigating the ecological benefits of these flats, and mapping their extent, is important as they are currently not protected or monitored, and large losses are occurring due to industrial activity. This is of great interest to Western Australian end-users.
Intertidal sediments	Intertidal habitats adjacent to RAMSAR wetland sites, WA: - Eighty Mile Beach - Yaruwu Nagulagun - Roebuck Bay	End-users are interested in mapping sediment attributes and infauna assemblages in the intertidal habitats adjacent to Ramsar sites. No further justification was provided.
Macroalgae – Subtidal*	Inshore Pilbara (Exmouth Gulf to North Dampier Peninsular, WA	Macroalgae are known to exist here but are unmapped. This region also has multiple development proposals by natural resource extraction companies, making understanding the habitat a priority.
Macroalgae – Subtidal*	Inshore WA south coast (Walpole to eastern Archipelago of the Recherche).	Macroalgae are known to exist here but are unmapped.
Macroalgae – Subtidal*	Northern Kimberley, (Pender Bay to the WA-NT Border)	Macroalgae are known to exist here but are unmapped.
Seagrass – Subtidal	Bass Strait, TAS	The is a large bed (approximately 520 km^2) of unmapped seagrass in eastern Bass Strait, Tasmania. Whilst this region does not appear threatened, mapping such a large seagrass bed

		has implications for Australia's blue carbon calculations.
Seagrass – Subtidal	Crocker Island, NT	This region is known to have extensive seagrass beds that have not been mapped.
Seagrass – Subtidal	Tiwi Islands, NT	Dugongs are regularly documented in the Tiwi Islands, indicative of seagrass meadows, but this region has not been mapped.
Seagrass – Subtidal	Inshore Pilbara (Exmouth Gulf to North Dampier Peninsular, WA	Seagrasses are known to exist but are unmapped. This region also has multiple development proposals by natural resource extraction companies, making understanding the habitat a priority.
Seagrass – Subtidal	Inshore south coast (Walpole to eastern Recherche Archipelago), WA	This region is known to have extensive seagrass beds that have not been mapped.
Seagrass – Subtidal & Intertidal	Northern Kimberley, (Pender Bay to the WA-NT Border)	This region is known to have extensive seagrass beds that have not been mapped.
Shorebirds	Western Port Philip Bay, VIC	Recent changes here including increasing human population, decommissioning of the saltworks, and tidal flat erosion are likely to have affected shorebirds but are not well understood. Assessing shorebird responses to these changes in this location and similar ones would help assess the impacts of threats.
Shorebirds	Pilbara region, WA	Shorebird researchers have found the area anecdotally seems important for shorebirds, yet very little systematic research has been done, despite massive scale development and likely future pressure.
Shorebirds	Gulf of Carpentaria, NT/QLD	There is limited data in this region due to lack of citizen scientists, creating a large gap in shorebird habitat knowledge for this area. This area has been flagged by researches as a priority region for future shorebird habitat mapping.

Appendix C

MEETING (DATE)	DESCRIPTION (MEETING PURPOSE AND WITH WHOM)
7/9/21	**Purpose:** DAWE (now DCCEEW) AWI Workshop – Update on projects (Project team)
3/11/21	**Purpose**: RAMSAR Moreton Bay stakeholder workshop. **Representatives:** Rod Connolly presented project objectives, and discussed QLD DES + Research Team
15/11/21	**Purpose:** Discussion on coastal wetland mapping in QLD. **Attendees**: QLD Department of Environment and Science + Research Team
16/11/21	**Purpose:** Discuss blue carbon mapping and synergies between project 1.5 and project 1.15 **Representatives:** University of Queensland + Research Team
16/11/21	**Purpose:** Parks Australia Meeting – Update on project 1.5 and links with Project 1.32 **Representatives:** NESP Marine and Coastal Hub, Parks Australia, James Cook University + Research Team
18/11/21	**Purpose:** Blue carbon meeting within project team **Representatives:** Deakin University + Research Team
24/11/21	**Purpose:** Discuss seagrass mapping priorities **Representatives:** James Cook University, University of Queensland University of WA, NT Gov) + Research Team
25/11/21	**Purpose:** Discuss scoping project progress. **Representatives:** DCCEEW – Wetlands Section) + Research Team
29/11/21	**Purpose:** Discuss overlap between DCCEEW Biodiversity Conservation Division Needs and Scoping Project (emails) **Correspondents:** DCCEEW – Protected Species & Communities) + Research Team
1/12/21	**Purpose:** Discuss saltmarsh mapping priorities

	Representatives: James Cook University
7/12/21	**Purpose:** Discuss WA Mapping Priorities and initial needs **Representatives:** Department of Water and Environmental Regulation, WA + Research Team
8/12/21	**Purpose:** AWI Meeting – Update on Projects (Presentation by Research Team) **Presentations**: - Research Team – Project 1.5: Scoping for an Australian Wetland Inventory - (DCCEEW – Wetlands Section) – Our Ramsar conservation and 'wise use' obligations - (DCCEEW – Climate Adaptation and Resilience Div) – Update on AG 'Blue carbon restoration program' James Cook University & CSIRO) – Project 1.6: Coastal Restoration Roadmap - University of Queensland and University of NSW – Overview of Blue Carbon Method for ERF
9/12/21	**Purpose:** Discuss remote sensing mapping for coastal wetlands **Representatives:** University of Queensland and University of NSW + Research Team
10/12/21	**Purpose:** Discuss Victoria's wetland mapping priorities **Representatives:** Victorian Government + Research Team
13/12/21	**Purpose:** Discuss New South Wales wetland mapping priorities (Preliminary chat) **Representatives:** NSW Department of Primary Industries + Research Team
13/12/21	**Purpose:** Parks Australia Meeting **Representatives:** DCCEEW – Wetlands Section, Parks Australia + Research Team
15/12/21	**Purpose:** Discuss Shorebird Habitat Mapping Priorities **Representatives:** DCCEEW – Migratory Species + Research Team
15/12/21	**Purpose**: Discuss saltmarsh mapping priorities **Representatives**: University of Adelaide & SA Water + Research Team
15/12/21	**Purpose:** Discuss end-user needs of DCCEEW Biodiversity Conservation Division

	Representatives: DCCEEW - Marine & Freshwater Species Conservation + Research Team
13/1/22	**Purpose:** Discuss blue carbon mapping priorities **Representatives:** CSIRO BHP Blue Carbon mapping team + Research Team
18/1/22	**Purpose:** Discuss wetland mapping priorities **Representatives:** Deakin University+ Research Team
18/1/22	**Purpose:** Discuss New South Wales wetland mapping priorities **Representatives:** NSW Government + Research Team
19/1/22	**Purpose:** Discuss Victoria Mapping Priorities **Representatives:** Victorian Department of Environment, Land, Water and Planning + Research Team
27/1/22	**Purpose:** Discuss Victoria mapping priorities and current Blue Carbon research **Representatives:** NSW Department of Primary Industries + Research Team
1/2/22	**Purpose:** Discuss Western Australia's wetland mapping priorities **Representatives:** WA Department of Biodiversity, Conservation and Attractions, WA Department of Water and Environmental Regulation, Edith Cowan University, Murdoch University + Research Team
3/2/22	**Purpose:** Discuss overlap between Project 1.5 and Project 1.32 **Representatives:** James Cook University + Research Team
7/2/22	**Purpose:** Discuss shorebird mapping priorities and overlap between NESP Projects (Email) **Representatives:** University of Queensland + Research Team
8/2/22	**Purpose:** Discuss current wetland mapping by SA Water **Representatives:** SA Water + Research Team
27/1/22	**Purpose:** Discuss Geoscience Australia's needs in future mapping projects **Representatives:** Geoscience Australia + Research Team
2/2/22	**Purpose:** Discuss blue carbon mapping priorities

	Representatives: DCCEEW Climate Adaptation and Resilience, DCCEEW Wetlands Section + Research Team
3/2/22	**Purpose:** Discuss Tasmania's wetland mapping priorities **Representatives:** NESP MaC Hub + Research Team
7/2/22	**Purpose:** Discuss South Australia's Mapping priorities **Representatives:** SA Department for Environment and Water + Research Team
7/2/22	**Purpose:** Discuss WA's data drive through WAMSI **Representatives:** WAMSI + Research Team
8/2/22	**Purpose:** Discuss current wetland mapping by SA Water **Representatives:** SA Water + Research Team
15/2/22	**Purpose**: Discuss blue carbon mapping priorities **Representatives**: University of Wollongong + Research Team
18/2/22	**Purpose:** Discuss wetland mapping priorities, findings, and synergies between wetland audit and Project 1.5 **Representatives:** Wetlands audit + Research Team
23/2/22	**Purpose:** Presentation of Project 1.5 findings to AWI Network and offer opportunity to provide draft feedback
7/3/22	**Purpose:** Discuss intertidal macroalgae mapping by Michael's team **Representatives:** Parks Australia + Research Team

Figure 19: Fitzroy River in Central Queensland. Photo by Kristin Jinks.

Marine and Coastal

National Environmental Science Program

CONTACT

Rod Connolly

r.connolly@griffith.edu.au

http://globalwetlandsproject.org

This project is supported with funding from the Australian Government under the National Environmental Science Program.