Research agenda for blue carbon in South Australia

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1 Background and objective

Blue carbon is a relatively new concept, recognising the role that mangrove, saltmarsh and seagrass beds play in carbon storage and sequestration to mitigate climate change (Nelleman et al. 2009; Herr et al. 2011). The integration of blue carbon into national and international policy frameworks (Herr et al. 2019) triggered research into blue carbon globally. Within Australia, most research on blue carbon ecosystems has been undertaken in New South Wales, Queensland, Victoria and Western Australia. In South Australia, which has the fourth largest area of blue carbon ecosystems in Australia, research effort has lagged. Two recently concluded Goyder Institute for Water Research projects have filled some of the knowledge gaps on blue carbon ecosystems and effects of disturbance and wetland restoration on carbon capture. They have also revealed how much more needs to be done to fully understand the potential for blue carbon in South Australia.

The two complementary projects focused on investigating coastal carbon opportunities for South Australia and tidal re-connection as a potential blue carbon project activity. Combined, the two projects provided valuable data for seagrass, mangrove and saltmarsh ecosystems from degraded and natural reference sites, and sites subject to various forms of coastal wetland restoration (Jones et al. 2019a). However, the studies were limited by project timeframes and spatial coverage, leaving large areas of South Australia understudied.

This research report identifies critical knowledge gaps for blue carbon in South Australia and proposes further research approaches, based on the two Goyder Institute blue carbon projects.

The recommendations for further research identified in this *Research agenda for blue carbon for South Australia* report will be progressed through the South Australian Government's Blue Carbon Strategy. The research will also inform the Commonwealth Government's assessment of potential blue carbon methods under the national Emissions Reduction Fund (ERF). Advancing a blue carbon method under the ERF will benefit from the specific default values identified in the blue carbon projects, which will be added to a growing database from Australia. This will also support the national inventories required to report on international climate agreements.

2 Critical knowledge and information gaps

Based on the findings of the two Goyder Institute for Water Research blue carbon projects (*Coastal carbon opportunities*: see Gillanders et al. 2019, Jones et al. 2019b, Jones et al. 2019c, Jones et al. 2019d, Lavery et al. 2019; *From Salt to C*: Dittmann et al. 2019a, Dittmann et al. 2019b) and discussions on their synthesis, key knowledge gaps emerged and were grouped into several research areas. This section outlines the key knowledge gaps, while section 3 summarises the research needed to address them.

2.1 Comprehensive blue carbon ecosystem mapping

2.1.1 AREA

The exact spatial extent of blue carbon ecosystems across South Australia is not yet known. Foster et al. (2019) identified some errors in the available mapping data for blue carbon habitats across the state, particularly for saltmarshes. Seagrass area estimates are affected by poor coverage and quality of spatial data, as the last state-wide mapping was done more than 15 years ago. There are also known gaps in the data sets, particularly in the South-East, Coorong and Murray Mouth. These issues lead to large (and in some cases unmeasurable) uncertainty when extrapolating estimates of stocks and accumulation rates.

Furthermore, natural variation assessments of blue carbon ecosystems in South Australia are also lacking. This knowledge gap will affect reporting for national greenhouse gas inventories, identifying opportunities for blue carbon projects, and forecasting changes in sea level rise (SLR).

2.1.2 ELEVATION

There is no elevation mapping of South Australian coastal ecosystems at high spatial resolution. While some areas have good quality coastal elevation data, there is no consistent cover for the entire coast. As sea levels are already rising along the South Australian coast, the lack of high-resolution digital elevation maps affects coastal planning in general as well as potential blue carbon projects.

Good quality coastal elevation data are required to accurately project the effects of sea level rise on coastal vegetation. For blue carbon projects, such as tidal re-connection, very high-resolution elevation data is needed to stratify coastal ecosystems and have confidence in predicting permanence of carbon stock changes that would occur over 100 years.

2.1.3 HABITAT CONDITION

The two blue carbon projects have shown that habitat condition, which is subject to site history; disturbance; or recovery, can affect the carbon stocks in soil and biomass, as well as carbon sequestration rates. This was also seen in an earlier study on different saltmarsh sites (Dittmann et al. 2019). Knowledge of past degradation is also relevant when evaluate the variability in sediment accumulation rates (Lavery et al. 2019).

Data and maps are needed on the extent and severity of degradation of South Australia's blue carbon ecosystems. These will inform assessments of habitat and stored carbon loss and the potential for carbon abatement through restoration (Lavery et al. 2019). Criteria for condition assessments have not been developed or tested, and may need to rely on remote sensing approaches on a state-wide scale.

2.2 Blue carbon stocks and sequestration in South Australia

2.2.1 CARBON STOCKS

Data from the two blue carbon projects revealed considerable variation in carbon stock estimates, within and between sites and habitats. Such variability has also emerged in other coastal regions (Owers et al. 2018; Lavery et al. 2013; Conrad et al. 2019). At present, data for blue carbon are only available for a small section of South Australia's coastal ecosystems, and only within the two gulfs.

Coastal geomorphology is known to affect blue carbon (Twilley et al. 2018; van Ardenne et al. 2018). With several geomorphological regions in South Australia (James & Bone 2011), knowledge gaps exist on the generality of carbon stock data available so far. Field data are missing from exposed coasts, the arid west coast, and sheltered coastal lagoons such as the Coorong. Further field data will also reduce uncertainty in carbon stock and sequestration data overall and provide better baseline data.

2.2.2 SEDIMENT ACCRETION AND CARBON SEQUESTRATION

We need to understand sediment accretions to determine carbon sequestration rates in soils. Short term sediment elevation changes can be measured with surface elevation tables (Cahoon et al. 2002 a, b), while long term accumulation rates are best determined through radiometric dating using radionuclides ^{210}Pb and ^{137}CS (lead and caesium respectively) (Arias-Ortiz et al. 2018). Both methods were used in the two blue carbon projects, and indicated large variation in accumulation rates, within and between sites and habitats.

The very limited information on sediment accretion in South Australia limits the ability to assess how blue carbon ecosystems respond to sea level rise. Key knowledge gaps are sediment supply, properties and dynamics across South Australia's coastal ecosystems. These are a key aspects of sediment accretion. Sediment accretion, and ability of saltmarshes and mangroves to build and keep pace with sea level rise, may be more limited in South Australia due to its lower river discharge compared to many other regions (Stralberg et al. 2011). Together with local hydrodynamic data, knowledge of local sediment supply and local accretion rates can help project how sea level rise will affect blue carbon wetlands.

Sediment accretion can be affected by disturbances that cause sediment layers to mix and thus complicate sediment core dating and chronology generation (timelines), particularly in seagrass beds, degraded sites and high energy coastlines. This could be an issue for any blue carbon project that restores degraded sites to abate carbon, unless it can be overcome with default values derived from a large regional data set.

2.2.3 ALLOCHTHONOUS CARBON

Accounting for allochthonous carbon (soil organic carbon originating outside of a project area) is an important step in carbon accounting. However, the role of allochthonous carbon inputs (e.g. seagrass wrack entering a tidal restoration trial site), and how further biogeochemical processing of these inputs influence carbon stocks and sequestration, is largely unknown. Allochthonous input was traced using carbon and nitrogen isotope analyses in soils of the Dry Creek tidal trial site (Dittmann et al. 2019a).

Allochthonous seagrass needs to be quantified as large quantities of seagrass wrack accumulate naturally on South Australia's coastline and within mangrove forests and saltmarsh. A further knowledge gap is the decomposition rate of seagrass wrack; how decomposition differs between mangrove, saltmarsh and other habitats; and the relevance of seagrass wrack decomposition for soil organic carbon and sequestration rates.

2.2.4 THE FATE OF BLUE CARBON UNDER SEA LEVEL RISE

We currently have little understanding of the fate of carbon stored in vegetation and soils when succession of coastal ecosystems occurs under sea level rise. We need to fill this knowledge gap to have confidence in predicting permanence in carbon stock changes over 100 years. When vegetation in blue carbon habitats is submerged because of rising sea levels and dies, its decomposition could contribute to GHG emissions. Submergence could also cause increased GHG emissions from soil organic matter (Steinmuller et al. 2019). However, higher carbon accumulation with rising sea levels has also been recorded (Watanabe et al. 2019). The fate of blue carbon with sea level rise will also depend on opportunities for inland retreat, the species' ability to recolonise landward areas, and other local and regional hydrodynamic conditions.

2.3 Co-benefits of blue carbon

The co-benefits of blue carbon projects are an important part of assessing carbon offset opportunities. They can include economic, environmental and social aspects. The two blue carbon projects collated overviews on ecosystem services and other co-benefits, but the projects were not designed to undertake the types of surveys and quantifications needed to evaluate ecosystem services. Unlike in several other parts of the world (Davidson et al. 2019), ecosystem goods and services have not been valued in Australian coastal wetlands (Himes-Cornell et al. 2018a, b).

Indications from a social survey carried out in the *Salt-to-C* project include strong cultural and even spiritual values associated with the coastal ecosystems north of Adelaide. A larger sample size across multiple regions of South Australia's coastal communities would be needed to comprehensively understand social co-benefits.

3 Key research areas

3.1 Comprehensive blue carbon ecosystem mapping

Knowledge gaps in the comprehensive mapping of blue carbon ecosystems can be addressed by combining various assessments of seagrass, saltmarsh and mangrove habitats to yield data and knowledge on area, elevation, living biomass and habitat condition. Such improved mapping will also reduce data uncertainty.

Blue carbon ecosystems can be mapped and classified using higher resolution imagery from remote sensing (satellite or air-borne), supported by aerial photography and on-ground surveys. State-wide coastal LiDAR data acquisition can fill knowledge gaps on elevation, tidal inundation and vegetation changes. Historical aerial photography can be used to study long term historical shifts in vegetation and will identify sites where vegetation succession and inundation has occurred. The choice of method is subject to the scale of change to be detected. Spatial and temporal resolution of remote sensing data has to be sufficient to detect change across time and space and meet demands for long-term monitoring. A combination of methods, such as satellite data and aerial photographs, can be used to detect changes in coastal vegetation, especially at a finer scale. This is important to capture trends in erosion or shifts in vegetation patterns, such as mangrove encroachment. It is important to recognise that data from these sources needs to be ground-truthed using on-ground surveys.

Validation of the state's Land Cover Dataset, particularly around detecting and mapping change in saltmarsh ecosystems, can be improved by developing a new model which focused specifically on this vegetation class. This ecosystem is currently poorly mapped. This leads to very high uncertainty when assessing changes over time in saltmarsh distribution and prevents confidence when modelling the key drivers/threats to its range dynamics. Mangrove may also require further validation, for example to assess whether an increase in area detected by successive Landsat data is real or not.

For some blue carbon ecosystems such as seagrass, aerial mapping can improve on poor or old data on ecosystem presence, species, and condition. This would fill gaps for parts of the state where seagrass extent is not well known. Some seagrass may be beyond the scope of aerial mapping and innovative approaches are needed to map deeper areas. Ground-truthing of remote sensing can be used to improve the existing (or any future) spatial mapping of seagrass.

The condition and restoration potential of blue carbon habitats should be incorporated into improved mapping assessments. Hyperspectral imagery can be added to remote sensing to obtain indications of blue carbon ecosystem condition. Ground-truthing and field-based observations can validate remote sensing and detect species-specific changes in distribution and abundance that cannot be detected by satellite.

3.2 Blue carbon stocks and sequestration in South Australia

Carbon stocks can be assessed through field investigations using a state-wide sampling approach that will allow for increased certainty in the stock and accumulation rate estimates for each of the blue carbon ecosystems. The assessment can be strategically designed to cover representative sites for different geomorphological settings of South Australia's coast and target under-represented ecosystems. The sampling design can consider disturbed/undisturbed, sheltered/exposed, depositional/erosional sites, or different vegetation types. Some seagrass types have not been sampled at all for blue carbon. Sites where vegetation succession and inundation has occurred should also be considered to assess the fate of vegetation carbon under these conditions. Organic carbon stocks and accumulation rates can be measured simultaneously and with further sampling, allochthonous carbon components can be identified via stable isotope or eDNA analyses. This approach would also support a better understanding of the variability across the state and how this relates to site-specific environmental settings and vegetation condition or site-specific historical disturbance.

A combination of surface elevation tables (SETs) and radiometric dating can be used to accurately determine sediment accumulation rates. Research and development of alternative dating methods or other ways of measuring accumulation rates will help to overcome the issues around dating in degraded sites. South Australia can become part of an Australian network of surface elevation tables with marker horizons (SET-MH). Installing SET-MH at strategic locations around the South Australian coast can inform trends in sediment accretion and vegetation transitions with sea-level rise and provide data to calculate blue carbon sequestration rates. SET-MH measurements for short term elevation changes can be taken on a routine basis, and are best accompanied by one-off radiometric assessments of long-term sediment and carbon accumulation rates at strategic sites.

3.3 Co-benefits of blue carbon

A variety of investigations can be undertaken to assess direct links between the presence, area and condition of blue carbon ecosystems and their economic, environmental and social values. Valuation is best accomplished through a combination of established methods in ecological economics (e.g. benefit–cost analysis, stated preference methods, or willingness to pay; see Atkinson et al. 2016; Salzman et al. 2018; Barbier 2019). If public awareness was higher, then more people would participate in valuation surveys. Socio-economic co-benefits (e.g. estimate of fisheries, tourism, recreation values) arising from coastal restoration activities can be quantified through surveys and targeted data collection. Case studies can also be carried out on specific services, such as nitrogen removal by seagrass for improved water quality.

If we assume that healthier ecosystems provide more ecosystem services, the link between ecosystem condition and its ability to provide ecosystem services can be quantified and modelled based on case studies. This information can be brought together with data from research outlined above (sections 3.1, 3.2), and fed into improved location and condition maps of blue carbon ecosystems, which can then be used to scale up and strengthen blue carbon projects.

3.4 Data platforms and applications

Findings from investigations on the outlined key research areas should be publicly available and communicated to the wider community. This can be achieved by incorporating data into national and international databases for blue carbon, such as the Coastal Carbon Atlas by the Coastal Carbon Research Coordination Network[1]. Uptake would be enhanced if databases were in an interactive format. Incorporating blue carbon and co-benefit data into sea/landscape-based GIS can link data with other data layers on site history or digital elevation maps. Expanding existing data platforms, such as Gulfview, could help integrate blue carbon in coastal development planning. Using a GIS approach will also allow sea-level rise scenarios to be considered. A geospatial approach using existing maps and proxies can also help prioritise further research efforts to areas of highest blue carbon potential.

[1] https://ccrcn.shinyapps.io/CoastalCarbonAtlas/

4 Research and policy environment

4.1 Market mechanisms, policy and regulatory framework

Research into and the development of novel business models and market mechanisms, such as carbon markets, is required to help develop public/private partnerships for investing in blue carbon schemes and creating blue carbon credits.

South Australia should continue to support the Commonwealth Government's progress towards developing methods for blue carbon under Australia's ERF. However, in the absence of the ERF method being implemented, alternative carbon markets could be explored. The Goyder Institute *Salt-to-C* blue carbon project (Dittmann et al. 2019b) provided a proof-of-concept for the applicability of the international Verified Carbon Standard (VCS) for tidal restoration (VM033). The VCS method provides a potential alternative method for carbon accounting in the absence of the ERF method. There are concerns around 'double counting' of emission abatement from VCS blue carbon projects. However, as abatement is also captured under national inventory carbon accounting and international GHG targets, this issue would need to be addressed if pursuing projects under the VCS.

Large blue carbon activities could be given major project status, with more efficient facilitation of approvals required. This could potentially reduce the regulatory burden (e.g. permits, licences) for associated research.

4.2 Research environment

South Australia has the potential to be a leader on blue carbon research, given the large area of blue carbon ecosystems in the state, and the growing expertise developed through Goyder Institute research partnerships. The outlook for research collaboration on blue carbon in South Australia is positive, following the recent build-up of expertise in the state (e.g. through the Goyder Institute Climate Action Impact Area projects), and with a leading blue carbon expert (Jeff Baldock) based at CSIRO on Waite campus.

Substantial capability by individual researchers and research teams is now present in the state. This expertise is interdisciplinary, drawing from botany, soil science, marine science, biogeochemistry, remote sensing and social sciences. Particular skills may need to be recruited for particular projects. We recommend that this is done in a way that passes the respective skills on to South Australian researchers. Blue carbon research can also be linked to existing research strengths and areas in the universities. Some analytical capabilities are present at the universities and CSIRO, and shared analytical equipment (e.g. automated carbon gas analysers) would help sustain long term capacity in SA. A Seagrass Partnership is under development, which will facilitate data sharing and collaboration, and be relevant to restoration efforts with potential blue carbon gain.

The research capacity that has been built around blue carbon in SA needs to be sustained into the future via sufficient funding. There needs to be an ongoing mechanism (e.g. blue carbon research centre or incubator) and funding (e.g. state agencies, Cooperative Research Centres or ARC linkage grants) for collaboration between universities in SA on blue carbon research. Providing funding for student scholarships is a good way to deliver cost effective research into key knowledge gaps, but funding is also needed for early to mid-career researchers, who can drive collaborative projects and publish. Public–private partnerships could also be explored with large companies that need to offset their emissions or environmental impacts. Alternative market mechanisms could be explored, like the Reef Credit scheme currently under development in Queensland or the Greenfleet approach to carbon offsetting.

An improved blue carbon research environment in South Australia will also increase collaboration between South Australian, interstate and international scientists in national collaborative research schemes. This could lead to higher success in applications for grants from the Australian Research Council or other funding bodies. It can also help to strengthen human and technological capabilities in the field of blue carbon in South Australia.

5 Outcomes and impacts

Addressing the knowledge gaps through key research areas will help advance blue carbon and have outcomes and impacts in South Australia and (inter-)nationally as outlined below.

5.1 Relevance of research for a blue carbon strategy in South Australia

The recommended research will be relevant to state and Commonwealth governments and provide the following benefits:

Reduce uncertainty in assessments – Additional information from further field investigations will increase data accuracy and precision and reduce the variability and uncertainty in data on carbon storage, sequestration and emissions. This will improve the development of local and regional specific default values that can be used for blue carbon project assessments. The additional values can also be used for carbon accounting in carbon credit projects and the development of a blue carbon method under the ERF.

Data for reporting requirements for inventories – The data generated through this research can improve the quantity, quality, and management of state and national data sets on blue carbon ecosystems. Data on carbon stocks, sequestration rates and emissions will be useful for national inventories on GHG (NGGI).

Data and maps to understand state-wide blue carbon opportunities – The investigations will generate maps on the distribution and condition of blue carbon habitats; reduce uncertainty in land cover; and help identify priority locations for carbon abatement projects. The maps can thus inform local, regional and state planning processes to implement state planning policies, such as Policy 13.9: "*Recognise and protect the high carbon storage values of areas such as mangrove and salt marshes*". It can also help identify the types of activities which are best suited for carbon offset projects. These can include identification of disturbed sites which can be restored; locations of areas threatened by development which could become projects if conservation allows avoided emissions projects; or landward retreat options.

Promote blue carbon projects – The additional data and maps generated can be used to assess baseline scenarios for blue carbon projects, and make project assessments easier through default values. It will enable targeted and process-based investigations which will reduce project costs, further facilitating the implementation of blue carbon projects. The research will support opportunities to align blue carbon with other coastal ecosystem management approaches, such as living shorelines.

Improve market mechanisms, integrated planning and regulatory framework – Development of novel business models and carbon market mechanisms will encourage and enable the public and private sectors to invest into blue carbon projects. By identifying opportunities to integrate blue carbon with wider coastal-management and land use planning, the permanence of coastal carbon sequestration and ecosystem service provision (co-benefits) will be supported.

5.2 Relevance for advancing science on blue carbon and coastal ecosystems

The advancement of science on blue carbon and coastal ecosystems in South Australia will address regional, national, and global knowledge gaps. These are summarised below.

Data to inform global estimates of blue carbon: Although the data generated will in some instances be region specific, it can be added to international data sets and used to inform blue carbon estimates in other international locations where similar data are not available. This will be particularly relevant for locations where ecogeomorphology and other environmental conditions may be similar. Investigations can also contribute to the global understanding and accounting of allochthonous material, which is an emerging project field.

Development of large-scale assessment methods: Existing methods for large-scale assessment of blue carbon stocks and sequestration rates will be improved. Novel methods, which could support such large-scale assessments, could also be developed. This will support the increasing global need for rapid and reliable assessment of blue carbon stocks.

Improved understanding of impacts of climate change on blue carbon ecosystems and coastal services: Although the global understanding of climate change's potential impacts on blue carbon and coastal ecosystem services is currently poor, it is important to identify sites that will be resilient to climate change impacts for potential blue carbon and/or coastal ecosystem conservation projects (Moraes 2019). The investigations will contribute to addressing these knowledge gaps, for example, by improving our understanding of the fate of vegetation carbon under sea level rise. Quantification of co-benefits will also allow the potential impacts on these to be better understood.

Leader in integrated approach for blue carbon in coastal management and conservation: Blue carbon markets and regulations are relatively new and developing areas (Moreas 2019). These investigations could position South Australia to lead in the development of integrated approaches for blue carbon in coastal conservation policy (Dittmann 2019).

6 Summary agenda

A summary of the research agenda for blue carbon research in South Australia is shown in Figure 1. The current knowledge gaps and barriers are impacting on the state's carbon accounting and research environment and addressing them will provide substantial benefits to South Australia and beyond.

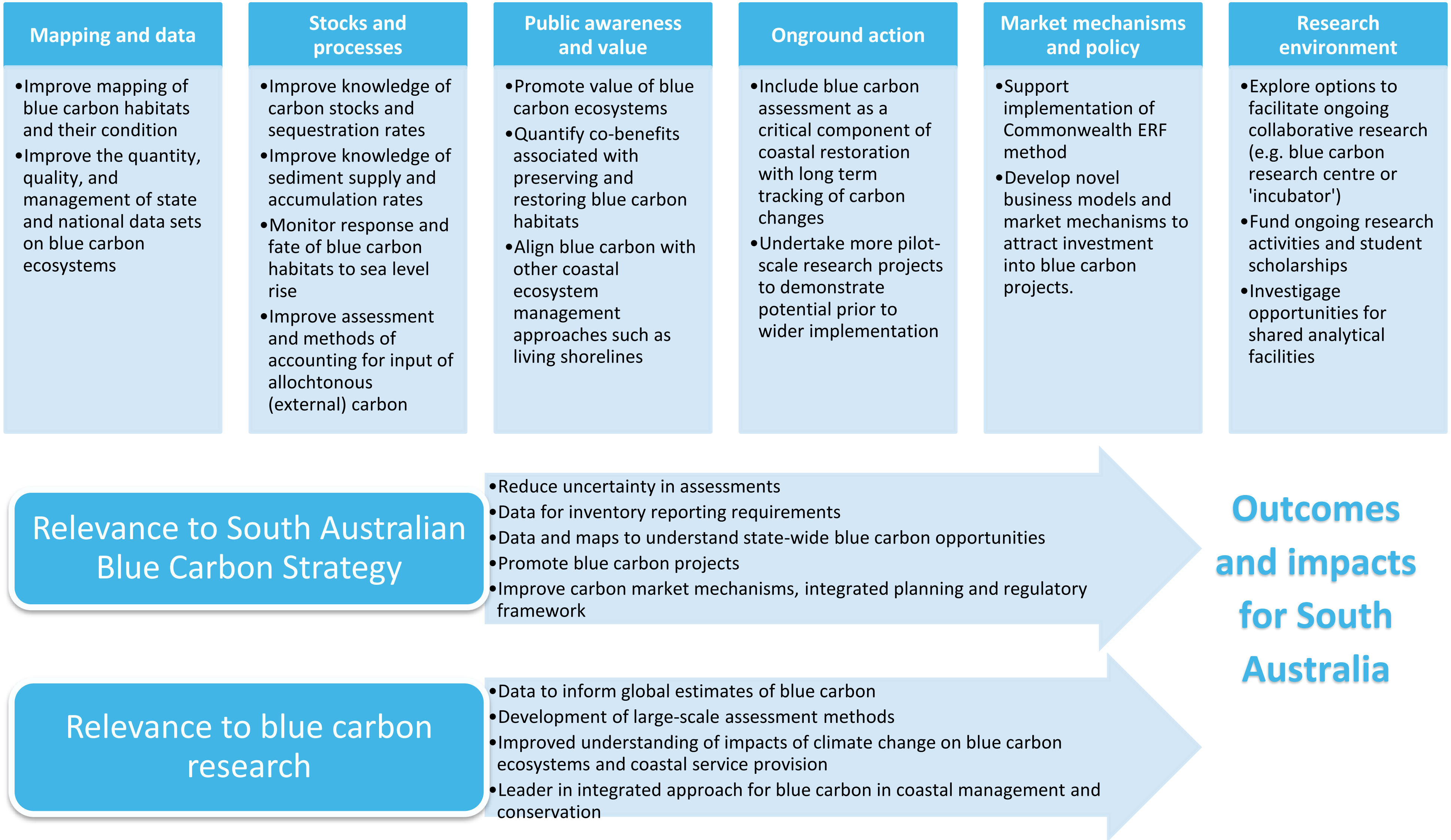

Figure 1. South Australian blue carbon research agenda.

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