**Protecting and repairing Australia’s coastal seascapes – a case for collecting and communicating quantitative evidence to foster sustainable coastal development**

#### Authors

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#### Abstract

Australia’s developed coasts are a heavily competed space subject to urban, industrial and agricultural development. A range of habitats such as mangroves, saltmarshes and seagrasses make up Australia’s coastal wetlands, collectively known as a coastal ‘seascape’ and provide a range of benefits including fisheries productivity, carbon storage, nutrient cycling and shoreline protection. Decision makers need to be able to weigh up the relative costs and benefits of coastal development, protection or repair and to do this they need robust, accessible and defensible data on the ecological function and economic value of Australia’s coastal seascapes. We reviewed the published literature to determine the availability and extent of metrics and information on key ecological functions to inform evaluations of ecosystem services. None of the publications we reviewed quantified nutrient cycling and coastal protection functions and only eleven studies presented quantitative information on carbon sequestration and fish and invertebrate productivity. These were limited geographically to sub-tropical and temperate areas in south-east Queensland, New South Wales, Victoria and the Barker Inlet-Port River Estuary in South Australia. This demonstrates a lack of quantitative information needed to substantiate and communicate the value of Australia’s coastal seascapes over different locations, scales and contexts. Research should focus on addressing these knowledge gaps and communicating evidence in a relevant form and context for decision making. We discuss four principles for research funding organisations and researchers to consider when prioritising investment and undertaking research on key ecological functions of Australia’s seascapes, to support sustainable coastal development, protection and repair for long-term economic and community benefit.

#### Key words

Function, ecosystem service, seascape, mangrove, saltmarsh

#### Introduction

Coastal wetlands by nature occur across the land-sea interface and consequently are subject to pressures from both terrestrial and marine sources, which have led to the loss of almost half of the world’s coastal wetlands (Davidson 2014; Duarte et al. 2008; Millenium Ecosystem Assessment 2005). Australia’s wetlands have experienced similar declines particularly near populated areas. For instance, in Port Phillip Bay, Victoria, around 50% of mangrove and saltmarsh habitats have been lost since European colonisation (Sinclair and Boon 2012) and in the Moreton Bay region of south-east Queensland, over half the saltmarsh habitat was lost between 1974 and 1998 (Duke et al. 2003). Recognising this decline, in 2013 the Australian Government listed subtropical and temperate coastal saltmarsh as a vulnerable ecological community under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC) (Department of the Environment 2016).

Coastal wetlands encompass a variety of habitats including mangroves, saltmarsh, seagrass, mudflats and sand bars, which in their entirety are termed coastal ‘seascapes’ (Barbier 2011; Nagelkerken et al. 2015; Sheaves 2009). Around 85% of Australia’s population lives within 50 kilometres of the coast (Australian Bureau of Statistics 2004), leading to the substantial alteration, removal or degradation of Australia’s coastal seascapes for urban, agricultural and industrial development (State of the Environment 2011 Committee 2011). In general, it is habitats higher in the intertidal zone, primarily saltmarshes, which have been most impacted by coastal development and will be most threatened by sea-level rise if there are barriers to landward migration of the saltmarsh (Saintilan and Rogers 2013). Urban and industrial development continues to occur in or adjacent to Australia’s coastal seascapes threatening the long-term health and function of these systems (State of the Environment 2011 Committee 2011) and extensive agriculture and infrastructure development is flagged in the relatively undeveloped coastal floodplains of Northern Australia (Commonwealth of Australia 2015b).

The loss of coastal seascapes worldwide has affected the viability of fisheries (33% decline), provision of nursery areas for fish and invertebrates (69% decline) and the filtering capacity of coastal habitats (63% decline) (Barbier et al. 2011). In Australia, halting further losses and restoring coastal areas is essential to improve the health and resilience of key assets such as the Great Barrier Reef (Great Barrier Reef Marine Park Authority 2012), worth in the order of AUS$6 billion per year (Deloitte Access Economics 2013). Deciding whether to develop, protect or repair Australia’s coastal seascapes is therefore not a trivial debate and has significant economic ramifications for local and regional communities and the Australian economy as a whole.

*Valuing seascapes and the role of valuation in decision making*

Coastal development is often justified in terms of private economic or social benefits, which can be communicated in defined, easily communicable metrics such as dollars or jobs (de Groot et al. 2006). The public economic, environmental or social repercussions from the loss or modification of coastal seascapes are much more difficult to define and measure (Barbier 2011) and hence the total costs and benefits of development versus wetland protection can rarely be evaluated. Coastal seascapes are consequently largely undervalued and the net public benefit of their economic, social and environmental functions is often unaccounted for in benefit-cost analysis of coastal developments (Atkinson et al. 2012; Barbier 2011; Marre et al. 2015).

Coastal seascapes provide a range of services that contribute to human well-being, including provisioning (i.e. food, fibre), regulating (i.e. pollutant removal, protection against natural hazards), cultural (i.e. spiritual and recreational) and supporting (i.e. nutrient cycling, soil formation and biodiversity) (Millenium Ecosystem Assessment 2005). Quantifying and communicating these benefits in economic terms (e.g. Barbier et al. (2011); Costanza et al. (1997)) provides a way to evaluate the trade-off between alternative management or land uses and can be an important tool in coastal management (Atkinson et al. 2012; Barbier 2011; Millenium Ecosystem Assessment 2005). It has been used for this purpose in the United Kingdom to assess options for managed realignment, whereby tidal inundation is returned to previously converted saltmarsh habitat (Foster et al. 2013; Luisetti et al. 2014). In Australia, the valuation of ecosystem services is sometimes considered in coastal management, however such considerations rarely have significant impact on management or policy decisions (Marre et al. 2015). Marre et al. (2015) suggested that one reason for this could be that the information was not robust enough, relevant or accessible.

A range of methods are used to value ecosystem services depending on the type of service, for example market prices for direct use values (e.g. fodder, fish), production function methods for indirect use values (e.g. coastal protection, nutrient trapping, fish nursery) and preference methods for non-use values (e.g. recreational, existence values) (Atkinson et al. 2012; Barbier 2000). The market price and production function methods require an understanding of how the ecological function contributes to the productivity of the marketed ‘output’, such as harvested fish (Atkinson et al. 2012; Barbier 2000; de Groot et al. 2006). This relationship is likely to differ spatially and temporally for any given habitat type within a coastal seascape. The benefit or value-transfer method is commonly used to cost-effectively apply knowledge from one study to other locations and contexts and is appropriate when the difference between sites is not significant enough to impact values (Atkinson et al. 2012).

For the results of this method to be robust and defensible the locations or contexts on which benefit or value-transfer is based need to be comparable with the target sites. That is, the variables which determine the value of a service at the study site need to be the same at the target site (Atkinson et al. 2012; Unsworth and Petersen 1995). However, coastal seascapes in Australia often have tidal regimes, climate and vegetation communities that differ from the areas where studies used as sources of benefit or value-transfer information have been conducted (Connolly 1999). Therefore transferring international knowledge to an Australian context is unlikely to produce robust and defensible results. It is also recognised that ecological functions, such as fisheries productivity, vary spatially, temporally and geographically (Nagelkerken et al. 2008). Therefore there is a need for knowledge on ecological function specific to Australia that quantifies spatial variability providing information at a relevant scale and context that will meaningfully inform evidence-based decision-making (Atkinson et al. 2012; Marre et al. 2015; Turner and Daily 2008).

*Current knowledge of Australia’s coastal seascapes*

Published reviews on Australian saltmarsh (Laegdsgaard 2006; Saintilan and Rogers 2013) and mangrove (Nagelkerken et al. 2008) communities summarise the current knowledge of these coastal habitats in Australia. Despite providing valuable ecological information on vegetation, extent, threats and fauna that utilise these habitats, their content indicates a shortage of available information quantifying their key ecological functions such as carbon sequestration, nutrient assimilation, coastal protection and fisheries productivity. This suggests that decisions-makers may not have the quantitative information they need to assess the costs and benefits of alternative land uses and make evidence-based decisions about the sustainable use, protection and repair of Australia’s coastal seascapes. To address this issue we undertook a structured review of primary publications on the ecological function of Australia’s coastal seascapes, with a focus on mangroves and saltmarshes, to determine what information is currently available and whether it quantifies their function in defined, spatial metrics that could potentially be used for ecosystem service valuation. To complement this we undertook a synopsis of Australian saltmarsh using a network of experts and review of secondary literature. We identify knowledge gaps and provide recommendations for collecting and communicating evidence that could be used to foster sustainable coastal development and the protection and repair of Australia’s coastal seascapes.

### Review of information on the function of Australia’s coastal seascape

Inventory of publications on Australian coastal seascape function:

We conducted a review of publications on the functions of coastal seascapes in Australia. A search was conducted via the ISI Web of Science ([www.webofknowledge.com](http://www.webofknowledge.com)), Scopus and Aquatic Sciences (Proquest) to identify primary literature related to this topic. ‘Mangrove’ and ‘saltmarsh’ were used as search terms as they are commonly used as key words in studies of coastal seascapes. Search terms were selected based on the main ecosystem services of saltmarsh and mangroves identified in Millenium Ecosystem Assessment (2005), except the use of mangrove for timber or fuel, which is not a common occurrence in Australia. The search terms for function included ‘carbon sequestration’, ‘coastal protection’, ‘nutrient cycling’ and ‘fish\*’ (using the wildcard \* for fish to encompass multiple derivatives of ‘fish’ such as fishing, fisheries, fish production etc.). Publications were screened to include only those containing information on the function of coastal seascapes in Australia. This involved reviewing the title or abstract to ascertain whether the publication included data on coastal seascapes in Australia.

Publications pertaining to mangroves in Australia exceeded those for saltmarsh for all functions investigated (Table 1). Fish (and its derivatives) were the most published function of Australian mangroves and saltmarsh with far fewer publications on nutrient cycling and carbon sequestration.

Table 1 Results from the searches and number of publications relevant to mangrove and saltmarsh function in Australia

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Search terms** | | | **Total number of publications** | **Number of publications relevant to Australian mangrove or saltmarsh function** |
| saltmarsh | Carbon sequestration | Australia | 9 | 7 |
| saltmarsh | Fish\* | Australia | 45 | 38 |
| saltmarsh | Coastal protection | Australia | 10 | 6 |
| saltmarsh | Nutrient cycling | Australia | 4 | 2 |
| mangrove | Carbon sequestration | Australia | 22 | 18 |
| mangrove | Fish\* | Australia | 435 | 242 |
| mangrove | Coastal protection | Australia | 113 | 60 |
| mangrove | Nutrient cycling | Australia | 48 | 30 |

*Review of published information quantifying function:*

To investigate whether these studies provide quantitative information on the target ecological functions, we reviewed a sub-set of the publications, focusing on the 53 publications identified using the ‘saltmarsh’ search term. Saltmarshes were selected due to historic losses and continued threats from coastal development, reflected in their recent listing as vulnerable under the EPBC, which points to their importance for decision makers and also because they often contain mangroves as a mosaic of habitats (Creighton et al. 2015a; Saintilan and Rogers 2013). We recorded the location of the study, habitats studied and information presented. We reviewed the publications to identify whether any original, quantitative information on the ecological functions was presented and whether it was in a comparable format to metrics that have been used in published valuation studies, such as tonnes of carbon stored per hectare per year (Barbier et al. 2011; Costanza et al. 2008; Luisetti et al. 2011).

Thirty per cent of the publications focused solely on saltmarshes with the remaining 70% including other habitats, principally mangroves and seagrass. Figure 1 illustrates the geographical distribution of published field studies on saltmarsh function in Australia. The majority of studies were undertaken in south-eastern Australia between Moreton Bay, Queensland (QLD) and Melbourne, Victoria with only one study undertaken in tropical Australia.

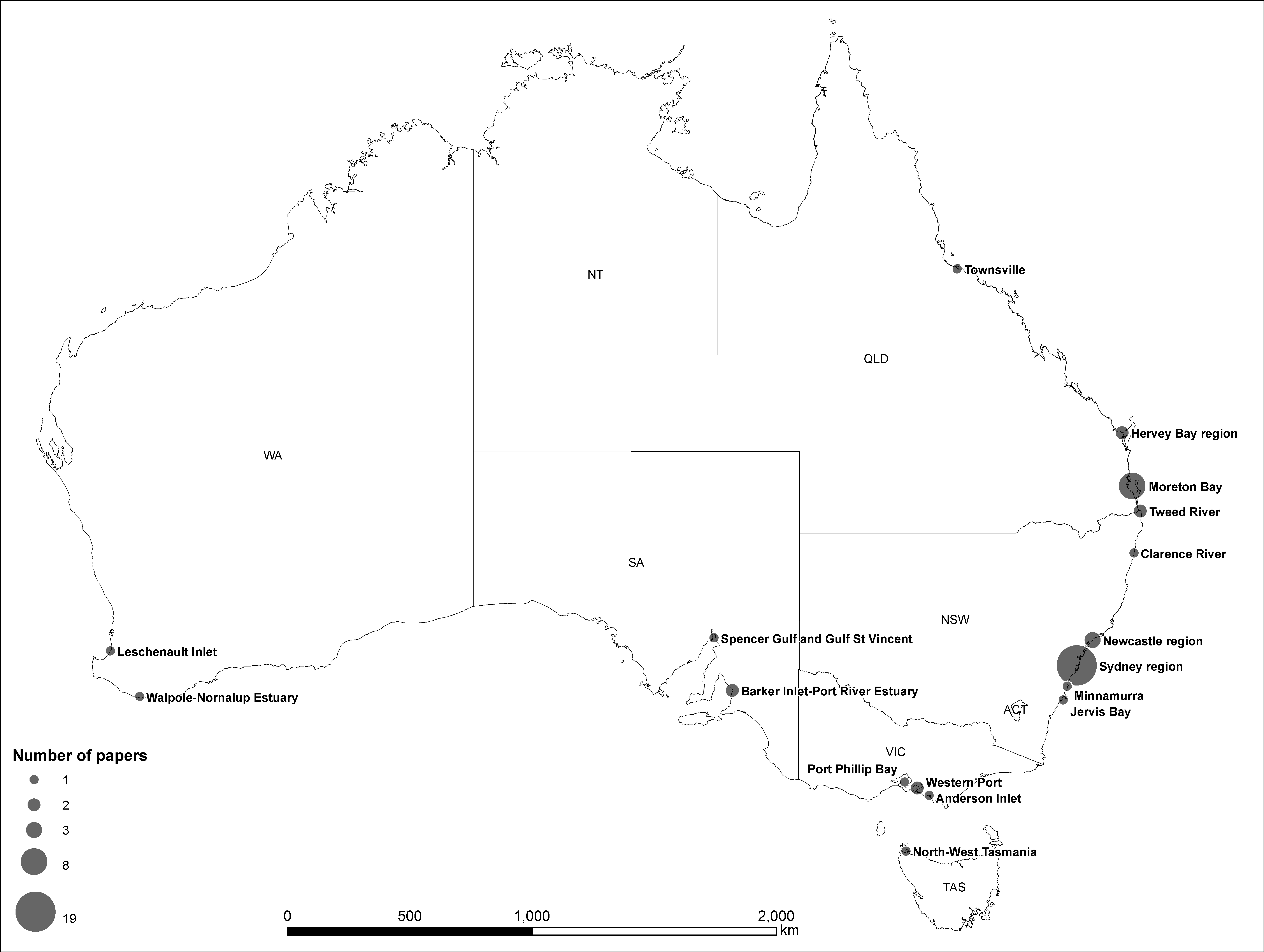


Figure 1 Number and location of published field studies related to saltmarsh function in Australia

Ninety percent of the publications presented primary data on the results of field or modelling studies, with a variety of information presented (Table 2). Five of the publications were reviews of current knowledge (Adam 2002; Harty 2009; Laegdsgaard 2006; Saintilan and Rogers 2013; Wilson 2002) and are not included in the results below. Detailed review of the results section of the publications identified that only 22% of the studies collected and presented quantitative information in defined, spatial metrics (Table 2), such as rates of carbon sequestration (e.g. mg carbon ha-1 yr-1) and density of fish or crustaceans (e.g. individuals m-2). Of the publications reviewed, none quantified the coastal protection and nutrient cycling functions of Australia’s coastal seascapes.

Table 2 Type of information presented for each key function and number of original studies providing quantifiable information on function, comparable to metrics used in international valuation studies

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Function** | **Number of publications providing original data** | **Types of information presented** | **Example of metric used in valuation studies to quantify function** | **Number of original studies that quantify function in defined spatial metrics** |
| Carbon sequestration | 6 | Rates of vertical accretion, surface elevation change, carbon sequestration, carbon density, N2O emissions. | Carbon stored e.g. t carbon ha-1 yr-1 | 3 |
| Coastal protection | 3 | Vegetation cover, percentage of eroded shoreline, wave fetch, bat activity and species. | Storm surge reduction e.g. cm km-1 | 0 |
| Nutrient cycling | 2 | Biomass and nitrogen content of estuarine plants, percent organic matter and nitrogen concentrations in estuarine soils. | Nutrient trapping e.g. kg nitrogen ha-1 yr-1 | 0 |
| Fish | 30 | Species richness, density and abundance, dietary composition, carbon isotopes, change in vegetation communities, correlation between fish catch and environmental variables, swimming speed of fish. | Fish or invertebrate production e.g. kg fish ha-1 yr-1 | 8 |

Three of the studies (Howe et al. 2009; Lovelock et al. 2014; Saintilan et al. 2013) quantified carbon sequestration rates and presented information on vertical accretion, surface elevation change and carbon sequestration in different habitats, primarily mangroves and saltmarshes (Table 3). These studies provide valuable information on carbon sequestration in estuaries between Moreton Bay in south-east QLD and Western Port in Victoria. These studies used the same methodology for measuring surface elevation change and calculating carbon sequestration and therefore the results can be used to compare and quantify carbon sequestration at different locations.

Table 3 Quantitative measure of carbon sequestration function presented in reviewed publications

|  |  |  |  |
| --- | --- | --- | --- |
| **Quantitative measures of carbon sequestration function presented in publications** | **Dominant vegetation community** | **Location** | **Reference** |
| Mangrove 0.89-1.05 mg C ha-1 yr-1  Saltmarsh 0.64-1.37 mg C ha-1 yr-1 | Saltmarsh: *Sarcocornia quinqueflora, Sporobolus virginicus*  Mangrove: *Avicennia marina* | Hunter Estuary, NSW | Howe et al. 2009 |
| Mangrove 2.56 (±2.24) mg C ha-1 yr-1  Saltmarsh herbfields 0.46 (±0.37) mg C ha-1 yr-1  Saltmarsh rushes 2.07 (±1.32) mg C ha-1 yr-1 | Saltmarsh herbfields: *S. quinqueflora, S. virginicus*  Saltmarsh rushes: *Juncus kraussii*  Mangrove: *A. marina* | Tweed River, NSW to Western Port Bay, Victoria | Saintilan et al. 2013 |
| *Sarcocornia* sp. 8.6 (±4) g C m-2 yr-1  Mangrove 76 (±16) g C m-2 yr-1 | Saltmarsh: *S. quinqueflora, Suaeda australis, J. kraussii*  Mangrove: *A. marina, Rhizophora stylosa* | Moreton Bay, QLD | Lovelock et al. 2015 |

Thirty publications provided primary data on fish in Australian saltmarshes. The results presented in these publications varied from fish diet (gut content and carbon isotope), abundance and density of fish and crustaceans, density of invertebrate prey (zooplankton), relationship between fish catch and environmental variables and changes in the extent of estuarine vegetation over time (Figure 2).

Figure 2 Number of publications presenting information on different topics related to fish in Australian saltmarsh

Eight publications provided density data in the form of a defined spatial metric (e.g. abundance per hectare) that could be used to quantify fish and invertebrate productivity. Of these, five contained density information for fish and invertebrates targeted by commercial and recreational fisheries in Botany Bay New South Wales (NSW), Moreton Bay QLD, Hervey Bay QLD and Barker Inlet-Port River South Australia (SA). As shown in Table 4, the quantitative measures of fish productivity presented in these publications vary in scale, habitat (i.e. mangrove, saltmarsh etc.) and sampling season. Half of these publications mentioned the links between different habitats and use of multiple habitats by fish and invertebrates that inhabit the coastal seascape. Pop-nets were used to quantify density in the five fish studies (Bloomfield and Gillanders 2005; Connolly et al. 1997; Connolly 2005; Saintilan et al. 2007; Thomas and Connolly 2001) and therefore there was consistency in sampling methodology. The way results were reported varied between studies, which limits the ability to readily compare fish and invertebrate density between locations.

Table 4 Quantitative measure of fish productivity function presented in reviewed publications

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Function** | **Quantitative information on fish productivity presented in publications** | **Dominant vegetation community** | **Location** | **Reference** |
| Invertebrate (prey) productivity | Mean zooplankton abundance:  Saltmarsh 8924.25 individuals m-3  Mangrove 3062.25 individuals m-3  Seagrass 2516 individuals m-3  Open water 2285.75 individuals m-3 | Saltmarsh: *Sarcocornia quinqueflora, Sporobolus virginicus*  Mangrove and seagrass not described | Botany Bay, NSW | Mazumder et al. 2009 |
| Mean crab larvae abundance:  Incoming tide 4 individuals m-3  Outgoing tide 2124.6 individuals m-3 | *Sarcocornia quinqueflora/ Sporobolus virginicus* | Botany Bay, NSW | Mazumder et al. 2006 |
| Mean density of snails: 0.09 snails m-2 | Not described | Botany Bay, NSW | Roach 1998 |
| Fish and invertebrate productivity – target and non-target species | Fish and crustacean density per 5.5m-2 pop net described for 28 species e.g. *Acanthopagrus australis* Yellow fin bream in seagrass 1.2 (±1.7), mangrove 1.29 (±2) and saltmarsh 0.44 (±1.11). | Saltmarsh: *S.quinqueflora, S.virginicus, Suaeda australis, Triglochin striata*  Mangrove: *Avicennia marina*  Seagrass: *Zostera capricorni* | Botany Bay, NSW | Saintilan et al. 2007 |
| Mean number (and standard error) of individuals caught in 9m-2 pop-nets in saltmarsh, mangrove, seagrass and non-vegetated habitats. Presented as a graph so exact numbers not discernable. | Saltmarsh: *S.quinqueflora*  Mangrove: *A.marina*  Seagrass: *Z.muelleri* | Barker Inlet-Port River Estuary, SA | Bloomfield and Gillanders 2005 |
| Fish and crustacean density per 100m-3 described for 20 species. Total density: 63.7 individuals 100m-3 in winter and 31 individuals 100m-3 in summer. | *S.quinqueflora, S.virginicus*  *A.marina,, Rhizophora stylosa* | Moreton Bay, QLD | Connolly 2005 |
| Fish density described for 18 species. Total density:  Moreton Bay site: 0.111 (summer) - 0.455 (winter) individuals m-2 Hervey Bay site: 0.023 (winter) – 0.152 (summer) individuals m-2 | Moreton Bay: *S.quinqueflora, S.virginicus*  Hervey Bay: *Halosarcia* sp.  Mangrove: *A.marina,, Rhizophora stylosa* | Moreton Bay and Hervey Bay, QLD | Thomas and Connolly 2001 |
| Estimated density of fish sampled is 1 fish per 23m-2 | *Sclerosteiga arbuscula, S. quinqueflora, A.marina* | Barker Inlet-Port River Estuary, SA | Connolly et al. 1997 |

*Synopsis of knowledge of Australia’s saltmarshes:*

To complement the quantitative literature review, a synopsis of existing knowledge on Australian saltmarshes was also undertaken. This involved a network of experts to collate available information from primary and secondary literature and report on the current status of saltmarshes in Queensland, New South Wales, Victoria, Tasmania and South Australia. Information was collated on: current extent of saltmarsh communities; losses and changes to the saltmarsh landscape; species composition and distribution; role in net primary productivity in Australia’s seascapes; legislation, regulations and protection mechanisms in each state, and priorities for repair. The synopsis also investigated whether simple indices, such as prawns, could be used to represent the benefits of saltmarshes and as a basis for return on investment analyses.

This synopsis supported what was found in the quantitative literature review, in that the current extent, vegetative communities and threats to Australia’s coastal seascape is relatively well understood and varies between states. Similarly, measures to manage and protect saltmarsh, through legislation and planning, differ considerably from state to state. It showed that there is broad consensus that saltmarsh provides numerous benefits, such as shoreline protection, fish nursery and cultural and recreational benefits, yet there is limited information quantifying these in an Australian context. The synopsis did demonstrate that simple indices, such as prawns, could be used to communicate the function and benefits of coastal seascapes and the costs and benefits of repair, if there was more quantitative information on the link between prawn density and coastal habitat, e.g. density of prawns per m-2 (Creighton et al. 2015b).

### Discussion

Our review revealed that there is limited published quantitative information on the key ecological functions of Australia’s coastal seascapes. In the detailed review of saltmarsh publications none of the studies provided quantitative information on the coastal protection or nutrient cycling functions in a defined spatial metric, comparable to those metrics used in ecosystem service valuation (e.g. kg nitrogen ha-1 yr-1). As market price and production function methods of ecosystem service valuation require information on how the ecological function contributes to the production of an output (Atkinson et al. 2012; Barbier 2000; de Groot et al. 2006) this deficiency of information limits the capacity for valuing these functions in a robust, defensible way. For the carbon sequestration and fish production functions of Australia’s coastal seascapes available quantitative information was limited in number and geographic spread to sub-tropical and temperate areas in south-east Queensland, New South Wales, Victoria and the Barker Inlet-Port River Estuary in South Australia. This information could contribute to the valuation of ecosystem services in the locations studied and similar sites using the benefit or value-transfer method, which is suitable when the difference between sites is not significant enough to impact values (Atkinson et al. 2012). Due to the limited geographic spread of the information and the diversity of Australia’s coastal seascapes the published information is unlikely to be representative of other seascapes, particularly those in northern and western parts of Australia. More robust, relevant and accessible information on the key ecological functions of Australia’s coastal seascapes would provide the information needed for valuation (Atkinson et al. 2012; Barbier 2000) to assist policy and decision makers to rationally compare the costs and benefits of competing interests at the land-sea interface. This could help to halt the loss and degradation of Australia’s coastal seascapes and provide a case for investment into ecosystem repair.

Research has an important role in addressing these knowledge gaps and providing information in a relevant form and context to inform decision making. To maximise its relevance and uptake by policy and decision makers research should align with society’s values, clearly identify policy processes, address weaknesses in current policy and explicitly state the relevance of the research to policy and stakeholders (Game et al. 2015). Based on these elements of *policy relevant conservation science* (Game et al. 2015) and the findings of our review, we identify and discuss four principles for research funding organisations and researchers to consider when prioritising investment and undertaking research on the key ecological functions of coastal seascapes.

*Principle 1 - Focus on the entire seascape at scales relevant to the ecological function*

Quantifying and valuing individual habitats in isolation does not account for synergistic benefits and may undervalue the function of the entire coastal seascape (Barbier 2011). The majority of the reviewed publications studied multiple habitats (i.e. saltmarsh, mangroves and seagrass) and often compared their relative contribution towards carbon sequestration or fish abundance or diversity. Half of the publications providing quantitative information on fish or invertebrate productivity discussed connectivity between habitats and the role of multiple habitats in contributing towards overall ecosystem function but did not go the next step to quantify production across the whole seascape. There is a need to consider the entire coastal seascape rather than discrete habitats (Barbier 2011; Nagelkerken et al. 2015; Sheaves 2009) and this is particularly pertinent when considering the role of coastal seascapes in fish and invertebrate productivity.

Management of coastal fisheries resources has often been focused on individual spatial units, such as seagrass beds (Holmer et al. 2008) or freshwater reaches (Kairo et al. 2001). However, recent advances in our understanding of the needs of estuarine and coastal fish and mobile crustaceans (e.g. Nagelkerken et al. (2015); Sheaves (2009); Weinstein and Litvin (2016)) emphasise that coastal fisheries depend on species being able to access specific habitats and resources for specific purposes and at different stages of their life-histories. Juveniles typically require different parts of the coastal ecosystem mosaic to adults and different habitats are used at different stages of the tide, day and season to provide protection and access to specific prey to fulfil their requirements (Beck et al. 2001; Sheaves 2009). Similarly, sources of nutrition are often contributed by habitats or units spatially separate from those the animal occupies (Abrantes and Sheaves 2008; Abrantes et al. 2014) and those sources often vary over time (Abrantes and Sheaves 2010).

To ensure the productivity and resilience of coastal fisheries, research on the fish nursery and habitat functions of seascapes should be undertaken at a scale that incorporates the entire ecosystem mosaic used by a species. The scale of the seascape is species dependent, but typically comprises the whole estuary, including subtidal waters, intertidal flats, rocky headlands, shellfish reefs, seagrass, mangroves and saltmarsh. This seascape view also emphasises that the linkages between habitats within the seascape need to be considered (Nagelkerken et al. 2015). Therefore a seascape perspective is needed to quantify the contribution of coastal ecosystems to fisheries productivity. The same holds true for other functions, yet the relevant scale will be different depending on the function being investigated. The scale of the research being conducted should also align with the scale that is relevant to management and decision making.

Research direction: We recommend that research focus on the coastal seascape at a scale relevant to the ecosystem function, such as fisheries production, being investigated and the management or policy decisions it aims to inform. This will require transitioning from research that focuses on individual habitats or patches in isolation, towards quantifying and communicating the function and benefits of coastal seascapes as a whole. A combination of bio-physical variables, such as substrate, depth, vegetation communities etc. could be used to map out ecosystem service provision across the coastal seascape at a scale more relevant to coastal management and policy development.

*Principle 2 - Use meaningful and communicable metrics*

To accurately assess the benefits and trade-offs between alternative land uses and coastal wetland protection or repair there is a need for meaningful and communicable metrics for the function and value of coastal seascapes. Metrics such as fish production per hectare or carbon sequestered per hectare have been used in economic valuation studies and to inform coastal management decisions internationally (Barbier et al. 2011; Foster et al. 2013; Luisetti et al. 2011). A limited number of publications that we reviewed (three for carbon sequestration and eight for fish and invertebrate production) presented quantitative information on Australian coastal seascapes in this form. Metrics need to be based on tangible, locally-relevant information to meet Government and public scrutiny and accountability and address barriers to the use of ecosystem services in decision making (Marre et al. 2015). We propose that metrics for key ecological functions need to be selected based on a set of rigorous criteria, for example: (i) are representative of the total coastal seascape, (ii) can be measured cost-effectively, (iii) are clearly defined, (iv) can be used to compare sites and identify priorities (v) are relevant and meaningful to decision makers, and (vi) are suitable for clear and effective communication to the public. They should also take a form that can be used in ecosystem service valuation to enable comparison to alternative land uses e.g. able to be valued in an economic sense.

Our review identified a lack of quantitative information on the coastal protection and nutrient cycling functions of Australia’s wetlands in a defined spatial context (e.g. kg nitrogen removed per hectare) that could inform ecosystem service valuation. These functions benefit coastal infrastructure and home owners and are relevant to environmental management agencies. Therefore quantifying and communicating them via metrics that meet the above criteria would help raise awareness and understanding of the benefits of protecting and conserving coastal seascapes.

Research direction: We recommend that research on key ecological functions should collect and communicate information in defined, meaningful and communicable metrics which are relevant to policy and management and resonate with the broader community. In the case of Australia’s coastal seascapes, quantitative data have been collected for carbon sequestration and fish and invertebrate production and these metrics (e.g. carbon sequestered per hectare per year or tonnes of invertebrate/fish production per hectare per year) can be used, or transformed, to communicate to decision makers and the public. Researchers collecting, analysing, reporting and managing data on key ecological functions of coastal seascapes should promote the use of consistent approaches that provide for comparison between habitats, sites and seascapes. The development of standard operating procedures or protocols is required.

*Principle 3 – Align research with policy priorities and current issues*

In Australia, as indeed across the developed world, there are multiple policy debates underway at any one time that are directly relevant to sustainable use, protection and repair of coastal seascapes. Current policy debates relevant to coastal Australia include: (i) Climate change, including the role of various landscape elements in carbon sequestration, the potential for sea level rise and the implications of climate change on coastal assets and amenity, i.e. coastal erosion, storm surge and inundation of coastal land (Commonwealth of Australia 2015a; Lawrence et al. 2012; Minister for the Environment 2015b; State of the Environment 2011 Committee 2011); (ii) Marine productivity and marine biodiversity, such as the health and resilience of the Great Barrier Reef (Commonwealth of Australia 2015c; Great Barrier Reef Marine Park Authority 2014); (iii) Food and water security, including how to ensure the sustainable production of protein to meet increasing domestic and export market demand and avoid future projected food shortages (HLPE 2014; PMSEIC 2010); (iv) Catchment water quality and the implications for clean water supply and the health and biodiversity of downstream receiving environments (ANZECC 2000; Commonwealth of Australia 2015c); (v) Community lifestyle, encompassing a range of issues such as human health, recreation, landscape amenity and lifestyle choices (Commonwealth of Australia 2011).

The way Australia’s coastal seascapes are protected, managed and repaired affects the functions that they provide. This has implications for these broad areas of community and policy interest in that it can impact on the resilience of coastal seascapes to climate change, affect sustainable fish production and alter carbon and nutrient assimilation (Great Barrier Reef Marine Park Authority 2014; Millenium Ecosystem Assessment 2005). There are also economic ramifications for the resilience and sustainability of coastal and marine industries, land uses and natural assets. The functions we reviewed, including carbon sequestration, coastal protection, nutrient cycling and fish production are of direct relevance to these policy areas. The shortage of quantitative information on these functions may be limiting the ability for science to contribute relevant, persuasive evidence to these debates.

Research direction: Research on key ecological functions should align with policy debates to inform decision making on sustainable development, protection and repair. We recommend research focus on generating evidence-based, communicable values of coastal seascape function that can contribute meaningful information to inform contemporary policy and management decisions, such as ecosystem based fisheries management, climate change action and abatement, arresting biodiversity decline and the development of northern Australia. Science should explicitly identify and link with policy and management actions and the communication of research results should also clearly state the relevance to stakeholders and the policy context more broadly (Game et al. 2015). Researchers should work with knowledge brokers to identify the best ways to scope research, synthesise results and communicate findings to decision makers and the broader public (Cvitanovic et al. 2015; Michaels 2009). This would ensure that research is topical, relevant and more likely to be utilised in policy development and coastal management decisions.

*Principle 4 – Align research to support existing or develop new payment for ecosystem service mechanisms*

Key ecological functions that are aligned to existing or emerging payment for ecosystem service mechanisms such as carbon markets can be readily compared in an economic sense to other market outcomes such as urban development or agricultural production (Barbier 2011). Therefore utilising existing or developing new monetary mechanisms for key ecological functions could help ensure coastal seascapes are considered as assets worthy of protection and repair.

Carbon sequestration and fish and invertebrate production functions of Australia’s coastal seascapes can and have been quantified, albeit so far just in a few, discrete locations. The most robust, quantitative data identified relates to carbon sequestration in estuaries in south-eastern Australia. This information meets many of the criteria listed above, in that it can be defined, communicated and represents the coastal seascape. These attributes form the basis of tradable commodities and allow the development of markets to buy and sell ‘carbon sequestration’ services. There is increasing interest in Australia in ‘blue carbon’, with saltmarshes and mangroves found to be able to sequester at least as much carbon per unit area as terrestrial forests (McLeod et al. 2011). The Australian Government has recently announced the establishment of an International Partnership for Blue Carbon (Minister for the Environment 2015a) and funding for research into carbon sequestration in coastal ecosystems (Minister for the Environment 2015b). This research should be aimed at filling the identified knowledge gaps pertaining to carbon sequestration of Australia’s coastal seascapes, for example by focusing on tropical, southern and western Australia where quantitative information is currently limited. This information could support a blue carbon market in Australia and help inform coastal management decisions, by identifying priorities for protection and repair to maximise blue carbon potential.

Carbon markets and global protocols for carbon projects, such as the Verified Carbon Standard, provide a framework for the development of other payment for ecosystem service mechanisms, such as nutrient trading markets which are in their infancy in Australia. A voluntary market-based mechanism for nutrient management has been introduced in south-east Queensland. This allows for the trading of nutrients generated from a point-source (e.g. sewage treatment plant) with other point sources or diffuse source nutrient reduction measures, such as best practice rural or urban land management and constructed wetlands (State of Queensland 2014). Nutrient trading is being also explored in north Queensland to address nitrogen losses from intensive agriculture (Smart et al. 2016). Coastal seascapes have not been included in these frameworks, possibility due to the current lack of quantitative information on the nutrient cycling function of coastal seascapes.

Commercially harvested fish and invertebrate species have a current and future market and have tangible meaning to policy and public audiences and could therefore be used to communicate coastal seascape value. Quantifying the biomass and production of commercially important fish and invertebrate species can contribute to coastal management decision making (Barbier 2011). For example, if deciding whether to convert a wetland into ponded pasture or restore ponded pastures back to a natural wetland, there is a benefit to society in generating income and food through cattle production, but the loss in fish and prawn productivity is largely unknown. This seafood productivity could be of higher value than the beef produced, yet due to a shortage of quantitative information on the fisheries production function of Australia’s coastal seascapes, is not currently able to be quantified and objectively compared.

Research direction: We recommend aligning research on key ecological functions to support existing or develop new payment for ecosystem service mechanisms. Initially research should focus on quantifying key ecological functions that have an established or emerging market value such as the productivity of commercial fish and invertebrate species or carbon sequestration, in areas where there are identified knowledge gaps. This could include research in tropical Australia on wild-catch species with a current market value, significant contribution to gross domestic product and a clear, measurable link to coastal seascapes, for example barramundi, banana prawns or mud crabs (Creighton et al. 2015a). Research should investigate a range of variables that can help predict the fisheries productivity of coastal seascapes and can be used to inform management of these areas. This could be modelled on the research undertaken in Galveston Bay, USA, where sixteen years of quantitative density data has been collected on the brown shrimp and was used to develop a density prediction model to designate and protect essential fish habitat (Clark et al. 2004). Consistency of data collection and communication is essential to enable comparison between studies and locations and contribute to a national inventory of information for ecosystem service valuation.

**Conclusion: an approach to collect and communicate evidence to foster sustainable coastal development, protection and repair**

There is a need for a more comprehensive understanding of the functions and benefits of Australia’s coastal seascapes. This information is a high priority to support evidence-based decision making that protects the values of Australia’s coastal seascapes and the ecological functions they provide as an asset contributing to the economy, warranting protection and repair.

We recommend establishing nationally consistent approaches to collecting, analysing, reporting and managing data on key ecological functions to substantiate the value of Australia’s coastal seascapes over different scales and contexts. Research should build upon and enhance the limited quantitative information currently available on the function of Australia’s coastal seascapes and contribute to an inventory of information for ecosystem service valuation. This could take the form of an information portal which utilises or is modelled off existing national portals such as the Terrestrial Ecosystem Research Network (TERN) or Australian Ocean Data Network portal (AODN). Research results need to be readily accessible and communicated in a format that can be used directly by policy and decision makers, explicitly stating the relevance to policy and management decisions (Game et al. 2015). Engaging the public is also essential and should focus on communicating the role of coastal seascapes in providing functions that the community cares about, to increase community knowledge and appreciation of coastal seascapes. Employing the skills of knowledge brokers would facilitate the collation, synthesis and communication of evidence that align research and information outputs with the needs of decision makers (Cvitanovic et al. 2015; Michaels 2009) and is meaningful to the broader public.

Research funding is required to build a seascape scale understanding across temperate, sub-tropical and tropical coastal Australia. Recognising that research resources will always be limited, the principles outlined can be used to prioritise research investment. For example, research that is (i) aligned to policy priorities and current or emerging issues (e.g. development of northern Australia (Commonwealth of Australia 2015b) and improving the health and resilience of the Great Barrier Reef (Commonwealth of Australia 2015c)); (ii) supports existing or emerging payment for ecosystem service mechanisms; (iii) enhances understanding of ecological functions at a seascape scale relevant to management or policy and (iv) is meaningful to policy and public audiences (e.g. fish or invertebrate productivity from natural or repaired coastal seascapes). Investment in this research is justified to provide information needed to make robust and defensible decisions about development, protection and repair of Australia’s coastal zone to ensure long-term economic and community benefits.

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