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Technical review of opportunities for including blue carbon in the Australian Government's Emissions Reduction Fund

Final Report

Prepared for the Department of the Environment and Energy

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Executive Summary

The capacity of blue carbon ecosystems (defined in this report to include mangroves, tidal marshes and seagrasses) to sequester carbon dioxide and mitigate climate change is generating significant interest among scientists and policy makers worldwide. The carbon stored within these blue carbon ecosystems represents nearly 50% of all carbon accumulation in marine sediments, despite occupying just 0.2% of the ocean surface (Duarte et al. 2013b). Australia is home to a substantial area of the world's blue carbon ecosystems and has also been a focal point of recent scientific advances in understanding the carbon dioxide storage function of these ecosystems (including through the CSIRO Coastal Carbon Cluster - www.csiro.au/en/Research/OandA/Areas/Coastal-management/Coastal-Carbon-Cluster). Australia has voluntarily elected to include blue carbon ecosystems in its national greenhouse gas (GHG) accounts. As a consequence, Australia is also considering the development of its domestic policy instruments to reduce national GHG emissions. These instrumentsinclude potential methods that allow for sequestration and emissions avoidance projects specifically in blue carbon ecosystems..

A pre-requisite to incorporating Australia's blue carbon ecosystems into the broader framework of the nation's carbon economy is an assessment of the potential for anthropogenic management activities to sequester carbon (remove additional carbon dioxide carbon, CO_2-C, from the atmosphere) and avoid GHG fluxes (avoiding emission of GHGs expressed as carbon dioxide equivalents, CO_2-e) against a business-as usual condition. To this end, the objectives of this report were to:

1. Identify the key *influencing factors* that can alter carbon storage, cycling and emission in Australian mangrove, tidal marsh and seagrass ecosystems.

2. Undertake a detailed assessment of anthropogenic management *activities* that have the potential to enhance carbon storage or reduce/avoid emissions of GHGs in Australian mangrove, tidal marsh and seagrass ecosystems.

3. Provide recommendations on anthropogenic blue carbon management activities that could be applied and prioritised for potential method development under the Emissions Reduction Fund (ERF). This will include estimation of likely carbon abatement potential (where possible), identification of barriers or constraints to implementation and outlining the steps required to address the identified barriers or constraints.

Influencing Factors

For each *influencing factor*, the mechanisms responsible for altering the magnitude of carbon sequestration or GHG emissions avoidance, existing management practices and legislation within Australian regions and the current and predicted trends have been identified. This has been completed with reference to the current literature, recent findings of the CSIRO Coastal Carbon Cluster and outcomes of a participatory workshop of blue carbon scientists and stakeholders (Section A). Significant knowledge gaps include limited information on the spatial extent over which each influencing factor operates in Australia as well as a lack of research or case studies relevant to Australian blue carbon ecosystems.

Activities Assessment

An outcome of the participatory workshop was the identification of anthropogenic activities that have the potential to enhance carbon sequestration or reduce/avoid GHG emissions (Section B) from blue carbon ecosystems. The report provides an overall suitability assessment of the identified anthropogenic blue carbon activities that fall within the policy context of the ERF, by comprehensively comparing each against the provided Abatement Integrity Assessment. This task has been completed considering protection and establishment or restoration of mangroves, tidal marshes and seagrasses.

Recommended activities

In the final section of the report recommendations on the appropriate steps that could be taken toward the inclusion of blue carbon enhancement activities in an ERF method are provided (Section C). This section also identifies potential barriers and/or constraints for those abatement activities and recommends steps that could be taken toward development and implementation of a potential ERF method.

It is important to recognise that the work included in this report and the recommendations have been developed considering the existing policy context (as at 2016/17) and that there may be policy shifts (at Federal or State level) which could influence the appropriateness of the recommendations for development of a potential ERF Method. In addition to using research outcomes to underpin potential method development, ERF method development must also consider social, economic and environmental impacts.

A summary of each of the recommendations for potential ERF method development follows. The ordering of these recommendations reflects the organisational approach taken in the report and does not imply any prioritisation or assessment of readiness for potential ERF method development.

<u>Introduction of tidal flow (mangroves and tidal marshes)</u>

Introduction (or re-introduction) of tidal flow has the potential to enable substantial carbon removals from the atmosphere through new growth of mangrove biomass organic carbon (C_{org}) pools and mangrove/tidal marsh soil C_{org} pools, plus reductions in GHG fluxes from sites which are currently drained or ponded with freshwater. Other advantages of this activity include a high potential for uptake, an existing information base and few barriers to implementation.

It is recommended that a new ERF method be considered for development for this activity with possible inclusion of appropriate components from existing ERF Vegetation management and Soil carbon methods.

<u>Avoided clearing (mangroves) and avoided soil disturbance (mangroves and tidal marshes)</u>

A one-off emission avoidance may be achieved where clearing of mangrove aboveground biomass that has been previously approved is avoided. Where both aboveground biomass plus soil disturbance is avoided, then this one-off avoided emission estimate may increase substantially. For tidal marshes there may be a large avoided emission from avoided soil disturbance, but because of the low levels of biomass, avoided emissions associated with avoided biomass clearing will be small and would not be included. In addition, avoided soil disturbance will allow the ecosystem (either mangrove or tidal marsh) to continue to accumulate soil C_{org} beyond that present at the time clearing would have occurred (sequestration). The impact of soil disturbance in both mangroves and tidal marshes could therefore include both an avoided emission and potential future sequestration.

It is recommended that the following be undertaken: 1) a review to determine the spatial extent of pre-existing approvals for clearing or disturbing mangroves and tidal marshes and the potential magnitude of C_{org} stocks affected in order to justify method development; 2) an assessment of the potential for expanding existing ERF land clearing methods to include mangrove ecosystems; 3) consideration of both the avoided emission associated with soil disturbance and subsequent sequestration that may occur by avoiding soil disturbance. Dependant on the outcomes of (1), (2) and

(3), it is recommended that a methodology which combines avoided biomass removal (an avoided emission) and avoided soil disturbance (an avoided emission and continued sequestration) for mangrove and tidal marshes be considered. There is potential to develop a single method for mangroves and tidal marshes for this activity.

Land-use planning for sea level rise (mangroves and tidal marshes)

Altering land-use for the purpose of allowing mangroves and tidal marshes to migrate with sea level rise has the potential to enable substantial CO_2-C removals through growth of mangrove biomass C_{org} stocks and the accumulation of soil C_{org} stocks in both mangroves and tidal marshes. Depending on existing land-use, reductions in GHG fluxes may also occur.

It is recommended that a preliminary review be undertaken to identify current capacity and adequacy to predict future sea level rise and C_{org} storage response of mangroves and tidal marshes. However, development of a specific ERF method would be required as this activity is not aligned with any existing methods.

Avoidance of seagrass loss and re-establishment or creation of new seagrass ecosystems

Poor management of catchment areas and activities within coastal environments are resulting in the deterioration of water quality, constituting the main threat to seagrass ecosystems in Australia and causing the loss of large areas of seagrasses.

Introduction of new management activities that mitigate decreases in the spatial extent of seagrass ecosystems, re-establish seagrass ecosystems in areas where they have been lost, or create new seagrass ecosystems may result in avoided emissions and sequestration of carbon. These outcomes could be achieved through:

- maintenance or improvement of water quality (i.e. reducing sediment, nutrient and pollutant loading) that improve or restore productivity of existing seagrasses,
- creation of new areas suitable for colonisation by seagrass (e.g. in situ and/or offsite activities such as modification of tidal flow or hydrodynamic energy) followed by direct revegetation (transplanting or planting new seedlings) and/or passive regeneration (allowing neighbouring seagrasses to spread and colonise).

Such activities have the potential to avoid emissions through the preservation of soil C_{org} stocks within seagrasses and the introduction, maintenance or increase of soil C_{org} sequestration by seagrasses. For seagrasses there may be a large avoided GHG emission from avoided soil disturbance, but because of the low levels of biomass, avoided emissions associated with avoided biomass loss will be small and would not be included.

It is recommended that potentially a new ERF method could be developed for this activity.

Avoidance of seagrass loss through direct physical disturbance

Avoided clearing of seagrass biomass and associated avoided disturbance to seagrass soils can result in substantial avoided GHG emissions from soils and a preservation of their carbon sequestration capacity. Poor management (e.g. dredging, construction of coastal infrastructure and boating activities) constitutes a significant threat to seagrass ecosystems in Australia and is resulting in the loss of seagrass ecosystems and associated soil C_{org} stocks and carbon sequestration capacity.

It is recommended that the spatial extent of pre-existing approvals for physical disturbance of seagrass ecosystems and the potential soil C_{org} stocks involved be determined and used to inform the magnitude of potential abatement to justify development of a potential method. Dependent upon the outcome of this assessment, a new methodology may be developed.

Recommendation for further research

In addition to the information needs identified for the above activities, the following have been identified as high-priority requirements:

1. For the soils of blue carbon ecosystems, the accumulation of C_{org} stocks can be derived from CO_2 captured within the ecosystem (autochthonous carbon) or from CO_2 captured outside the ecosystem and transported into the ecosystem (allochthonous carbon). It is recommended that a review be undertaken to derive appropriate Australian values of autochthonous and allochthonous contributions to soil C_{org} in blue carbon ecosystems. This information could be included as a component associated with the development of any ERF method for carbon sequestration in blue carbon ecosystems. Support for taking such an approach to estimate the autochthonous component of soil C_{org} stock change would potentially result in a reduction in measurement costs that ERF projects would incur relative to a situation where they were required to derive project specific differentiation of autochthonous and allochthonous C_{org} sources by measurement.

2. GHG emissions from existing land-uses (e.g. coastal grazed pastures) that could be converted to blue carbon ecosystems should be reviewed to improve our ability to estimate CO_2-e emissions under the business as usual situation. Improved business as usual estimates will allow a more appropriated calculation of the net abatement associated with conversion of various land-uses to blue carbon ecosystems. As an example, consider conversion of a coastal grazed pasture back to mangroves. In addition to the carbon that could be sequestered by the mangrove ecosystem, the net benefit of this transition may also include a reduction or elimination of a soil C_{org} stock loss, nitrous oxide emission (from fertilisers and manure) and methane emission (from soils flooded with fresh water and enteric fermentation) often associated with coastal grazed pasture systems.

1 Introduction

Blue carbon ecosystems contribute nearly 50% of the carbon accumulation in marine sediments, despite occupying just 0.2% of the ocean surface (Chmura et al. 2003, McLeod et al. 2011, Duarte et al. 2013b). Together, mangroves, tidal marshes and seagrasses have been termed 'blue carbon' ecosystems (Nellemann et al. 2009) due to their exceptional capacity to sequester and store organic carbon (C_{org}) over millennial time-scales (McKee et al. 2007, Lo Iacono et al. 2008). Consequently, there has been growing interest in understanding the processes governing C_{org} accumulation and storage in blue carbon habitats (McLeod et al. 2011, Lavery et al. 2013, Ouyang and Lee 2014) and their potential to mitigate climate change associated with anthropogenic inputs of carbon dioxide (CO_2) to the earth's atmosphere, among other global change threats such as sea level rise (Duarte et al. 2013b, Siikamäki et al. 2013, Ullman et al. 2013, Murdiyarso et al. 2015).

Over recent years, the recognition of the value of blue carbon ecosystems in sequestering C_{org} has intensified interest in their conservation as a measure to offset greenhouse gas emissions expressed as CO_2-equivalents (CO_2-e). In 2009, the United Nations identified opportunities to use the high C_{org} sink capacity of blue carbon ecosystems (Nellemann et al. 2009). This initiative led to additional research (Bouillon et al. 2008, McLeod et al. 2011, Duarte et al. 2013b) to better understand the mechanisms, magnitudes, and uncertainties associated with the accumulation of C_{org} in blue carbon ecosystems. Additionally, the Intergovernmental Panel on Climate Change (IPCC) initiated the development of a Supplement to the 2006 assessment and guidance for greenhouse gas accounting (IPCC 2007) acknowledging the role of coastal wetlands, including mangroves and tidal marshes in sequestering CO_2-C. In the interim, many nations, including India and Indonesia, have embraced blue carbon strategies in their portfolio of initiatives to abate climate change impacts.

Australia, despite its extensive marine area that contains a significant fraction of the global C_{org} stores within blue carbon ecosystems, has not yet developed blue carbon strategies to contribute to mitigating climate change. Whereas anthropogenic disturbances and climate change may possibly impact on these ecosystems and their role as carbon sinks or in mitigating CO_2-e emissions, the absence of a baseline on C_{org} budgets and flows in Australian coastal ecosystems weakens our capacity to detect changes and propose management or compensatory actions. Moreover, in a low carbon economy that Australia is moving towards, blue carbon sinks represent a significant asset for which conservation may generate important monetary benefits (via carbon offset markets), as well as indirect benefits to Australia's blue economy (e.g. fisheries, social amenity, and coastal protection). A pre-requisite to incorporating Australia's blue carbon into the broader framework of the nation's carbon economy is an assessment of the magnitude of the carbon sequestration capacity associated with our coastal ecosystems, and the changes in greenhouse gas (GHG) fluxes derived from local and regional anthropogenic impacts and conservation activities under future global change scenarios (Figure 1).

To this end, the objectives of this report are to:

1. Identify the key factors that influence C_{org} storage and cycling, and GHG emissions in mangroves, tidal marshes and seagrasses.

2. Undertake detailed assessment of management activities that have the potential to enhance C_{org} storage or reduce/avoid emissions GHG in Australian mangroves, tidal marshes and seagrasses.

3. Provide recommendations of blue carbon activities that should be prioritised for consideration and potential method development for the Emissions Reduction Fund (ERF). This will include estimation of likely C_{org} abatement potential (where possible) as well as identification of barriers or constraints to implementation and outline of steps required for implementation.

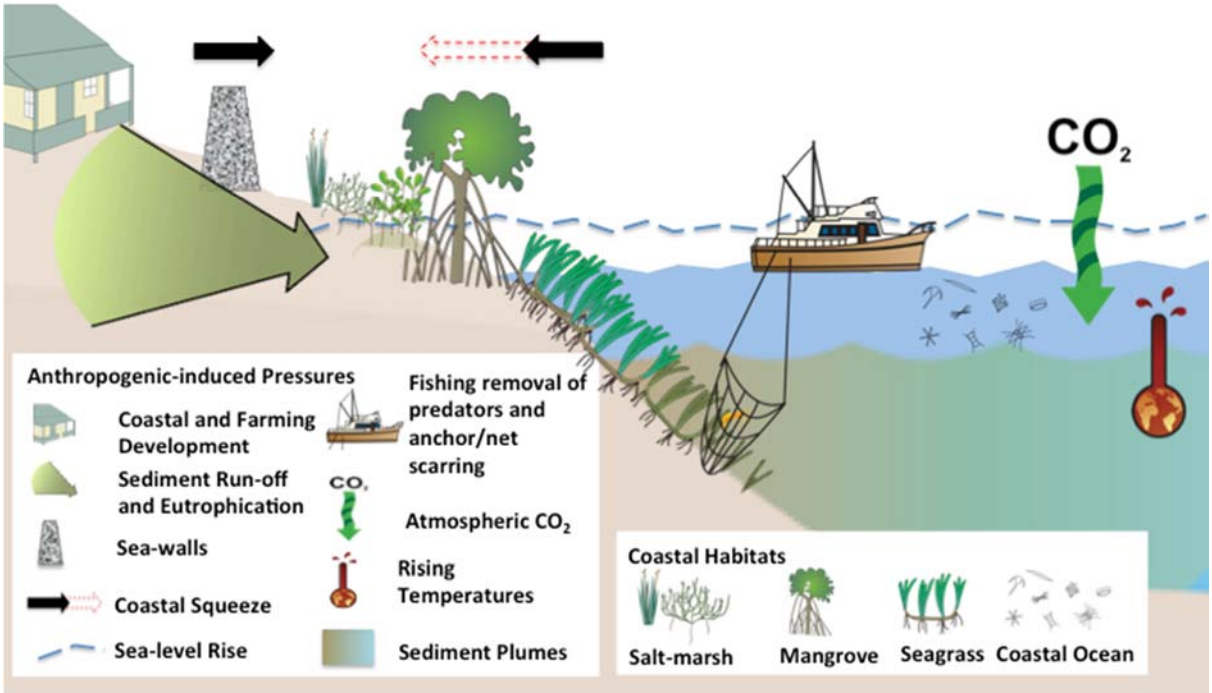


Figure 1: Conceptual diagram of some of the activities that influence C_{org} storage in blue carbon ecosystems (drawn by Charlotte Robinson and Stacey Trevathan-Tackett).

2 Blue carbon ecosystems

Mangroves, tidal marshes and seagrasses are net autotrophic ecosystems that make a significant contribution to the global carbon cycle (Nixon 1980, Gattuso et al. 1998, Alongi 2002).

Blue carbon ecosystems store C_{org} in two main pools:

- Aboveground pool: standing biomass (leaves, stems, branches, and trunks), *in situ* dead biomass (such as standing dead trees), and biomass litter on the soil surface and autogenic epiphytes that may colonise the surface of these materials (especially for seagrasses).
- Belowground pool: living belowground biomass (roots and rhizomes), dead belowground plant organs and soil C_{org}.

Stocks of C_{org} in blue carbon ecosystems are mainly found in the soil (Duarte et al. 2013b). Typically, around 90% of the C_{org} stocks in tidal marshes and seagrasses are found in the soil, while 75% of the C_{org} stocks in mangroves are found in the soil (Nellemann et al. 2009, Alongi 2014). This potential storage of C_{org} within the soils – and conversely, the possibility of substantial CO_2-e emissions after ecosystem disturbance – makes belowground C_{org} stocks the primary interest in blue carbon initiatives (Sutton-Grier et al. 2014).

Blue carbon ecosystems encompass a wide variety of species across a range of depositional environments and water depths (Carruthers et al. 2007), and the variability in the sedimentary C_{org} stocks has been found to be high among seagrasses up to 18-fold (Lavery et al. 2013), and up to 4-fold in mangroves and tidal marshes (Pendleton et al. 2012). Geomorphological settings (i.e. encompassing variation in landscape and hydrology), soil characteristics (e.g. mineralogy and texture) and biological features (e.g. primary production and remineralisation rates) control soil C_{org} storage in blue carbon ecosystems (Donato et al. 2011, Adame et al. 2013, Ouyang and Lee 2014). Whilst the factors influencing C_{org} stocks and GHG emissions from blue carbon ecosystems are known, improved understanding of how C_{org} stocks and GHG emissions respond to variations in these factors over both space and time would be useful in predicting potential outcomes (Chmura et al. 2003, Nellemann et al. 2009, Duarte et al. 2010, Serrano et al. 2014, Kelleway et al. 2016a).

Based on terrestrial analogues and limited research undertaken on blue carbon ecosystems, it is likely that multiple factors influence C_{org} storage, including biotic and abiotic factors acting in the water column, canopy and the soils as well as the history of the landscape and past variation in sea level. The plants themselves will exert a primary control on C_{org} storage through production of biomass and nutrient cycling (Lavery et al. 2013, Serrano et al. 2014, Miyajima et al. 2015, Kelleway et al. 2016c, Serrano et al. 2016c), both of which are highly variable depending upon plant species and ecosystem conditions (Alcoverro et al. 1995, Collier et al. 2007, Lovelock et al. 2013, Saintilan et al. 2013). Plant density, biomass and productivity are strongly related to the underwater light penetration and soil type in seagrass (Dennison 1987, Duarte 1991) while salinity and nutrient supply may be important factors for mangroves and tidal marshes (Reef et al. 2010, Wigand et al. 2015, Lovelock et al. 2016). Once C_{org} is buried in the soil biotic and abiotic factors are likely to control the degree of C_{org} accumulation and preservation (Burdige 2007). The rates of sediment accumulation, the soil structure and the biochemical composition of the organic matter buried may strongly influence C_{org} accumulation and preservation, and are highly variable among blue carbon ecosystems (De Falco et al. 2000, Kennedy et al. 2010, Duarte et al. 2013a, Saintilan et al. 2013, Ouyang and Lee 2014). If the accumulated sediments are fine-grained, then they are likely to enhance the preservation of C_{org} by reducing oxygen exchange and redox potentials, which reduces remineralisation rates (e.g. Keil and Hedges 1993).

Finally, while both autochthonous (e.g. plant detritus and epiphytes) and allochthonous (e.g. seston and terrestrial matter) sources contribute to the soil C_{org} pool in blue carbon ecosystems (Kennedy et al. 2010, Kelleway et al. 2016a) the proportion of plant-derived C_{org} may be an important factor controlling C_{org} storage capacity. Plant tissues contain relatively high amounts of degradation-resistant organic compounds (e.g. lignin; (Harrison 1989, Klap 2000, Burdige 2007, Torbatinejad et al. 2007, Trevathan-Tackett et al. 2015) compared to seston and algal detritus (Laursen et al. 1996), which are more prone to remineralisation during early diagenesis (Henricks 1992). It is clear that a large number of influencing factors can potentially alter stocks and accumulation rates of C_{org} in blue carbon ecosystems. As a result, anthropogenic activities offering a potential to impact these influencing factors could provide opportunities to enhance C_{org} stocks or avoid emissions of GHG, contribute to the mitigation of Australian GHG emissions and form the basis for blue carbon methods within the Australian Government's Emissions Reduction Fund – the centrepiece of the Australian Government's policy suite to reduce emissions.

2.1 Tidal marshes

Tidal marshes are coastal, saline ecosystems that may be vegetated by higher plants (comprising a diversity of grasses, rushes, and herbs often referred as saltmarshes). Tidal marshes also include coastal saline ecosystems devoid of higher plants but often covered by cyanobacterial mats (referred to as salt flats), though these forms of tidal marsh are not considered in this report. Tidal marshes are important habitats for a range of species, including birds, fish and invertebrates. Tidal marshes exist in the intertidal to supratidal zones of many of Australia's estuaries, embayments and sheltered coasts (Figure 2). Although tidal marshes in south-eastern Australia have been relatively well-studied, much remains unknown about the ecological functioning of tidal marshes in many other parts of Australia. Tidal marshes are disproportionately important in sequestering C_{org} relative to their spatial extent (Duarte et al. 2005, McLeod et al. 2011). Despite their blue carbon storage potential, substantial losses of tidal marsh have occurred in some parts of Australia. In New South Wales it has been estimated that up to 70% of all coastal wetlands may have been lost since European settlement (Zann 2000), with this value likely to be broadly true for Australian tidal marshes. In SE Queensland mapping has shown that just 36% of the 1955 extent of tidal marshes remains today (Accad et al. 2016). Subtropical and temperate tidal marshes are listed as vulnerable under the Commonwealth *Environmental Protection and Biodiversity Conservation Act 1999*. Globally, tidal marshes are declining in area at a rate of 1–2% per year (Duarte et al. 2008), and these systems are vulnerable to climate change and sea level rise, as well as coastal development.

2.2 Mangroves

Mangroves are comprised of trees and shrubs that are adapted to live in the intertidal zone of low-energy coastlines (Figure 3). Australia has the third largest area of mangroves globally, occurring throughout the tropical north of the country, but also extending through the subtropical and temperate coasts of Australia's mainland. Mangroves provide numerous ecosystem services, such as coastal protection against storms and coastal erosion, and provide a nursery ground for important economic, ecological and recreational fauna. Large areas of mangroves have been retained in Australia because their distribution includes extremely isolated areas such as in northern Australia and in areas of sparse human population. However, in areas where there is intensive coastal development, historical loss of mangroves has been extensive. These systems are also vulnerable to climate change and sea level rise, as well as pressures associated with coastal development.

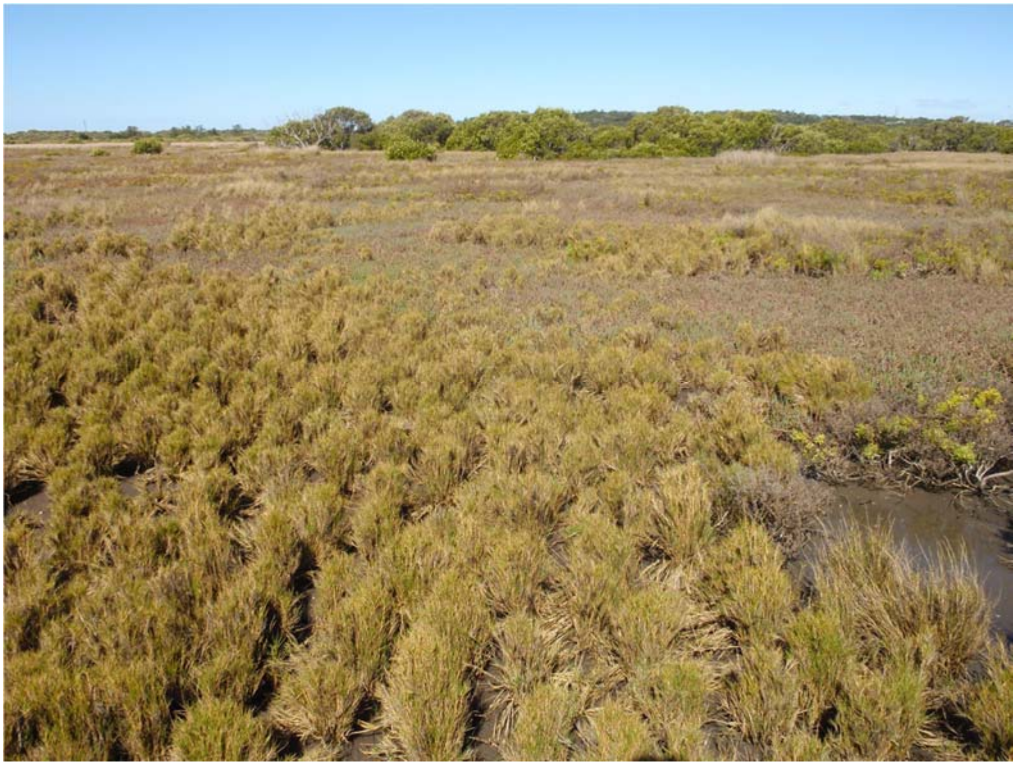


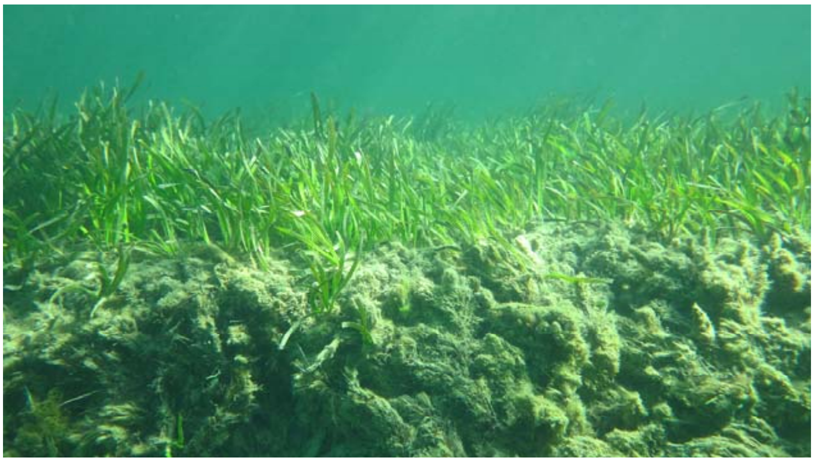
Figure 2: A mosaic of tidal marsh plants including grasses, succulents, herbs and rushes within Towra Point Nature Reserve, south of Sydney, NSW. Photograph by Jeff Kelleway.

Figure 3: *Avicennia marina* mangroves in Weeney Bay, Towra Point Nature Reserve south of Sydney, NSW. Photograph by Jeff Kelleway.

2.3 Seagrasses

Seagrasses are flowering plants that grow in marine and estuarine areas. They are common in intertidal and shallow waters to depths of about 20 m where there is sufficient light for them to grow. They provide several ecosystem services, including the sequestration and storage of carbon as organic matter. Some of this C_{org} is contained in the living plants, but the majority is buried in the soils underneath the meadows. There are approximately 30 species of seagrass in Australia, from large forms with strap-like leaves (e.g. *Posidonia*), through to small forms with oval-shaped leaved (e.g. *Halophila*) (Figure 4). Seagrasses are distributed around the entire Australian coastline, covering an approximate area of 125,500 km^2. The global seagrass loss rate has been estimated at 7% per year since the 1980s (Waycott et al. 2009). Seagrass ecosystems require protection to safeguard their C_{org} stocks and protect habitats for marine organisms and human populations living in coastal areas. These systems are also vulnerable to climate change and sea level rise, as well as pressures associated with coastal development.

a)



b)

Figure 4: a) *Posidonia* escarpment in Shark Bay, Western Australia, with living plants at the surface and a deep layer of organic-rich soil underneath, exposed by erosional processes; b) *Halophila* meadow in Perth, Western Australia, with living plants at the surface and a sandy substrate.

2.4 Conservation and restoration of blue carbon ecosystems

Among the multiple ecosystem services provided by mangroves, tidal marshes and seagrasses, their capacity to sequester C_{org} and mitigate climate change has generated interest among scientists and policy makers (Bouillon et al. 2008, McLeod et al. 2011, Fourqurean et al. 2012, Duarte et al. 2013b, Ouyang and Lee 2014). Coastal areas have remained strategic points of human settlement through history, resulting in persistent and intense impacts on blue carbon ecosystems (Lotze et al. 2006). Blue carbon ecosystems and the services they provide are threatened by a wide variety of human activities (Barbier et al. 2011, Kirwan and Megonigal 2013). However, coastal developments have caused a net decline in the area of Australian blue carbon ecosystems, estimated at 1-3% yr^{-1} (Valiela et al. 2001, Waycott et al. 2009, Short et al. 2011, Hamilton and Casey 2016).

The preservation and restoration of C_{org} storage in terrestrial ecosystems is considered a valuable mechanism for climate change mitigation (Agrawal et al. 2011). Effort to reduce CO_2 emissions caused by forest clearance and land degradation led to the development of global climate change mitigation solutions, including the Reducing Emissions from Deforestation and Forest Degradation program (REDD+; IPCC (2003)). The foundation of this solution is to financially compensate countries to maintain and manage forests sustainably, which in the process benefits people in poverty and sustains ecosystem services and biodiversity. The term blue carbon was coined to describe global initiatives led by United Nations, International Union for Conservation of Nature and other non-government organizations that have the objective of exploring the potential of blue carbon ecosystems to mitigate climate change. Development of REDD+-like mechanisms, payments for ecosystem services (Thomas 2014) or Nationally Appropriate Mitigation Actions (NAMAs, UNFCCC) for blue carbon ecosystems will facilitate the maintenance of the benefits they provide, including fisheries, coastal protection, and related ecosystem services that support coastal communities and their livelihoods (Barbier et al. 2011, Duarte et al. 2013b). These strategies must be underpinned by strong scientific evidence as well as community consensus (Thomas 2014).

Estimates of the risk of CO_2 emissions after disturbance of blue carbon ecosystems can inform the development of policy and management strategies for these resources (McLeod et al. 2011, Coverdale et al. 2013, Lovelock et al. 2013, Macreadie et al. 2013, Sidik and Lovelock 2013, Kauffman et al. 2014, Bu et al. 2015, Marbà et al. 2015, Serrano et al. 2016d); however, the implementation of blue carbon mitigation schemes is in its infancy (Duarte et al. 2013b). The lack of comprehensive estimates of ecosystem area, C_{org} stocks and accumulation rates at national and sub-national scales, as well as uncertainties in the loss of C_{org} storage after disturbances, hinder the application of blue carbon conservation schemes as a low-cost method to mitigate climate change.

Previous studies have also highlighted the need to accurately measure and understand C_{org} storage variability within ecosystems in order to support robust estimates of blue carbon storage at local, regional, national and global scales (Chmura et al. 2003, Donato et al. 2011, Lavery et al. 2013, Lovelock et al. 2013, Saintilan et al. 2013, Serrano et al. 2014, Kelleway et al. 2016c, Samper-Villarreal et al. 2016, Serrano et al. 2016b).

3 CSIRO Marine and Coastal Carbon Biogeochemistry Cluster

Over 2012-2016, the CSIRO Marine and Coastal Carbon Biogeochemistry Cluster (CSIRO Coastal Carbon Cluster - www.csiro.au/en/Research/OandA/Areas/Coastal-management/Coastal-Carbon-Cluster), comprised of a team of experts from eight Australian universities and research organisations, together with the CSIRO, has advanced our understanding of the stocks and fluxes of C_{org} within Australian blue carbon ecosystems. The CSIRO Coastal Carbon Cluster collated existing and new data on C_{org} stocks and accumulation rates within Australian blue carbon ecosystems, and has made significant progress towards establishing a new inventory of the sources and flows of C_{org}. CSIRO Coastal Carbon Cluster members have advanced our process-based understanding of the changes in C_{org} cycling resulting from natural and anthropogenic change and provided data to improved models of C_{org} fluxes in Australian blue carbon ecosystems. This data underpins the assessment of the sequestration potential for these ecosystems as well as its vulnerability, and will be used by the CSIRO to enhance their modelling capacity to predict national blue carbon budgets.

National and international studies and the research conducted within the CSIRO Coastal Carbon Cluster have established that disturbance and/or management actions applied to blue carbon ecosystems can cause changes in C_{org} stocks and accumulation rates, demonstrating the potential for developing ERF carbon abatement methods. A risk assessment tool for managers and policy makers has been developed (Lovelock et al. 2017(In press)), which presents a risk assessment framework that provides a process to assess the likelihood of CO_2 emissions resulting from disturbance of blue carbon ecosystems (Table 1). These advances in knowledge allow informed decision-making for planning, policy and management of our coastal assets.

In addition to data collected by the CSIRO Coastal Carbon Cluster, comprehensive sampling of mangroves, tidal marshes and seagrasses has recently taken place throughout Victoria (e.g. Carnell et al. 2015), while smaller-scale sampling elsewhere is likely to continue for other research projects. Nevertheless, it is important to recognise that there remain substantial geographic gaps in data availability for all three blue carbon ecosystems. This includes little to no data from vast areas of northern Australia and some sub-tropical and temperate coastlines (most notably, Tasmania where tidal marsh and seagrass occur). Targeted sampling of such locations may be required to fulfil the needs to Australia’s National Greenhouse Gas Inventory and to aid the development of blue carbon methods by the ERF.

Table 1. The relative risk of CO_2 emissions from blue carbon ecosystems based on the potential for CO_2 emission and the size of the soil carbon stock present. The risk varies from Low (blue, scores 1-4); Moderate (Mod, green, 5-9); Moderately high (Mod-High, yellow, 10-12); High (orange, 15-16); and Very high (red, 20-25). Final scores (from 1 - Low likelihood to 25 – Very high likelihood) were obtained by multiplying the scores related to likelihood of remineralisation and the magnitude of C_{org} stocks.

			Size of the soil carbon stock				
			Low C_{org} stock (< 50 tonnes ha^{-1})	Low-Moderate C_{org} stock (50 – 100 tonnes ha^{-1})	Moderate C_{org} stock (100 – 250 tonnes ha^{-1})	Moderate-high C_{org} stock (250 – 500 tonnes ha^{-1})	High C_{org} stock (> 500 tonnes ha^{-1})
		Relative scores	***1***	***2***	***3***	***4***	***5***
Potential for CO_2 emission	**Low**	***1***	**1 (Low)**	**2 (Low)**	**3 (Low)**	**4 (Low)**	**5 (Mod)**
	Moderate	***2***	**2 (Low)**	**4 (Low)**	**6 (Mod)**	**8 (Mod)**	**10 (Mod-High)**
	Moderate-High	***3***	**3 (Low)**	**6 (Mod)**	**9 (Mod)**	**12 (Mod-High)**	**15 (High)**
	High	***4***	**4 (Low)**	**8 (Mod)**	**12 (Mod-High)**	**16 (High)**	**20 (Very High)**
	Very High	***5***	**5 (Mod)**	**10 (Mod-High)**	**15 (High)**	**20 (Very High)**	**25 (Very High)**

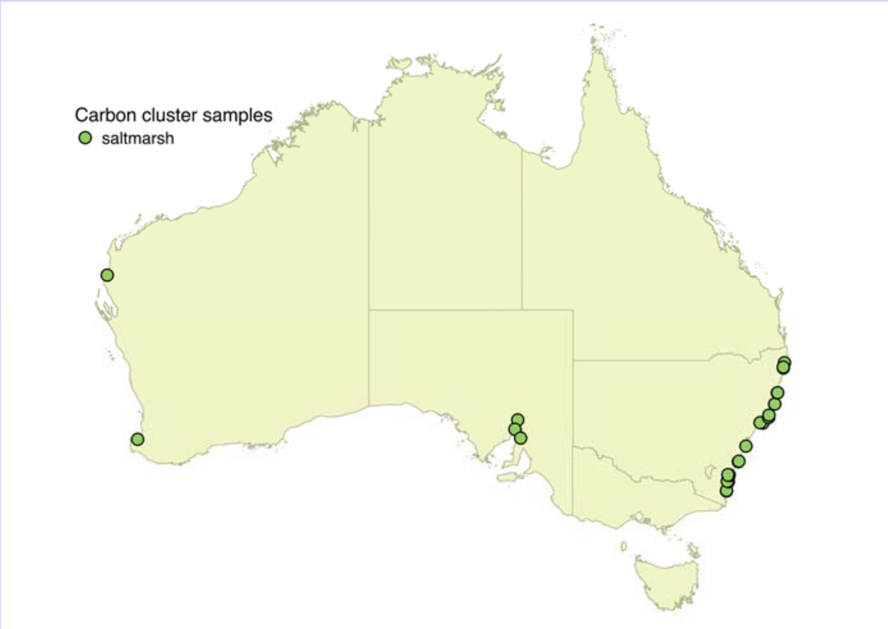
BOX 1: Coastal Carbon Cluster Outcomes

- A digital C_{org} inventory on the sources, stocks and flows of C_{org} in Australian blue carbon ecosystems
- A process-based understanding of changes in C_{org} cycling resulting from natural and anthropogenic change that can be used to underpin assessment of sequestration potential, ecosystem status and vulnerability.
- Improved methods to estimate blue carbon stocks at a regional level.

BOX 2: Tidal marshes

Research summary

- Over 50 soil cores were sampled and studied for C_{org} stocks and accumulation rates in South Australia, Western Australia, New South Wales and Victoria, funded by the CSIRO Coastal Carbon Cluster and other sources. Some assessments included vegetation types and geographic settings.
- Targeted studies were carried out to investigate C_{org} quality and sources in soil pools.
- The compilation of primary data is now being used as a basis to further CSIRO models, to improve our understanding of tidal marshes in the Australian carbon budget.



Key findings

- Estimates of C_{org} stocks and accumulation rates in tidal marshes in Australia.
- Understanding of spatial variability in C_{org} stocks and accumulation rates: there were no significant relationships between C_{org} storage and plant species, latitude or temperature. Geomorphology was found to be an important predictor of C_{org}, with fluvial sites having twice the amount of C_{org} as seaward sites.
- Understanding of drivers and rates of change around vegetation shifts (changes in spatial and temporal shifts in tidal marshes distribution and their associated C_{org} stocks).

BOX 3: Mangroves

Research summary

• Over 100 soil cores were sampled and studied for C_{org} stocks and accumulation rates in South Australia, Western Australia, New South Wales, Victoria and Queensland, funded by the CSIRO Coastal Carbon Cluster and other sources (e.g. Australian Research Council, Catchment Management Authorities, SA Water and SA EPA).

• C_{org} stocks and fluxes in South Australia and Western Australia were assessed, including regional assessments specifically in Queensland, New South Wales and Victoria.

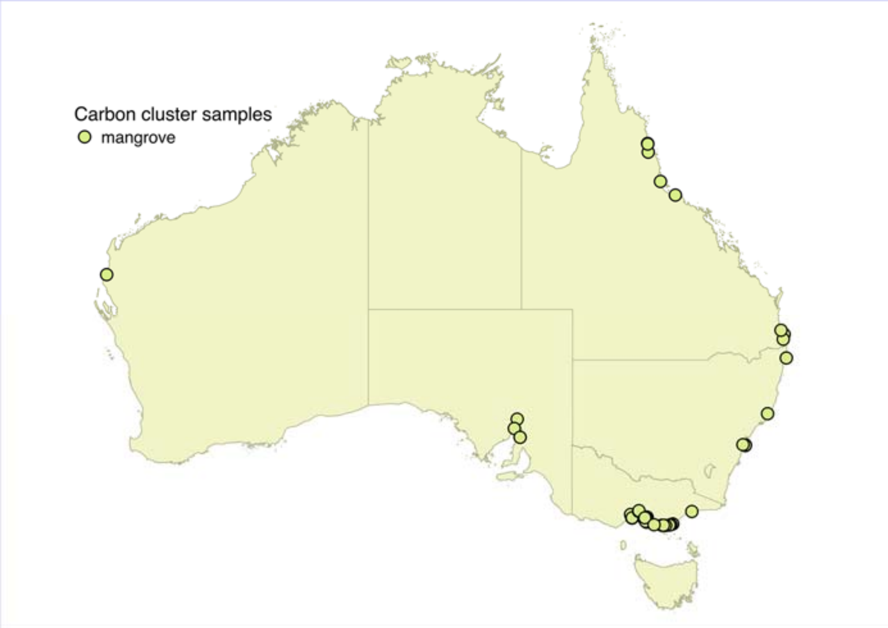
• C_{org} stock and flux data of mangroves in the Northern Territory were collated from the literature and through new CSIRO Coastal carbon cluster driven fieldwork assessments.

• Mapping of spatio-temporal variations in mangrove environments was carried out, including scaling to include C_{org} estimate maps.

• C_{org} stocks and accumulation rates were assessed in soil cores. Some assessments included vegetation types and geographic settings.

• Targeted studies were carried out to investigate C_{org} quality and source (and age) of C_{org} stocks.

• The compilation of primary data is now being used as a basis to further CSIRO models, to improve our understanding of mangroves in the Australian carbon budget.



Key findings

• Estimates of C_{org} stocks and accumulation rates in Australian mangrove ecosystems.

• Understanding of spatial variability in C_{org} stocks and accumulation rates. Variation may be driven by species composition, spatial and geomorphic settings.

• Knowledge of drivers and rates of change in mangrove distribution and their associated C_{org} stocks.

• Origin of C_{org} contributing to soil C_{org} stocks (allochthonous versus autochthonous).

• Quantification of mangrove C_{org} stocks, which are large but variable due to differences in species composition, spatial/geomorphic settings and biological factors (i.e. top-down predator control).

• A growing knowledge of drivers of mangrove expansion within the intertidal zone, and variation in C_{org} storage associated with vegetation change.

• GHG emissions from disturbed ecosystems can be very large.

BOX 4: Seagrasses

Research summary

• Over 300 seagrass soil cores were studied around Australia (except for the NT) to determine their C_{org} stocks, accumulation rates and how these vary among different sites, and in response to physical and chemical disturbances (funded by the CSIRO Coastal Carbon Cluster and other sources).

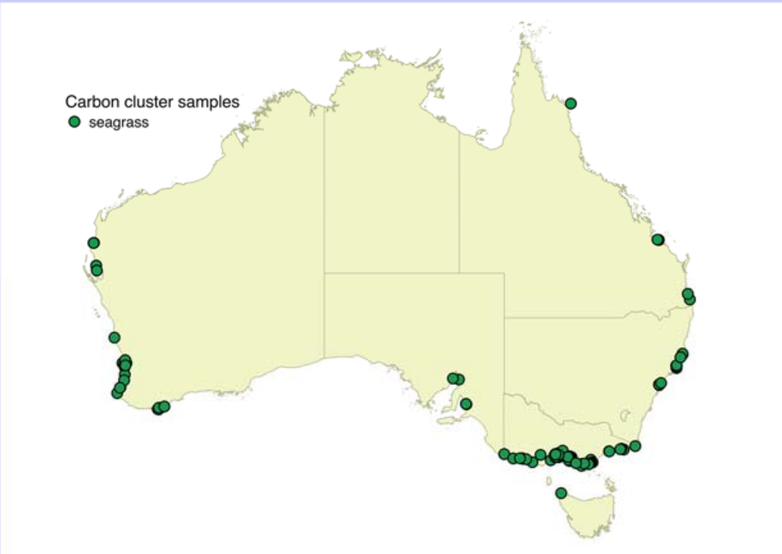
• Finer-scale regional assessments were carried out in Queensland, New South Wales and Victoria.

• Areas such as Moreton Bay (Queensland) and world-heritage listed Shark Bay (Western Australia) have been intensively studied.

• Targeted studies have characterised the types of C_{org}, together with biogeochemical factors driving C_{org} stocks and accumulation, and examined environmental proxies for C_{org} content.

• In some cases, seagrass C_{org} sequestration processes (i.e. microbial degradation, bioturbation and decomposition) were defined and quantified.

• The compilation of primary data is being used to further CSIRO models, to improve our understanding of seagrass in the Australian carbon budget.



Key findings

• Estimates of C_{org} stocks and accumulation rates in Australian seagrasses.

• Australia has some of the largest seagrass C_{org} stocks relative to other countries (e.g. Shark Bay alone contains 1–2% of the total global seagrass C_{org} stocks).

• Seagrass C_{org} stocks and accumulation rates are highly variable, due to the species of seagrass and habitat characteristics (e.g. depositional environment, water depth).

• Disturbance (e.g. eutrophication, moorings) affect C_{org} stocks and accumulations rates.

• Some seagrass restoration programs have demonstrated the return of C_{org} stocks and accumulation rates.

•Biological drivers of C_{org} stock change were evaluated, including top-down predator control, bioturbation, bacterial diversity, seagrass tissue type and degradation.

• Quantification of the contribution of seagrass biomass (i.e. detritus, roots) to the soil C_{org} pool in seagrass ecosystems.

• Mapping (spatial extent) of seagrass ecosystems needs to be improved.

3.1 Spatial extent and organic carbon stocks in Australian blue carbon ecosystems.

Australia has 1.5 Mha of tidal marshes, 1.1 Mha of mangroves and 12.6 Mha of seagrass meadows (Mount 2008, Giri et al. 2011, Lavery et al. 2013, Coles et al. 2014, Geoscience Australia 2015) and references therein). The estimated C_{org} storage in Australian blue carbon ecosystems (i.e. mangroves, tidal marshes and seagrasses) in both living biomass and 1 m-thick soil deposits was 1,700 Tg C_{org} (200 Tg C_{org} and 1,500 Tg C_{org}, respectively; Table 2). Annual soil C_{org} accumulation rates for Australian blue carbon ecosystems were estimated at 5.5 Tg C_{org} yr^{-1} (Table 2).

Australian seagrasses contribute most to total Australian blue carbon C_{org} stocks in soil and living biomass (1,000 and 22 Tg C_{org}, respectively), compared to tidal marshes (230 and 17 Tg C_{org}) and mangroves (260 and 160 Tg C_{org}; Table 2). The majority of C_{org} stocks in seagrasses and tidal marshes are found in soils (98% and 93%, respectively), while C_{org} stocks in mangroves were distributed in both soil (62%) and living biomass (38%) pools. Seagrasses accumulate 2- to 6-fold higher C_{org} on an annual basis (3.5 Tg C_{org} yr^{-1}) compared to tidal marshes and mangroves (0.5 Mg C_{org} yr^{-1} and 1.4 Tg C_{org} yr^{-1}, respectively; Table 2) because of their approximately 10-fold greater area.

In Australia, on a per unit area basis, mangroves have the highest C_{org} stocks in soil and living biomass (251 and 125 Mg C_{org} ha^{-1}, respectively) and soil C_{org} accumulation rates (1.3 Mg C_{org} ha^{-1} yr^{-1}) compared to tidal marshes (168 and 19.6 Mg C_{org} ha^{-1} and 0.4 Mg C_{org} ha^{-1} yr^{-1}) and seagrasses (112 and 1.9 Mg C_{org} ha^{-1} and 0.36 Mg C_{org} ha^{-1} yr^{-1}; Table 3). It should be noted that soil C_{org} stocks and soils C_{org} accumulation rates may vary considerably within each ecosystem type – for example, Saintilan et al. (2013) reported a C_{org} accumulation rate of 2.07 Mg C_{org} ha^{-1} y^{-1} for SE Australian tidal marshes vegetated by the rush *Juncus kraussii*, far in excess of the accumulation rates of tidal marshes vegetated by grass and succulent species (0.46 Mg C_{org} ha^{-1} yr^{-1}).

The vast majority of tidal marsh and mangrove ecosystems in Australia are found in tropical regions (62% and 73%, respectively; Table 4). The tropical tidal marsh classification includes extensive high intertidal salt flats that can be covered with cyanobacterial mats and sparse woody chenopods. These are currently under-represented in the Cluster data set. Mangroves in the tropics are highly diverse and can reach heights of up to 30 m. Seagrasses cover a larger area in subtropical and tropical regions (39% and 33%, respectively). The soil C_{org} storage capacity (stocks and accumulation rates) of tropical tidal marshes and mangroves are 3- to 18-fold and 3- to 132-fold higher than in other bioregions, respectively (Table 4). Seagrass meadows from subtropical regions hold 2 to 7-fold higher C_{org} stores than seagrasses from other regions. The majority of blue carbon ecosystems C_{org} stocks (in soil and living biomass) and annual accumulation of C_{org} are found in Queensland, Northern Territory and Western Australia (Table 5).

Australia holds around 12% of worldwide blue carbon ecosystems (8% of tidal marshes, 7-8% of mangroves and 21-71% of seagrasses). The C_{org} storage within Australian blue carbon constitutes around 7-12% of worldwide blue carbon storage (Duarte et al. 2013b), placing Australia among the nations with the largest potential to benefit from developing blue carbon-focussed climate change mitigation schemes, along with other nations including Indonesia and Brazil.

Destruction and degradation of natural ecosystems is responsible for approximately 12-20% of the CO_2 released to the atmosphere (Le Quéré 2009, Houghton et al. 2012). Increasing coastal development (i.e. population growth, oil, gas, coal and iron ore exports and associated infrastructure) and global change in Australia is causing a net decline in the area of blue carbon ecosystems, estimated at 1-3% yr^{-1} (Valiela et al. 2001, Waycott et al. 2009, Short et al. 2011, Hamilton and Casey 2016). Loss of blue carbon ecosystems can result in erosion of soils and, potentially, the remineralisation of the soil C_{org} accumulated over millennia and possible releases of other GHGs, which hamper efforts to mitigate atmospheric accumulation of GHGs (McLeod et al. 2011, Pendleton et al. 2012, Marbà et al. 2015).

Blue carbon strategies build on the opportunity to avoid or mitigate GHG emissions through the conservation and restoration of blue carbon ecosystems (Nellemann et al. 2009, McLeod et al. 2011). We estimate that present rates of blue carbon ecosystems loss in Australia (around 2% yr^{-1}) could result in 4 to 14 Tg C_{org} yr^{-1} potentially at risk of being remineralised and released as CO_2 (Table 6). This estimate assumes that 25-75% C_{org} stocks in living biomass and 1 m soil deposits are remineralised after disturbance (Coverdale et al. 2013, Lovelock et al. 2013, Macreadie et al. 2013, Kauffman et al. 2014). However, the loss rates of Australian blue carbon ecosystems and the loss and fate of C_{org} stores after disturbance remains poorly understood, and therefore the estimates presented in Table 6 are subject to large uncertainties.

Growing human populations and activities across many of the world's coastlines are associated with increasing impacts on coastal ecosystems (Lotze et al. 2006), and thus enhanced levels of protection and restoration of Australian blue carbon ecosystems could constitute a mechanism to offset Australian GHG emissions while enhancing biodiversity and ecosystem services. Inclusion of the creation, restoration and conservation of Australian blue carbon ecosystems within Australia's Emission Reduction Fund scheme could potentially reduce Australian CO_2 emissions by 3% per annum.

Table 2. Total area of blue carbon ecosystems (ha) in Australia and their estimated total C_{org} stock in living biomass, soil C_{org} stock and soil C_{org} accumulation rates for seagrasses, tidal marshes and mangroves (1 Mha equals to 1,000,000 ha) (1 Tg equals 1,000,000 Mg).

Ecosystem	Area (Mha)	Accumulation rates (Tg C_{org} y^{-1})	Stock – Soil (Tg C_{org})	Stock – Biomass (Tg C_{org})	Total stock (Soil+Biomass) (Tg C_{org})
Seagrass	12.6	3.5	1000	22	1057
Tidal marsh	1.5	0.5	230	17	251
Mangrove	1.1	1.4	260	160	415
TOTAL	15.1	5.5	1500	200	1700

Table 3. Estimates of mean C_{org} stock in living biomass, soil C_{org} stock and soil C_{org} accumulation rates per unit area (ha) for the Australian seagrasses, tidal marshes and mangroves.

Ecosystem	Accumulation rates (Mg C_{org} ha^{-1} y^{-1})	Stock – Soil (0-1 m) (Mg C_{org} ha^{-1})	Stock – Biomass (Mg C_{org} ha^{-1})	Total stock – (Soil+Biomass) (Mg C_{org} ha^{-1})
Seagrass	0.36	112	1.9	114
Tidal marsh	0.39	168	19.6	188
Mangrove	1.26	251	125.0	376
TOTAL	2.01	531	147.0	678

Table 4. Total area occupied by blue carbon ecosystems (Mha) within bioregion in Australia. Estimates of total C_{org} stock in living biomass, soil C_{org} stock and soil C_{org} accumulation rates for the three ecosystems within Bioregions in Australia. (1 Mha equals to 1,000,000 ha) (1 Tg equals 1,000,000 Mg)

Ecosystem	Variable	Arid	Semi-arid	Subtropical	Tropical	Temperate
Seagrass	Area (Mha)	2.11	0.89	4.87	4.14	0.56
	Accumulation rates (Tg C_{org} yr-1)	0.80	0.10	1.25	1.06	0.28
	Stock - Soil (Tg C_{org})	272.60	107.80	438.50	153.50	62.97
	Stock - Living biomass (Tg C_{org})	5.36	2.26	12.38	1.88	0.15
	Total stock (Soil + Biomass, Tg C_{org})	277.96	110.06	450.88	155.38	63.12
Tidal marsh	Area (Mha)	0.05	0.33	0.12	0.95	0.09
	Accumulation rates (Tg C_{org} yr-1)	0.03	0.10	0.04	0.33	0.04
	Stock - Soil (Tg C_{org})	11.34	44.41	18.12	144.56	15.54
	Stock - Living biomass (Tg C_{org})	0.51	3.26	1.18	9.41	2.23
	Total stock (Soil + Biomass, Tg C_{org})	11.85	47.67	19.30	153.97	17.77
Mangrove	Area (Mha)	0.02	0.10	0.15	0.76	0.01
	Accumulation rates (Tg C_{org} yr-1)	0.02	0.08	0.13	1.17	0.02
	Stock - Soil (Tg C_{org})	3.31	15.13	55.27	179.83	3.39
	Stock - Living biomass (Tg C_{org})	2.84	11.13	15.26	127.63	0.97
	Total stock (Soil + Biomass, Tg C_{org})	6.14	26.26	70.53	307.47	4.35

Table 5. Total area occupied by blue carbon ecosystems (ha) within States in Australia. Estimates of total C_{org} stock in living biomass, soil C_{org} stock and soil C_{org} accumulation rates for the three ecosystems within States in Australia. Estimates marked with * were based on data from nearby States. The seagrass are of NT and QLD was apportioned 50/50 (1 Mha equals to 1,000,000 ha) (1 Tg equals 1,000,000 Mg).

Ecosystem	Variable	State						
		NT	QLD	NSW	VIC	TAS	SA	WA
Seagrass	Area (Mha)	4.5	4.5	0.02	0.05	0.08	0.96	2.5
	Accumulation rates (Tg C_{org} y^{-1})	1.1*	1.1*	0.01*	0.02*	0.04*	0.19*	0.94*
	Stock - Soil (Tg C_{org})	294*	294*	1.7*	5.3*	9.6*	119*	311*
	Stock - Living biomass (Tg C_{org})	7.0*	7.0*	0.01*	0.01*	0.02*	2.4*	5.4*
	Total stock (Soil + Biomass, Tg C_{org})	301*	301*	1.7*	5.3*	9.6*	121*	317*
Tidal marsh	Area (Mha)	0.43	0.60	0.02	0.05	0.01	0.05	0.38
	Accumulation rates (Tg C_{org} y^{-1})	0.15	0.21	0.00	0.02	0.01	0.02	0.13
	Stock - Soil (Tg C_{org})	65.0	90.2	2.6	8.6	2.2	7.8	58
	Stock - Living biomass (Tg C_{org})	4.3	6.0	0.31	1.2	0.31	0.70	3.8
	Total stock (Soil + Biomass, Tg C_{org})	69	96	2.9	9.8	2.5	8.5	61
Mangrove	Area (Mha)	0.38	0.41	0.01	0.01	n/a	0.03	0.21
	Accumulation rates (Tg C_{org} y^{-1})	0.6	0.51	0.01	0.01	n/a	0.02	0.28
	Stock - Soil (Tg C_{org})	89	114	3.7	1.4	n/a	4.4	44
	Stock - Living biomass (Tg C_{org})	63	58	1.0	0.4	n/a	3.3	32
	Total stock (Soil + Biomass, Tg C_{org})	153	171	4.8	1.8	n/a	7.7	76

Table 6. Estimates of C_{org} stocks at risk of remineralisation according to blue carbon ecosystem loss rates in Australia (1 Tg equals 1,000,000 Mg).

Ecosystem	Total stock (Soil+Biomass) (Tg C_{org})	Habitat loss (ha y^{-1})	C_{org} at risk of remineralisation (Tg y^{-1})
Seagrass	1057	251000	5-16
Tidal marsh	251	30700	1-4
Mangrove	415	21000	2-6
TOTAL	1722	302700	4-14

Sustainable management of Australia's marine environment is a high priority for the Australian Government and requires an informed understanding of the ecological and economic significance of natural resources. The Australian government has led efforts to establish an International Blue Carbon partnership after the UNFCCC's Conferences of the Parties in Paris 2016, and this project provides key data and approaches for the implementation of blue carbon-based climate change mitigation policies to enhance protection and restore blue carbon ecosystems. Our comprehensive estimates of blue carbon stocks and accumulation rates across Australia's climatic bioregions can be used to obtain preliminary estimates (i.e. IPCC Tier 1 or 2) of blue carbon stocks and sequestration in other countries (IPCC 2007). The destruction of blue carbon ecosystems may also increase GHG emissions (i.e. methane and nitrous oxide) and the reduction of coastal protection, biodiversity and fisheries. The economic and ecological significance of blue carbon ecosystems (www. bluecarbonpartnership.org) therefore greatly exceeds their CO_2 storage capacity alone, with further studies required to comprehensively estimate their real ecologic and socio-economic value.

3.2 Cluster conclusions

The estimates of blue carbon stocks and accumulation rates around Australia derived from the CSIRO Coastal Coastal Carbon Cluster are amongst the most comprehensive in the world, along with a detailed understanding of the processes responsible for sequestering C_{org}. The CSIRO Coastal Carbon Cluster has collated and analysed new and existing Australian coastal carbon data to deliver a process-based understanding of changes in C_{org} cycling resulting from natural and anthropogenic change that can now be used to underpin assessments of the sequestration potential of our blue carbon ecosystems. An accessible database was created to store this new Australian carbon inventory that consists of sources, species, stocks and flows of C_{org} in Australian coastal environments. In a low carbon economy, it is important to be confident in our ability to estimate carbon sources, sinks and their rates of change. CSIRO is a leader in coastal carbon biogeochemical modelling and applies coupled hydrodynamic, biogeochemical and ecological models in both ocean and coastal regions. Coastal Carbon Cluster outcomes will enhance these CSIRO models to address issues of national importance such as ocean acidification, C_{org} sequestration potential of our coastal assets and primary productivity and deliver better predictions for national coastal carbon budgets.

4 Uncertainties in blue carbon science

The publication of the 'Blue Carbon' report (Nellemann et al. 2009) highlighted the potential of coastal marine ecosystems to sequester CO_2-C. By necessity, there has been a tendency to generalise the C_{org} capture attributes of blue carbon ecosystems due to limitations on the amount of data available. Nellemann et al. (2009) recognized that their assumptions were likely to have produced an upper estimate of the blue carbon sink, in part because of uncertainties in the C_{org} storage of different blue carbon ecosystems. Blue carbon science has now identified uncertainties in the assumptions linked to the C_{org} sequestration and GHG mitigation potentials in natural and disturbed blue carbon ecosystems.

Below we provide a list of uncertainties and limitations in assessing the C_{org} sequestration capacity of Australian blue carbon ecosystems:

a. The magnitude of intra- and inter-ecosystem variability in blue carbon storage makes it difficult to develop robust estimates at local, regional and national scales. Australia has made great progress compared to other countries in estimating blue carbon stocks and accumulation rates, although there are regional gaps in datasets that have necessitated the incorporation of assumptions when developing national inventories.

b. Mapping of Australian blue carbon ecosystems is reasonable for tidal marshes (in some States) and mangroves, but mapping of seagrasses is poor. Remote sensing has been successfully used to determine the extent of Australian tidal marshes and mangroves (and changes in spatial extent at local and regional scales despite limitations to identify vegetation types with imagery). However, the subtidal distribution and ephemeral dynamics of some seagrasses make mapping difficult because water depth and transparency interferes with light penetration leading to sub-optimal imagery. Knowing the spatial extent of blue carbon ecosystems is key to determine the capacity of blue carbon ecosystems to mitigate GHG emissions. For example, a recent discovery of 35,000 km^2 of seagrass habitat in deep areas of the Great Barrier Reef (Coles et al. 2014) increased our estimates of seagrass C_{org} inventories by 25%.

c. The methods used to estimate blue carbon storage differ between studies, making it difficult to compare results and leading to larger assumptions when estimating C_{org} fluxes at regional or national scales. Methodological variability is largely due to the protocols used in the field (e.g. sampling to different soil depths, C_{org} accumulation estimated over different periods of time and accounting for core compression/shortening during coring) and in the laboratory (e.g. removal of coarse plant matter from the soil and variable acid-treatment methods to remove inorganic carbon before C_{org} analyses). The development of standard methods or calibration formulas to standardize data on blue carbon storage is required to constrain uncertainties linked.

d. The biogeochemical processes (e.g. carbon cycling, fluxes of GHG and loss and fate of C_{org}) occurring in natural and disturbed blue carbon ecosystems require further research to confidently predict their impact on C_{org} stocks and GHG emissions. Despite peer-reviewed literature demonstrating enhanced C_{org} sequestration or avoided GHG emissions linked to anthropogenic activities in blue carbon ecosystems, further studies are required to constrain present estimates and increase certainty. In particular, the fate (i.e. remineralisation or preservation) of C_{org} stocks after disturbance remains unclear.

e. The precipitation of forms of carbonate (e.g. calcium carbonate) in blue carbon ecosystems adds complexity to the determination of carbon fluxes. Calcification entails a net emission of CO_2, however, it is unknown whether the CO_2 released increases alkalinity (i.e. adding to the role of blue carbon ecosystems as CO_2 sinks) and/or returns to the atmosphere (i.e. increasing CO_2 emissions). The role of carbonate precipitation in blue carbon ecosystems as CO_2 sink or source needs to be determined, since biogeochemical carbon cycles are constrained by multiple factors that can play a key role in the accumulation and preservation of C_{org}.

f. The presence of allochthonous C_{org} in blue carbon ecosystems complicates accounting exercises, since there is a risk of duplicating C_{org} sequestration gains or avoided emissions already accounted for in adjacent terrestrial ecosystems. Previous studies determined that around 50% of the C_{org} sequestered in seagrass ecosystems originated in adjacent oceanic and terrestrial ecosystems (Kennedy et al. 2010). Despite this, it is possible to determine the proportion of allochthonous and autochthonous C_{org} in blue carbon stores in seagrass ecosystems (Kennedy et al. 2010). The main methods used to date (stable carbon and nitrogen isotopic signatures of the soil C_{org}) are less powerful for tidal marshes and mangroves because their isotopic signatures often overlap with each other and from neighbouring terrestrial sources of allochthonous C_{org}. Molecular genetic techniques have been found to provide a better understanding of the origin of C_{org} in blue carbon ecosystems (e.g. Environmental DNA), but further studies are required and it is known that inter- and intra-ecosystem variability can be large, adding difficulty in the accounting of allochthonous and autochthonous C_{org} storage.

g. In terrestrial ecosystems, the owners of the land have the right to claim benefits from enhancing C_{org} sequestration and/or avoiding GHG emissions in their lands under the ERF scheme. However, the location of many blue carbon ecosystems in the interface between terrestrial and marine ecosystems may make the determination of C_{org} ownership difficult, in particular in subtidal seagrass ecosystems that belong to the Government (i.e. Crown Land). Therefore, there is a need to determine who owns any anthropogenically-induced accumulation of C_{org} or avoided GHG emissions in blue carbon ecosystems.

h. The location of blue carbon ecosystems in the coastal fringe makes them susceptible to off-site activities (e.g. changes in the catchment area). The connectivity between terrestrial and coastal ecosystems can result in C_{org} gains and/or avoided GHG emissions in blue carbon ecosystems linked to conservation activities undertaken inland, thereby adding complexity to the determination of C_{org} owners. Processes linked to the connectivity between terrestrial and blue carbon ecosystems are complex, adding difficulties for ERF policy compared to existing policies for terrestrial carbon.

i. Climate change has the potential to impact the functioning and health of blue carbon ecosystems and impact on their C_{org} sequestration capacity. For example, Seddon et al. (2000) reported a major dieback of seagrass in South Australia (12,000 ha) associated with a hot *El Niño* summer, whereas intensification of millennial-scale ENSO cycling have been associated with greater blue carbon gains (Macreadie et al. 2015). Severe blue carbon ecosystem losses linked to climate change have been reported for Australia (such as the recent dieback of mangroves at Carpentaria Gulf). Overall, the effects of sporadic or continuous climatic events related to global change (e.g. increase in the occurrence and magnitude of extreme events such as cyclone, lack of rainfall and high temperatures, and sea level rise) are difficult to attribute directly to human activities and/or to be managed, and therefore they have been excluded from this assessment. The peer-reviewed literature assessing impacts of climate change on blue carbon sequestration capacity is steadily growing (e.g. (Campbell and Fourqurean 2013, Garrard and Beaumont 2014, Thomson et al. 2015).

5 Methodology and structure of report

The remainder of this report is divided into three sections:

- Section A – Factors influencing emissions avoidance and sequestration in Australian blue carbon ecosystems.
- Section B – ERF suitability assessment of blue carbon ecosystem enhancement activities.
- Section C – Recommendations for incorporating priority blue carbon activities into the ERF.

Mangroves and tidal marshes are combined in sections A and B, while in Section C seagrasses, mangroves and tidal marshes are addressed separately.

SECTION A – Factors influencing emissions avoidance and sequestration in Australian blue carbon ecosystems.

For each blue carbon ecosystem, Section A identifies the influencing factors that impact upon the accumulation, preservation or removal of CO_2-C and emission of CO_2-e in mangroves, tidal marshes and seagrasses. The list of influencing factors is the same for mangroves and tidal marshes because of the broader similarities between these ecosystems. Seagrasses have been considered separately due to their subtidal to lower intertidal setting and the unique anthropogenic pressures to which they are subject.

These influencing factors are central to existing and ongoing sources of ecosystem degradation and rehabilitation including anthropogenically induced degradation, removal or land-use changes, and existing management practices.

Key information sources consulted in the listing and review of influencing factors included:

- published and unpublished work that have been produced by the CSIRO Coastal Carbon Cluster;
- published international literature and reports that have addressed blue carbon stocks and accumulation rates, and blue carbon ecosystem loss, and those that have addressed the impacts of conversion, rehabilitation and restoration on blue carbon storage;
- reports that have assessed loss or restoration of blue carbon ecosystems, largely for fisheries benefits or agriculture, but where C_{org} sequestration is also likely to be affected e.g. (Creighton et al. 2015, Wegscheidl et al. 2015);
- outcomes of a participatory workshop and teleconference undertaken in Canberra on July 28, 2016.

For each influencing factor identified, the tables below provide detailed and substantiating evidence, where available, for the following:

a) Identify the influencing factor and associated cause.
b) How does the influencing factor affect either the C_{org} sequestered or the GHG released by blue carbon ecosystems?
c) Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.
d) In what Australian location/s and jurisdiction/s does the influencing factor occur?

e) Is the influencing factor historic, current or anticipated?
f) Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?
g) Where data exists, what is the recognised extent of the affected areas, and where do these occur?

SECTION B – ERF suitability assessment of blue carbon ecosystem enhancement activities.

For each blue carbon ecosystem, Section B contains a list of potential blue carbon enhancement activities which were determined through the analyses of influencing factors conducted in Section A and outcomes of the participatory workshop. For each of these potential activities a comprehensive suitability assessment was undertaken following guidelines provided by The Department of Environment and Energy (Attachment B). All potential activities were subjected to an initial assessment (Questions 1-3 in Section B) and Abatement Integrity Assessment (Question 4 in Section B). Activities that received a score ≥8 in the Abatement Integrity Assessment were also subjected to a more detailed assessment (Questions 5-11 in Section B). This task was completed for protection of mangroves, tidal marshes and seagrasses, and alternatively for the establishment or restoration of each of these ecosystems (Figure 5).

The Section B suitability assessments were informed by expert knowledge within the project team, expert knowledge gained in the participatory workshop, Australian and international scientific literature and case studies. The volume of abatement activities was estimated on the basis of best available information and expert assessment of the current area of ecosystem available for the various forms of abatement, including restoration, and protection for disturbing activities with the potential to enhance GHG emissions.

All non-CO_2 emissions have been converted to CO_2-e, following updated values recommended by the IPCC Fifth Assessment Report (Myhre et al. 2013). That is, methane emissions are multiplied by a global warming potential of 28 over 100 years, and nitrous oxide emissions multiplied by a global warming potential of 265 over 100 years.

Additionality was assessed by comparing 'do nothing', 'worse-case' and 'best-case' scenarios. Key information gaps in relation to the abatement integrity assessment were also identified as part of the assessment. The activity assessment also provided details, where appropriate, of how existing ERF methodologies may be modified for blue carbon ecosystems and where modifications of existing methodologies, such as those that are available within other frameworks (e.g. Clean Development Mechanism, Verified Carbon Standard) could be considered.

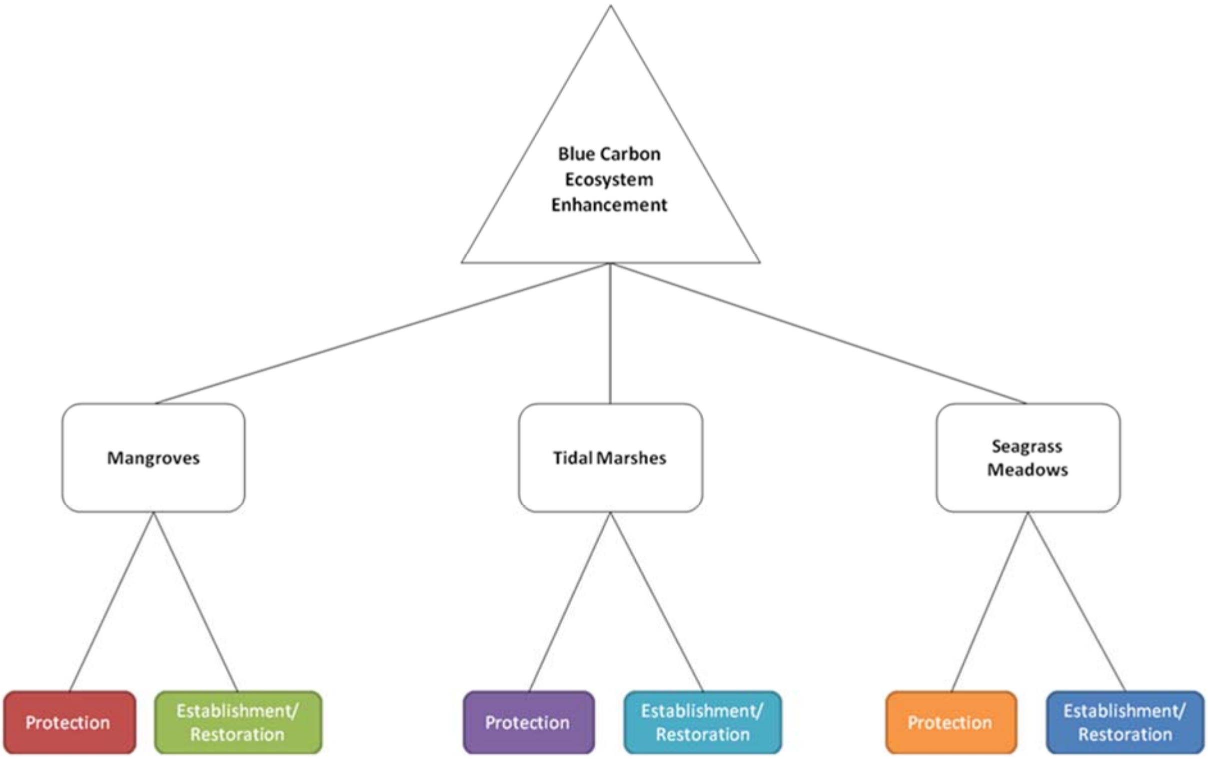


Figure 5: Outline of activity categories considered in the ERF Suitability and Activity Assessment

SECTION C – Recommendations for incorporating priority blue carbon activities into the ERF.

For each blue carbon ecosystem, Section C reviews the information gathered in Sections A and B and provides recommendations as to the appropriate steps toward the inclusion of blue carbon enhancement activities in an ERF methodology determination. Section C also highlights likely barriers and/or constraints for abatement activities with recommendations on ways to overcome these barriers and make allowance for the constraints.

6 MANGROVES AND TIDAL MARSHES

SECTION A: FACTORS INFLUENCING EMISSIONS AVOIDANCE AND SEQUESTRATION IN AUSTRALIAN MANGROVES AND TIDAL MARSHES.

6.1 Introduction to Influencing Factors relevant to mangroves and tidal marshes

In this section mangroves and tidal marshes are grouped together due to the broad similarities these two ecosystems share in terms of their position in the coastal landscape (situated within the intertidal zone of estuaries and low energy coasts) and the similarity of anthropogenic pressures that they both face.

There are a broad range of natural and anthropogenic factors that can influence the cycling, sequestration and emission of carbon in mangroves and tidal marshes. In this section we identify the influencing factors that are of most importance to carbon sequestration and CO_2-e emissions in mangroves and tidal marshes and the most amenable to human intervention or management actions. That is, we identify existing and ongoing sources of ecosystem degradation including human induced degradation, removal or land use changes, as well as existing management and rehabilitation practices which have influence upon carbon sequestration and CO_2-e emissions. Importantly, we consider not only existing areas which support mangroves and tidal marshes, but areas which may have historically supported these ecosystems, and which may once again support mangroves or tidal marshes through effective restoration activities.

Thematically, we have separated the list of influencing factors into physical, biological and chemical categories (Figure 6), but it should be noted that there may be a high degree of linkage among influencing factors from these three categories. For example, a change to the hydrology of a site (physical factor) by reintroducing tidal flow may also influence the vegetation composition and primary productivity of a site (biological factors) whilst also altering the salinity or nutrient status (chemical factors). For this reason, there may be some overlap in the information reported across the different influencing factors below.

6.2 National and state legislation relevant to mangroves and tidal marshes

There are numerous national and state legislation and policies pertaining to the protection of mangroves and tidal marshes and the influencing factors operating on these ecosystems. This legislation has been recently reviewed and summarised by Rogers et al. (2016). Legislation and policies relevant to influencing factors have been summarised in the tables below.

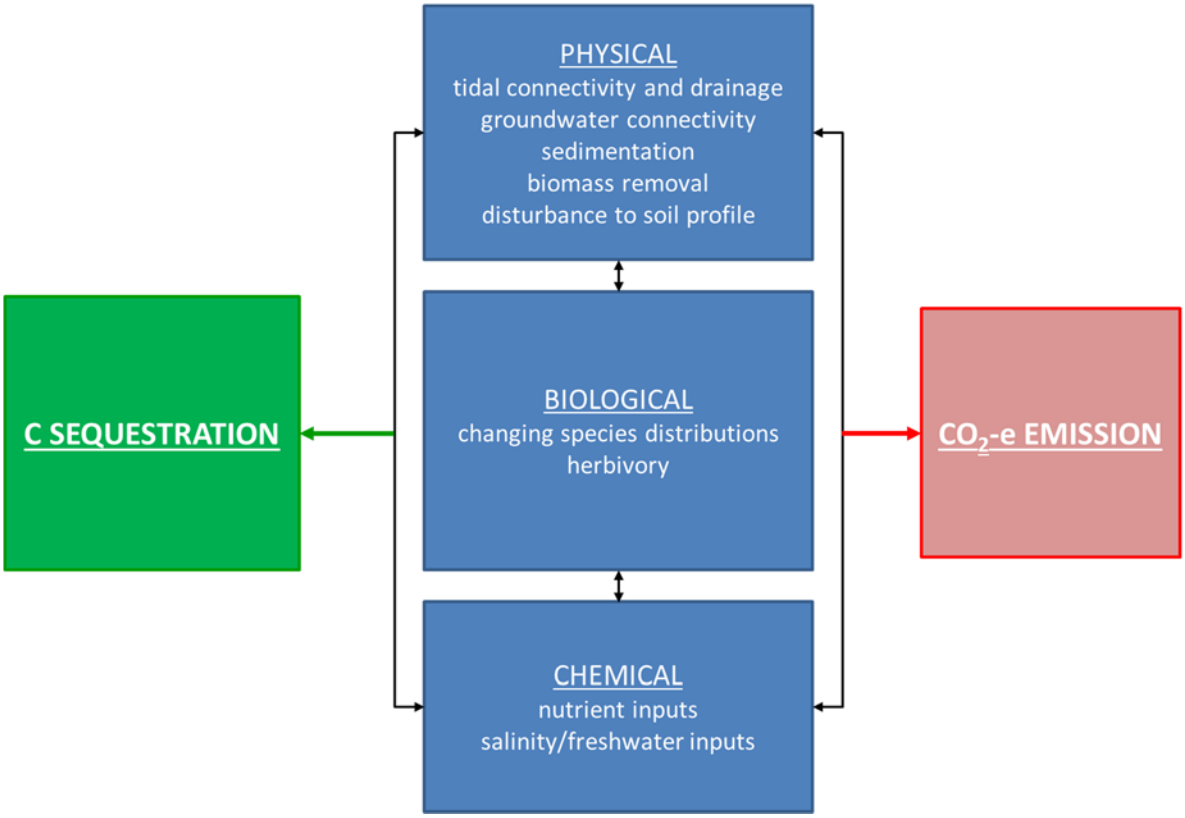


Figure 6: List of important physical, biological and chemical influencing factors for C_{org} sequestration and GHG emissions in mangroves and tidal marshes which are amenable to human intervention.

6.3 Influencing factors for mangroves and tidal marshes

6.3.1 Tidal connectivity and drainage.

Table 7. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: tidal connectivity and drainage

Question	Response	References
Identify the influencing factor and associated cause	Tidal connectivity and drainage. Loss of tidal connection and change to drainage patterns of a wetland can result from installation or changes to water management structures such as the creation of artificial levees and floodgates.	Turner and Lewis III (1996) Bashan et al. (2013) Howe et al. (2009)
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Where tidal connection has been lost to a site, the following may occur: - Loss or change in vegetation composition and/or structure due to alterations in water depth, salinity, hydroperiod and surface elevation (i.e. subsidence and sedimentation). - Exclusion of sulphates contained within marine tidal water may increase methane production. - Exclusion of tidally transported carbon sources - Reduced sediment supply may result in subsidence of substrate such that vegetation 'drowns' - Oxidation of soils in drained wetlands, causing remineralisation of previously stored carbon Where structures limit the drainage of ponded water out of a site, the following may occur: - Ponding of water may increase remineralisation of C via methanogenic pathways - Downstream impacts upon plant communities including shifts in species distributions	Hicks et al. (1999) Macklin et al. (2014) Workshop participants
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Water Act 2007* – regulates water management and infrastructure. *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Water Act 2000* and *Sustainable Planning Act 2009* – regulate water management and infrastructure. *Ponded Pastures Policy 2001* – replaced a previous moratorium on ponded pastures. Indicated that ponded pastures should only be located in areas that are not: - tidal areas below Highest Astronomical Tide (HAT); or - in or adjacent to natural wetlands; or	www.austlii.edu.au Rogers et al. (2016) Challen and Long (2004) Workshop participants

Question	Response	References
	- of high conservation or fish habitat values. The Policy deemed that existing banks that impound freshwater or prevent seawater incursion should remain. *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Coastal Management Plan* – Impacts of climate variability, including sea level rise are considered in managing the coast. The regulation of water infrastructure is also influenced by the *Sustainable Planning Act 2009* and *Water Act 2000.* NSW *Water Management Act 2000* – regulates water management and infrastructure. *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* – local Councils are encouraged to give local sea level rise projections due and proper consideration. Strategic planning to accommodate the effects of sea level rise on landward migration of wetlands and recognition of wetland migration in development applications. VIC *Water Act 1989* – regulates water management and infrastructure. *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. TAS *Water Management Act 1999* – regulates water management and infrastructure. *Nature Conservation Act 2002* – designates the protection of ‘Saline Aquatic Herblands’ and ‘Wetlands Undifferentiated’, but excludes other specific vegetation units relevant to coastal tidal marshes *Coastal Policy Statement* – areas subject to significant risk from coastal processes and hazards, including sea level rise, will be identified and managed. Retreat pathways for natural ecosystems prioritised when planning new infrastructure. SA *Natural Resources Management Act 2004* – regulates water management and infrastructure.	

Question	Response	References
	Fisheries Management Act 2007 – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA NOTE – water legislation in WA is currently under review. *Rights in Water and Irrigation Act 1914* - provides for regulating the take and use of water from watercourses and wetlands in proclaimed rivers, surface water management areas, irrigation districts and groundwater areas *Water Agencies (Powers) Act 1984*, *Country Areas Water Supply Act 1947, Metropolitan Water Supply, Sewerage and Drainage Act 1909* and *Waterways Conservation Act 1976* - also relate to the management of water *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. NT *Water Act 1992* - regulates water management and infrastructure. *Pastoral Land Act* - provides for the monitoring, prevention of degradation, and rehabilitation of Crown lands under pastoral leases. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries - some introduced plant species growing within ponded pastures may be listed as noxious weeds in certain locations, requiring their removal and/or control. - likely to be influenced by coastal management acts and local planning schemes - Potential Ramsar convention implications	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	- Ponded pastures in monsoonal tropics (QLD, NT; WA). Ponded pastures in Queensland extend from the coastal areas of Central Queensland to the Dawson and Callide Valleys, the Mackenzie-Isaac Rivers, along the Fitzroy River, to Capella, Clermont, Jericho, and north of Aramac. Other locations include Charters Towers, around the Burdekin, Mt Garnet and the Gulf Country in north Queensland. - Extensive floodplain drainage or floodgates/levees along mid to north coast of NSW. Shoalhaven also floodgates as well as ponded pastures - Disconnection of former ecosystem areas from tidal flow and drainage also appears to be common throughout other parts of Australia with the following examples identified by members of the workshop: - Southern VIC including the Gippsland Lake region - Bayswater Estuary in southern WA - Rocky Point canelands protected by walls in South East QLD - canal estates including the Gold Coast (QLD), parts of NSW and WA - saltworks in and around Port river estuary, SA	Challen and Long (2004) Hyland (2002) Workshop participants

Question	Response	References
	- former saltworks in Western Port Bay and Port Phillip Bay, VIC - East Kimberley, WA.	
Is the influencing factor historic, current or anticipated?	Historic Mostly historic changes associated with the expansion of floodplain agriculture in eastern Australia (in the 19th and 20th centuries). Coastal saltworks in southern Australia date back to the early 19th century Current Potential shift in freshwater inflow, from either drainage, groundwater and/or surface runoff, coupled with high temperatures (air, SST) in 2015/2016 *are associated with* significant die-back in mangrove patches along 700 km of the Gulf of Carpentaria coastline in the NT. Anticipated These historic changes have current and anticipated future impacts on carbon stocks and emissions as previously stored carbon in the drained floodplains remineralises.	Creighton (2014) Hough (2008) Workshop participants
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Disconnection from tidal flow is likely to lead to a permanent change in the character and carbon storage/emission dynamics of a site. Where restoration is undertaken, this may be reversed, thereby making the influence temporary.	
Where data exists, what is the recognised extent of the affected areas (ha), and where do these occur? (This could be demonstrated with assistance of a map)	This influencing factor is expected to be extensive across the developed coastal catchments of Australia, particularly those supporting floodplain agriculture. Data on extent is limited, though the following estimates of tidal barriers have been made in Queensland and New South Wales: - 5,536 barriers to tidal flow across 19,674 km of stream length in Wet Tropics basin (QLD). - 1525 floodgates; 626 weirs and 1628 road crossings in coastal NSW - Ponded pastures in QLD – up to 35,000ha of saltmarsh lost - Drained coastal wetlands in northern NSW– 62,000 ha of 'prime fish habitat' lost (inclusive of tidal marshes and mangroves) - Salt ponds in the range in size from 70 ha to 4,000 ha occur in South Australia	Creighton (2014) Wegscheidl et al. (2015) Neldner et al. (2005) Rogers et al. (2015) Hough (2008)

6.3.2 Groundwater connectivity

Table 8. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: groundwater connectivity

Question	Response	References
Identify the influencing factor and associated cause	Groundwater connectivity. Access to groundwater can be important for continued production of mangrove and tidal marsh biomass. It may also influence the preservation of carbon in belowground stocks. Changes to the water table resulting from groundwater extraction within the groundwater catchment may therefore influence carbon dynamics.	
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Where groundwater connection has been lost to a site, the following may occur: - Loss or change in vegetation due to alterations in water salinity and hydroperiod - Change in surface elevation, influencing susceptibility to impacts of Sea Level Rise - Increased oxidation of substrate if groundwater saturation decreases - Abstraction or dewatering activities altering fresh/saline groundwater interface - Changes in lateral groundwater carbon exports, e.g. tidal pumping (relates to form of C released as endpoint of remineralisation, DIC/Alkalinity vs CO_2) - Saltwater intrusion due to freshwater extraction (leading to changes in vegetation communities and carbon remineralisation)	Maher et al. (2013) Sadat-Noori et al. (2015) Rogers and Saintilan (2008)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	For the most part groundwater use is regulated by state and territory based water management legislation. These acts and other legislation which may apply are listed here: Commonwealth *Water Act 2007* – regulates water management and infrastructure. *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Water Act 2000* and *Sustainable Planning Act 2009* – regulate water management and infrastructure. *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). NSW *Water Management Act 2000* – regulates water management and infrastructure.	www.austlii.edu.au Rogers et al. (2016) Workshop participants

Question	Response	References
	Fisheries Management Act 1994 – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC *Water Act 1989* – regulates water management and infrastructure. *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. *Flora and Fauna Guarantee Act 1988* – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 saltmarsh plants are listed as 'rare' on the Advisory List. TAS *Water Management Act 1999* – regulates water management and infrastructure. *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal tidal marshes *Coastal Policy Statement* – areas subject to significant risk from coastal processes and hazards, including sea level rise, will be identified and managed. SA *Natural Resources Management Act 2004* – regulates water management and infrastructure. *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA *Rights in Water and Irrigation Act 1914* - provides for regulating the take and use of water from watercourses and wetlands in proclaimed rivers, surface water management areas, irrigation districts and groundwater areas *Water Agencies (Powers) Act 1984*, *Country Areas Water Supply Act 1947, Metropolitan Water Supply, Sewerage and Drainage Act 1909* and *Waterways Conservation Act 1976* - also relate to the management of water NOTE – water legislation in WA is currently under review. *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community.	

Question	Response	References
	NT *Water Act 1992* - regulates water management and infrastructure. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	There is potential for this influencing factor to occur in all States and the Northern Territory where there is extensive coastal infrastructure that could influence surface and subterranean groundwater flows and where groundwater extraction occurs. Particular areas of impact identified by workshop participants include: - WA - significant use of groundwater for mines, agriculture, and urban water supply. - South East QLD - large scale groundwater extraction from Sand Islands	Workshop participants
Is the influencing factor historic, current or anticipated?	Historic - Extensive changes to coastal hydrology due to built infrastructure and sand mining activities along many coastal landscapes of Eastern Australia - Changes to hydrology due to abstraction historically in WA Current - Current changes to hydrology due to water use from abstraction, climate change, mining, and dewatering activities - Potential role of decline in groundwater inflow linked to north Australian monsoonal dynamics, leading to recent mangrove dieback in Gulf of Carpentaria. Impacts intensified with enhanced variability of north Australian monsoon, especially severe when coupled with heat waves and below average wet seasons. Anticipated WA has planned 'water for food' projects which look to access untapped groundwater resources for irrigated agriculture - with some locations in Kimberley which may be close enough to affect mangroves.	Workshop participants NT mangrove dieback - news item, no formal investigative study yet; http://www.abc.net.au/news/2016-07- 10/unprecedented-10000-hectares-of-mangroves-die/7552968
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Where changes in groundwater cause the dieback of existing mangrove and tidal marsh vegetation this will cause the permanent loss of the aboveground biomass carbon pools. Drainage and oxidation of soils may also lead to the permanent loss of soil C_{org} pools through enhanced remineralisation.	.
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	Very little data exists on the spatial extent of groundwater influence in mangroves and tidal marshes. While national mapping of groundwater dependant ecosystems exists (National Groundwater Information System - http://www.bom.gov.au/water/groundwater/ngis/) at present mapping this does not include marine and estuarine ecosystems. The Western Australian 'Water for Food' (see- http://www.waterforfood.wa.gov.au/Projects) website shows locations where new groundwater use is being encouraged. The location of many of these areas is near mangrove habitat, especially in the Kimberley region. A recent study across a broad latitudinal range in Australia suggests that the magnitude of pore water exchange in mangroves is equal to about one third of annual global river discharge to the ocean (3.84×10^{13} m^3 yr^{-1}).	www.bom.gov.au/water/groundwater/ngis/ www.waterforfood.wa.gov.au/Projects Tait et al. (2016)

6.3.3 Sedimentation

Table 9. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: sedimentation

Question	Response	References
Identify the influencing factor and associated cause	Sedimentation. This is a natural process in mangroves and tidal marshes, however changes in catchment land-use, local hydrology, and physical disturbances may increase or decrease rates of sedimentation. Sedimentation can also include the intentional addition of sediments to a site.	
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	- Insufficient sedimentation to mangrove and tidal marshes may cause an 'elevation deficit' whereby the wetlands are unable to keep paces with sea level rise. Consequently, vegetation may die and soils subject to deeper inundation may erode. - Increases in sedimentation rates can drive substantial increases in soil C_{org} accumulation in mangroves and tidal marshes - Sedimentation has the potential to support development of mangrove on unvegetated flats, thereby representing and increasing biomass and soil C_{org} pool. - Sedimentation is a source of allochthonous carbon. Changes to sedimentation rates will affect this pool. - Sedimentation may be a source of nutrients supporting primary productivity	Slocum et al. (2005) Swales et al. (2015) Osland et al. (2012) Howe et al. (2009)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Environment Protection (Sea Dumping) Act 1981 (the Sea Dumping Act)* and *National Assessment Guidelines for Dredging 2009* – regulate the disposal of dredged materials *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Coastal Management Plan* – Impacts of climate variability, including sea level rise are considered in managing the coast. *Sustainable Planning Act 2009* - includes development conditions requiring adequate erosion and sediment control measures to be implemented and maintained on construction sites The regulation of water infrastructure is also influenced by the *Sustainable Planning Act 2009* and *Water Act 2000.*	Rogers et al. (2016) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	NSW *Protection of the Environment Operations Act 1997* – regulates environmental management operations associated with development activity *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* – local Councils are encouraged to give local sea level rise projections due and proper consideration. Strategic planning to accommodate the effects of sea level rise on landward migration of wetlands and recognition of wetland migration in development applications. VIC – *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. *Flora and Fauna Guarantee Act 1988* – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 tidal marsh plants are listed as 'rare' on the Advisory List. TAS – *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal tidal marshes *Coastal Policy Statement* – areas subject to significant risk from coastal processes and hazards, including sea level rise, will be identified and managed. Retreat pathways for natural ecosystems prioritised when planning new infrastructure. SA – *Environment Protection Act 1993* – regulates environmental management operations associated with development activity *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA – Soil and Land Conservation Act (1945) – is the principal Act relating to the control of soil erosion Fish Resources Management Act 1994 – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. Wildlife Conservation Act 1950 – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. NT – Erosion and Sediment Control Plans required for a range of activities including rural development and clearing General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries	

Question	Response	References
In what Australian location/s and jurisdiction/s does the influencing factor occur?	High levels of sedimentation or reduction of sedimentation may occur in all developed catchments around the country. Particular impacts may occur: - Mangroves and tidal marshes downstream of dams - Mangroves and tidal marshes downstream of land clearing operations - Mangroves and tidal marshes downstream / lateral to dredging activities Increases in sedimentation have been widely associated with land clearance after European colonisation	Morelli et al. (2012) Nguyen et al. (2010)
Is the influencing factor historic, current or anticipated?	Historic - Sedimentation associated with development of coastal catchments may be partly responsible for expansion of mangrove into tidal marsh habitat, which is likely to have altered environmental values including carbon stocks. - Historic construction and operation of dams within coastal catchments may have reduced sedimentation rates in mangroves and tidal marshes downstream. Current - Improvements in sediment control during development activities in recent decades are likely to have reduced the sediment loads entering urban mangroves and tidal marshes (relative to prior practices). - Continued operation of dams in coastal catchments may be reducing sedimentation rates in mangroves and tidal marshes downstream. Anticipated - There is a likelihood of more dams in northern Australia to enable agricultural expansion. - There is a likelihood of dredging in northern Australia to enable expansion of port operations. - Increasing intensity of storms under climate change may alter coastal sedimentation/erosion dynamics. - Anticipated improvements in management of coastal agricultural lands may reduce sediment supply to downstream mangroves and tidal marshes (e.g. in the Great Barrier Reef catchments).	Kelleway et al. (2016c) Swales et al. (2015) Shoo et al. (2014) Workshop participants
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Sedimentation may have either temporary or permanent effects on mangroves and tidal marshes. For example: - A pulse of enhanced sedimentation may temporarily increase allochthonous soil C_{org} accumulation rates. - Dieback of vegetation associated with either insufficient or excessive sedimentation will result in permanent loss of that carbon pool.	Ellison (1999)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	No data currently exists. The Surface Elevation Table monitoring network is the best resource currently available regarding the surface sediment dynamics of mangroves and tidal marshes and for determining their susceptibility to sea level rise. Findings from this network suggest: - many mangrove sites across the Indo-Pacific are currently experiencing rates of sea level rise which exceed soil surface elevation gains - tidal marshes in SE Australia generally experience lower rates of sedimentation than mangroves	Lovelock et al. (2015) Rogers et al. (2006)

6.3.4 Biomass removal

Table 10. Influencing factors for carbon sequestration and emissions in mangroves and tidal marshes: biomass removal

Question	Response	References
Identify the influencing factor and associated cause	Biomass removal. Anthropogenic causes include land clearing or activities which promote the dieback of existing vegetation. Grazing of biomass if treated as a separate influencing factor	.
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Removal of biomass may have the following implications for carbon storage and cycling in mangroves and tidal marshes: - removal of aboveground carbon pool - loss of source of production for belowground biomass carbon pool - change in trapping capacity of sediment surface - change in erodibility of soils and soil C_{org} pool - change in soil microbial community - changes in macrofaunal community (e.g. bioturbation) - export of carbon to coastal waters	Lang'at et al. (2014) Lovelock et al. (2011) Workshop participants
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Vegetation Management Act 1999* – regulates clearing of woody vegetation within and near watercourses and wetlands NSW *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Fisheries Management (General) Regulation 2010* – amendments now make it illegal for livestock of any type to graze and trample marine vegetation (including tidal marsh and mangroves) on public water land (e.g. Crown land or Council land). *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community.	Rogers et al. (2016) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	State Environmental Planning Policy No 14 Coastal Wetlands —Precludes clearing within designated wetlands and includes requirements for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC – *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. *Flora and Fauna Guarantee Act 1988* – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 tidal marsh plants are listed as 'rare' on the Advisory List. TAS – *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal tidal marshes SA – *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA – *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. NT – *Department of Land Resource Management (DLRM) Land Clearing Guidelines (2010)* – guidelines relevant to land clearing *Pastoral Land Act* - provides for the monitoring, prevention of degradation, and rehabilitation of Crown lands under pastoral leases. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries. - some introduced plant species growing within ponded pastures may be listed as noxious weeds in certain locations, requiring their removal and/or control.	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	Still occurring - fairly well monitored e.g. Qld wetland mapping Relevant to large developments that require offsetting of environmental impacts (e.g. for biodiversity reasons)	Accad et al. (2016)
Is the influencing factor historic, current or anticipated?	Historic Substantial areas of mangrove and tidal marsh cleared and reclaimed for the development of residential, agricultural and industrial areas. Current - Regulation of development on mangrove and tidal marsh vegetation are strict in most states and territories, however, this does not preclude development (e.g. recent expansion of Brisbane airport) - Clearing of mangroves in Darwin harbour, small patches but multiple sites.	Workshop participants

Question	Response	References
	- Development controls on unvegetated salt flats (which might be filled to increase elevation, rather than cleared) may not be as strict in many jurisdictions as protection status may be related to the presence of defined vegetation communities. Anticipated - Development proposals in northern Australia - Priority Development Areas for major coastal developments in Queensland. - Clearing of areas permitted under offset agreements - Future development on unvegetated salt flats (which might be filled to increase elevation, rather than cleared) may not be as strict controlled in many jurisdictions as protection status may be related to the presence of defined vegetation communities.	
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	This will depend upon the level of biomass removal. For example, pruning of mangrove trees may allow the survival of the tree and retention of carbon pools in above- and below-ground biomass. Clearing of entire trees or which causes death of mangrove trees will represent a permanent loss of carbon pools, unless circumstances allow natural regeneration or the site is restored.	.
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	No data is currently available on the current extent of biomass removal in these ecosystems in Australia, though it is expected to be low. There is some historic data available. For example, mapping by the Queensland Herbarium shows a 2621 ha loss of mangrove area in the Moreton Bay region (QLD) between 1955 and 2012 to a variety of land uses (Accad et al. 2016). This area is equivalent to 18% of the 1955 extent of mangroves. This same mapping project reported the loss of 3410 ha or 64% of tidal marsh in the same period. Most of the land-use conversions responsible for these losses would have involved the clearing of biomass or destruction of biomass through other means (e.g. infilling of sediment). It is unclear what area of mangrove and tidal marsh may be subject to future clearing of biomass, however this may include more substantial areas in northern Australia.	Accad et al. (2016) Workshop participants

6.3.5 Disturbance to the soil profile

Table 11. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: disturbance to the soil profile

Question	Response	References
Identify the influencing factor and associated cause	Disturbance to soil profile. This may be caused by authorised or unauthorised activities taking place within mangroves and tidal marshes, including grazing by domestic or feral animals, dredging and 'reclamation' activities, vehicle and pedestrian passage.	
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Physical disturbances operating within mangroves and tidal marshes may include: - Excavation to enable port, harbour and marina construction - feral animals (pig, deer, buffalo, donkeys) - grazing and rooting (hooved animals) - vehicle access - people trampling - runnelling for mosquito management - introduction of salt ponds and aquaculture - maintenance of infrastructure e.g. seawalls. These disturbances may impact soil C_{org} dynamics through: - oxidation of substrate and changes in carbon oxidation pathway (e.g. aerobic vs anaerobic, CO_2 vs CH_4) - change in compaction of soils - change of water infiltration characteristics - change in erodibility of soils	Workshop participants Breitfuss et al. (2003) Laegdsgaard et al. (2009) Kelleway (2005) Alongi et al. (1996)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas).	Rogers et al. (2016) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	NSW *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Fisheries Management (General) Regulation 2010* – amendments now make it illegal for livestock of any type to graze and trample marine vegetation (including tidal marsh and mangroves) on public water land (e.g. Crown land or Council land). *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC – *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. TAS – *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal tidal marshes. SA – *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA – *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. NT – *Pastoral Land Act* - provides for the monitoring, prevention of degradation, and rehabilitation of Crown lands under pastoral leases. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries.	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	May occur in all developed coastal catchments, including urban and agricultural mangroves and tidal marsh habitats. Disturbance by feral animals may also operate in otherwise pristine areas.	.
Is the influencing factor historic, current or anticipated?	Historic Substantial historic loss of mangrove and tidal marsh has been caused by disturbance to soil profiles, particularly in urban and semi-urban areas. This has primarily occurred through infilling or reclamation of areas whereby soil elevation is raised above the tidal plane and land is used for 'dryland' purposes (including parkland, ports, housing estates, etc.). In some areas there is a historic record of disturbance to soils through activities such as stock or feral animal grazing and vehicle passage.	Adam (2002) Laegdsgaard et al. (2009) Kelleway (2005)

Question	Response	References
	Development of coastal salt ponds dates back to the 19th century in South Australia. **Current** Disturbance from domestic stocks, feral animals and human use currently occurs. **Anticipated** It is expected that disturbance from domestic stocks, feral animals and human use is likely to continue in the future.	
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Permanency will be determined by the extent of disturbance and the subsequent land use after disturbance. Permanent – impacts upon the soil profile render it unable to support the previous vegetation and may lead to permanent loss of previously stored soil C_{org} stocks. Temporary – recolonization is possible due to a reduced extent of disturbance and/or restoration activities and opportunity exists for this to occur.	.
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- Trampling by domestic stock is likely to be widespread across all coastal states and territories, particularly on private land and outside of urban areas, though little to no quantitative data exists regarding the extent of affected areas. The NSW Scientific Committee stated in 2004 that trampling by domestic stock and feral herbivores occurred 'at a number of [tidal marsh] sites' in New South Wales. - The proportion of tidal marsh directly impacted by vehicle use in some urban wetlands has been estimated at >40%. Across multiple sites in the Georges River this area was estimated at 2.1 ha, which represents approximately 3% of the tidal marsh in that urban estuary. - Salt ponds in the range of 70 ha to 4,000 ha occur in South Australia.	NSW Scientific Committee (2004) Kelleway (2005) Hough (2008)

6.3.6 Changing species distribution

Table 12. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: changing species distributions

Question	Response	References
Identify the influencing factor and associated cause	Changing species distributions of mangrove and tidal marsh plants. Driven largely by climatic changes, but also indirectly by human influence. Active management of species composition (e.g. selective removal of mangroves or introduced species) may have implications for carbon storage. Planting of unvegetated areas may also occur.	Asbridge et al. (2016)
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Shifts in species composition may alter the above- and below-ground carbon stocks, depending on the biomass of the species involved. Differences in plant structure (e.g. root depth) may also influence soil C_{org} stocks.	Kelleway et al. (2016c) Doughty et al. (2015)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD – *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Vegetation Management Act 1999* – regulates clearing of woody vegetation within and near watercourses and wetlands NSW - *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC – *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation.	Rogers et al. (2016) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	Flora and Fauna Guarantee Act 1988 – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 saltmarsh plants are listed as 'rare' on the Advisory List. TAS – *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal saltmarshes SA – *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA – *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries - some introduced plant species may be listed as noxious weeds in certain locations, requiring their removal and/or control.	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	The expansion of mangroves into areas previously dominated by tidal marsh vegetation has been documented in Queensland, New South Wales, Victoria and South Australia. Recent observations suggest it is also occurring in the Northern Territory. Mangroves do not currently occur in Tasmania, though anecdotally there may be opportunity for their expansion there. In northern Australia and parts of SE Australia, both seaward and landward expansion of mangroves has been observed over decadal timescales. Movement of mangrove species (primarily *Rhizophora stylosa, Ceriops tagal* and *Avicennia marina*) within the mangrove zone has been observed here, reflecting their different adaption to more or less favourable conditions. Removal of mangrove seedlings (for the purpose of maintaining open habitat structure for roosting birds) is known to occur in New South Wales, but may also be undertaken elsewhere. Direct manipulation of mangrove and tidal marsh species composition could potentially be undertaken in any jurisdiction (though mangroves do not occur in Tasmania)	Saintilan and Williams (2000) Asbridge et al. (2016) Lucas et al. (2002) Eslami-Andargoli et al. (2009)
Is the influencing factor historic, current or anticipated?	Historic Mangrove expansion within estuaries is a near ubiquitous trend in south-eastern Australia, and has been occurring since the time of earliest aerial photographic records (1950s), and perhaps earlier. There are multiple potential climatic and non-climatic drivers of this phenomenon. There is evidence of poleward migration of the tropical mangrove species *Rhizophora stylosa* and *Bruguiera gymnorrhiza* in eastern Australia over recent decades. There is no known historical occurrence of direct manipulation of mangrove or tidal marsh species composition.	Saintilan et al. (2014) Asbridge et al. (2015) Asbridge et al. (2016)

Question	Response	References
	Current Mangrove expansion within estuaries is a near ubiquitous trend in SE Australia. Rapid expansion of mangrove into paperbark and other wetlands types is also occurring in northern Australia. There is some evidence of a latitudinal shift in the distribution of some mangrove species is currently underway (i.e. the tropical mangrove species *Rhizophora stylosa* and *Bruguiera gymnorrhiza* in eastern Australia) Removal of mangrove seedlings (for the purpose of maintaining open habitat structure for roosting birds) is known to occur in New South Wales, but may also be undertaken elsewhere. **Anticipated** Mangrove expansion and latitudinal shifts in mangrove distribution are likely to occur with rising sea level and changing climate (especially temperature, rainfall and atmospheric CO_2 concentrations). Removal of mangrove seedlings is likely to continue in certain locations (for the purpose of maintaining open habitat structure for roosting birds), unless other habitat maintenance options are available (e.g. creation of upslope buffers for tidal marsh migration).	
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Mangrove expansion permanently affects blue carbon ecosystem structure and function (including potential to increase carbon storage). Direct manipulation of mangrove species composition is also likely to cause permanent changes in ecosystem structure and function.	Kelleway et al. (2016a)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	Numerous quantifications of historic distributions changes of mangroves relative to tidal marsh have been undertaken across SE Australia. A median value of ~30% decline in tidal marsh area due to mangrove encroachment has been determined, though these assessments are now dated. Seaward migration of mangroves in the Gulf of Carpentaria has been measured up to 1.9km (perpendicular to the coast) between 1987-2014, with maximum annual expansion measured at 195 m/year, though average rates of expansion are much lower.	Saintilan and Williams (2000) Straw and Saintilan (2006) Asbridge et al. (2016)

6.3.7 Herbivory

Table 13. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: herbivory

Question	Response	References
Identify the influencing factor and associated cause	Herbivory of plant biomass. Causes include consumption of biomass by native and/or introduced fauna species (including vertebrates and invertebrates) in both natural settings and agriculture settings. Grazing of tidal marsh vegetation by macropods may occur between tidal events (NSW Scientific Committee 2004)	
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	- complete or partial removal of aboveground carbon pool - change in species composition - loss of source of production for belowground biomass carbon pool OR enhancement of belowground biomass allocation - change in trapping capacity of sediment surface - change in erodibility of soils and soil C_{org} pool	Elschot et al. (2015) Adam (1990) Laegdsgaard et al. (2009)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Ponded Pastures Policy 2001* – replaced a previous moratorium on ponded pastures. Indicated that ponded pastures should only be located in areas that are not: - tidal areas below Highest Astronomical Tide (HAT); or - in or adjacent to natural wetlands; or - of high conservation or fish habitat values. The Policy deemed that existing banks that impound freshwater or prevent seawater incursion should remain. *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Vegetation Management Act 1999* – regulates clearing of woody vegetation within and near watercourses and wetlands	NSW Department of Primary Industries (http://www.dpi.nsw.gov.au/fishing/habitat/protecting-habitats). Rogers et al. (2016) Challen and Long (2004) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	Environmental Protection Act 1994 and *the Chemical Usage (Agricultural and Veterinary) Control Act 1988* - Reef protection requirements under these acts and associated regulations require graziers in the Wet Tropics, Burdekin and Mackay-Whitsundays to: - keep records of their use of fertilisers and agricultural chemicals; - undertake soil tests and use results of soil tests, and the regulated method, to calculate and apply no more than the optimum amount of fertiliser (nitrogen and phosphorus) - follow product label instructions when using agricultural chemicals such as herbicides and insecticides - follow specific controls when using herbicide products containing atrazine, ametryn, hexazinone and diuron. NSW *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Fisheries Management (General) Regulation 2010* – amendments now make it illegal for livestock of any type to graze and trample marine vegetation (including saltmarsh and mangroves) on public water land (e.g. Crown land or Council land). A maximum penalty of $110,000 for an individual or $220,000 for a Corporation applies. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. *Flora and Fauna Guarantee Act 1988* – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 saltmarsh plants are listed as ‘rare’ on the Advisory List. TAS – *Nature Conservation Act 2002* – designates the protection of ‘Saline Aquatic Herblands’ and ‘Wetlands Undifferentiated’, but excludes other specific vegetation units relevant to coastal tidal marshes SA – *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA – *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community.	

Question	Response	References
	NT – *Pastoral Land Act* - provides for the monitoring, prevention of degradation, and rehabilitation of Crown lands under pastoral leases. General - Grazing by domesticated fauna is generally prohibited within the conservation estate under State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) - some introduced plant species growing within ponded pastures may be listed as noxious weeds in certain locations, requiring their removal and/or control.	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	This influencing factor is likely to be widespread across all coastal states and territories, particularly on private land and outside of urban areas.	Creighton (2014) NSW Scientific Committee (2004)
Is the influencing factor historic, current or anticipated?	Historic, current and anticipated.	.
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	In most cases plant biomass will regrow following the exclusion or reduction in grazing, thereby allowing aboveground and belowground biomass carbon pools to recover. In such instances this influencing factor would be considered to have a temporary effect. In some cases, it is possible that herbivory may cause a change in vegetation composition, which in turn may alter aboveground and belowground biomass carbon pools in the longer term.	.
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with a map)	This influencing factors is likely to be widespread across all coastal states and territories, particularly on private land and outside of urban areas. Little to no quantitative data exists regarding the extent of affected areas. The NSW Scientific Committee stated in 2004 that trampling by domestic stock and feral herbivores occurred 'at a number of [tidal marsh] sites' in New South Wales.	Creighton (2014) NSW Scientific Committee (2004)

6.3.8 Nutrient input

Table 14. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: nutrient inputs

Question	Response	References
Identify the influencing factor and associated cause	Nutrient inputs. Causes may include diffuse sources such as fertiliser use across an agricultural catchment or point sources such as sewerage treatment plants which discharge into wetlands. Isotope studies show that catchment sources of nitrogen are reflected in mangrove biomass and the food webs they support.	Mazumder et al. (2015)
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	- Nutrients are required for the growth of biomass carbon pools and maintenance of primary productivity. Nutrient additions can increase growth. - Enhanced nutrient input can alter biomass allocation (increase in aboveground:belowground biomass), however this may not occur in all settings - Excessive nutrient input can cause mortality and subsequent loss of mangrove and tidal marsh, especially during arid periods - Enhanced nutrient concentrations may stimulates rates of microbial decomposition of C stocks and lead to loss of soil structure. - Increase in N_2O emissions resulting from enhanced nitrogen inputs	Lovelock et al. (2009) Deegan et al. (2012) Wigand et al. (2014) Workshop participants
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Environmental Protection Act 1994* regulates operation of point sources of nutrients. A voluntary market-based mechanism now exists which provides an alternative investment option for licensed point source operators to meet their water emission discharge requirements under the Act, while delivering an improvement in water quality in the receiving environment. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas).	Rogers et al. (2016) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	Environmental Protection Act 1994 and *the Chemical Usage (Agricultural and Veterinary) Control Act 1988* - Reef protection requirements under these acts and associated regulations require all cane farmers in the Wet Tropics, Burdekin and Mackay-Whitsundays to: - keep records of their use of fertilisers and agricultural chemicals; - undertake soil tests and use results of soil tests, and the regulated method, to calculate and apply no more than the optimum amount of fertiliser (nitrogen and phosphorus) NSW *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. VIC *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. NT *Pastoral Land Act* - provides for the monitoring, prevention of degradation, and rehabilitation of Crown lands under pastoral leases. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	Enhanced nutrient concentrations are likely to occur from diffuse sources in most estuaries around the country which have urban and/or agricultural development within their catchments (i.e. in all jurisdictions). Point source nutrient enhancement may occur adjacent to or downstream of land uses such as: - Waste Treatment Plants - Cane farms (dissolved inorganic nitrogen) - Agricultural properties under fertiliser application.	Workshop participants
Is the influencing factor historic, current or anticipated?	Historic NSW Estuary Monitoring and Reporting data suggest significant increases in nitrogen and phosphorus concentrations of NSW estuaries relative to pre-European conditions (with an average increase of 190% in TN and 426% in TP Current Nutrient inputs to many catchments are currently substantially higher than pre-European conditions, but there has been substantial efforts to reduce nutrient inputs in many systems e.g. Moreton Bay Healthy Waterways; Port Phillip Bay; Peel Harvey Inlet	Roper et al. (2011) Morelli et al. (2012) Workshop participants

Question	Response	References
	Anticipated There may be future reduction in nutrient inputs in some catchments associated with attempts to enhance water quality (e.g. in reef catchments)	
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Impacts may either be temporary (for example, a temporary alteration to productivity or decomposition rates associated with a pulse of nutrient inputs) or permanent (e.g. excessive nutrient inputs causing plant mortality or soil collapse).	.
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	No definitive data are available on the extent of mangrove and tidal marsh influenced by nutrient inputs. NSW Estuary Monitoring and Reporting data suggest most NSW estuaries experience enhanced nutrient loads relative to pre-European conditions (with data reported by estuary).	Roper et al. (2011) Workshop participants

6.3.9 Freshwater inputs

Table 15. Influencing factors for carbon sequestration and emission in mangroves and tidal marshes: freshwater inputs

Question	Response	References
Identify the influencing factor and associated cause	Salinity/freshwater inputs. Modifications to natural pathways of tidal water (brackish and saline water) and catchment runoff (freshwater) may alter the salinity dynamics of mangroves and tidal marshes. Management of freshwater, brackish and saline water sources might be used to increase carbon storage capacity and reduce emissions	
How does the influencing factor affect either the carbon sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	- freshwater inputs may influence species distributions, with implications for vegetation structure and biomass volume. - freshwater inputs can increase growth of halophytes where soils are saline. Mangroves can preferentially use freshwater when available - alter biomass allocation of existing species (aboveground v belowground): mangroves characteristically increase allocation of carbon to growth of roots relative to shoots with increase in salinity, with this pattern being amplified with decreasing humidity - crossing salinity thresholds which dictate types of emissions from wetlands (CO_2 v CH_4), with IPCC Wetlands Supplement stating salinity of 18ppt as the upper threshold at which CH_4 production is effectively suppressed. However, high water column CH_4 concentrations have also been reported under hypersaline conditions in a mangrove driven by tidal pumping of groundwater. - saline conditions supress microbial activity	Ball (1988) Hiraishi et al. (2014) Call et al. (2015) Reef et al. (2015) Santini et al. (2014) Ewe et al. (2007)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	Commonwealth *Water Act 2007* – regulates water management and infrastructure. *Convention on Wetlands of International Importance (Ramsar Convention)* – requires the maintenance of ecological character of designated sites (19 Ramsar wetlands in Australia include mangrove or saltmarsh wetland types). *Environment Protection and Biodiversity Conservation Act 1999* – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems (including subtropical and temperate coastal saltmarsh ecological community) QLD *Water Act 2000* and *Sustainable Planning Act 2009* – regulate water management and infrastructure. *Environmental Protection (Water) Policy 2009* – designates that activities are required to avoid, minimise and offset any significant impacts on wetland environmental values (in mapped areas). *Ponded Pastures Policy 2001* – replaced a previous moratorium on ponded pastures. Indicated that ponded pastures should only be located in areas that are not:	Rogers et al. (2016) Challen and Long (2004) Workshop participants Legislation (www.austlii.edu.au)

Question	Response	References
	- tidal areas below Highest Astronomical Tide (HAT); or - in or adjacent to natural wetlands; or - of high conservation or fish habitat values. The Policy deemed that existing banks that impound freshwater or prevent seawater incursion should remain. *Fisheries Act 1994* – designates the protection of tidal marine plants in declared fish habitat areas. Coastal wetlands outside declared fish habitat areas (e.g. on pasture land) is precluded. NSW *Water Management Act 2000* – regulates water management and infrastructure. *Fisheries Management Act 1994* – any development or activity that may harm mangrove or saltmarshes must be referred to the NSW Department of Primary Industries for approval. *Threatened Species Conservation Act 1995* - coastal saltmarsh listed as Endangered Ecological Community. *State Environmental Planning Policy No 14 Coastal Wetlands* —Places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries. VIC *Water Act 1989* – regulates water management and infrastructure. *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* – Apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. NB: A new Marine and Coastal Act has been drafted and is currently undergoing public consultation. *Flora and Fauna Guarantee Act 1988* – provides a fundamental level of protection to all native vegetation including mangroves and vegetated tidal marshes. The only mangrove in VIC (*Avicennia marina*) as well as 16 saltmarsh plants are listed as 'rare' on the Advisory List. TAS *Water Management Act 1999* – regulates water management and infrastructure. *Nature Conservation Act 2002* – designates the protection of 'Saline Aquatic Herblands' and 'Wetlands Undifferentiated', but excludes other specific vegetation units relevant to coastal saltmarshes SA *Natural Resources Management Act 2004* – regulates water management and infrastructure. *Fisheries Management Act 2007* – mangrove, but not tidal marshes, are explicitly identified. The objective is to protect and conserve aquatic habitats. WA	

Question	Response	References
	Rights in Water and Irrigation Act 1914 - provides for regulating the take and use of water from watercourses and wetlands in proclaimed rivers, surface water management areas, irrigation districts and groundwater areas *Water Agencies (Powers) Act 1984*, *Country Areas Water Supply Act 1947, Metropolitan Water Supply, Sewerage and Drainage Act 1909* and *Waterways Conservation Act 1976* - also relate to the management of water NOTE – water legislation in WA is currently under review. *Fish Resources Management Act 1994* – designates areas as fish habitat protection areas. Some mangrove and tidal marsh areas are included. *Wildlife Conservation Act 1950* – Sub-tropical and temperate coastal saltmarsh listed as a threatened ecological community. NT *Water Act 1992* - regulates water management and infrastructure. General - State- and territory-based legislation regarding public conservation estates (e.g. National Parks and Marine Parks) may apply to mangroves and/or tidal marshes within estate boundaries	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	May apply in all coastal areas and jurisdictions, but would have particular application in: - High rainfall areas - Cane farming areas - ponded pasture freshwater (QLD, NT, WA) - Flood prone catchments - Highly impounded estuarine areas/coastal catchments	Workshop participants
Is the influencing factor historic, current or anticipated?	Historic Mostly historic changes associated with the expansion of floodplain agriculture in eastern Australia (in the 19th and 20th centuries) and development of coastal water storages. Damming of the Ord River, WA, in the 1970s represents a significant water development in northern Australia. Current Current operation of water structures which influence freshwater inputs will continue to influence mangrove and tidal marsh function. Potential shift in freshwater inflow, from either drainage, groundwater and/or surface runoff, coupled with high temperatures (air, SST) in 2015/2016 *may* have induced significant die-back in mangrove patches along 700 km of the Gulf of Carpentaria coastline in the NT. Anticipated Potential for future development of water control structures (including water storages), including in northern Australia.	Creighton (2014) Thom et al. (1975) Wolanski et al. (2001) Workshop participants

Question	Response	References
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Impacts may either be temporary (e.g. temporary change in productivity associated with a temporary change in freshwater input) or permanent (e.g. permanent change in vegetation distribution, structure and function associated with long-term change in freshwater inputs)	
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	There may be extensive opportunity for freshwater/salinity management across the developed coastal catchments of Australia, particularly those supporting floodplain agriculture. Data on extent is limited, though the following estimates of tidal barriers have been made in Queensland and New South Wales: - 5,536 barriers to tidal flow across 19,674 km of stream length in Wet Tropics basin (QLD). - 1525 floodgates; 626 weirs and 1628 road crossings in coastal NSW The following locations are used as case studies to demonstrate the areas which may be affected: - Damming of the Ord River, WA, in the 1970s appears to have suppressed large river floods while associated siltation may have decreased salinity intrusion length by about 50% in the East Arm following river damming - It has been suggested that the proposed Tillegra Dam above the Hunter River estuary, NSW, may reduce freshwater flow to estuarine habitats by as much as 15-21% and may increase the upstream limit of saline intrusion. - Conversely, saltwater intrusion in the Mary River estuary (Northern Territory) has impacted more than 17,000 hectares of freshwater vegetation with a further 35–40% of the plains identified as threatened. Management responses here have included the construction of barrages and earthen blocks in an effort to limit the intrusion of saltwater upstream.	Creighton (2014) Neldner et al. (2005) Wegscheidl et al. (2015) Wolanski et al. (2001) Kingsford and Hankin (2010) Mulrennan and Woodroffe (1998)

SECTION B: ERF suitability assessment of blue carbon ecosystem enhancement activities for mangroves and tidal marshes

6.4 Introduction to activities for mangroves and tidal marshes

This section contains detailed assessments of short-listed potential blue carbon enhancement activities which were determined through the analyses of influencing factors conducted in Section A and outcomes of the participatory workshop (Table 16). For each of these potential activities a comprehensive suitability assessment was undertaken following guidelines provided by the Department. All potential activities were subjected to an initial assessment (Questions 1-3) and Abatement Integrity Assessment (Question 4 in Section B). Activities that received a score ≥8 in the Abatement Integrity Assessment were also subjected to a more detailed assessment (Questions 5-11 in Section B).

Table 16. Summary table of activities with the potential to sequester additional carbon or avoid emissions against the business as usual scenario within blue carbon ecosystems

Mangroves and Tidal Marshes
Introduction of tidal flow • Changes to walls, culverts, etc. followed by passive and/or active revegetation.
Enhancing sediment supply • Earthworks to alter water flow and enhance sediment deposition • Altered flooding and associated sedimentation regimes • Dredge spoil addition to reduce vulnerability to sea level rise
Land-use change • Alteration of land-use in existing mangrove and tidal marsh areas (grazing and alternative land-use, including agriculture) • Land-use planning to allow upslope and upstream migration of mangroves and tidal marshes with rising sea level
Avoided clearing and avoided soil disturbance • Revoke or do not act on existing planned clearing and/or soil disturbance activities (e.g. including mangrove seedling removal from tidal marshes/mudflats, aquaculture developments)
Change in species composition • Improved biomass production due to enhanced adaptation to local conditions
Offsite management options to impact site processes • Nutrient management in catchments to reduce loads into mangroves • Catchment water flow management to obtain optimal salinity conditions or reduce sub-optimal conditions

6.4.1 Introduction of tidal flow

Category: Mangrove establishment/restoration; Tidal marsh establishment/restoration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

Introduction of tidal flow may include changes (removal, modification, relocation, installation) to water regulation structures (artificial levees, seawalls, culverts, etc.) which influence tidal connection. Earthworks might be used to modify the contour of impacted areas and increase tidal connection. These activities may be followed by passive and/or active revegetation techniques.

This activity may have implications for biomass carbon pools (sequestration), soil C_{org} pools (sequestration) and atmospheric fluxes of nitrous oxide and methane from soils (avoided emissions).

Where tidal connection has been previously lost to a site, the following may occur:

- Loss or change in vegetation composition and/or structure due to alterations in water depth, salinity, hydroperiod and surface elevation (i.e. subsidence and sedimentation).
- Exclusion of sulphates contained within marine tidal water may increase methane production.
- Exclusion of tidally transported carbon sources
- Reduced sediment supply may result in subsidence of substrate such that vegetation dies from submergence
- Oxidation of soils in drained wetlands will likely result in an increased remineralisation of previously stored C_{org}, emissions of N_2O due to conversion of organic nitrogen to nitrate and partial reduction in anoxic conditions and emission of methane due to a reduction of the supply of sulphate from marine waters.

Where physical structures limit the drainage of ponded water out of a site, the following may occur:

- Ponding of fresh water behind physical structures created on land converted from mangroves or tidal marsh may increase emissions of CH_4.
- Downstream impacts upon plant communities including shifts in species distributions

Re-introduction of tidal flow to areas from which it has been removed will allow re-establishment of areas previously occupied by mangroves and tidal marshes. This will lead to sequestration (mangrove biomass and mangrove and tidal marsh soils) and avoided emissions (reduced losses of C_{org} as CO_2, organic nitrogen as N_2O and CH_4 from soils that were previously removed from tidal influence). Where land previously not subjected to tidal flow is introduced to tidal flow and the land is placed at a suitable elevation within the tidal frame (e.g. behind natural levees, subsided or excavated coastal lands), sequestration of carbon in biomass (mangroves) and soil (mangroves and tidal marshes) would occur.

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Introduction or re-introduction of tidal flow can be carried out where tidal flow has historically been disconnected. There are numerous circumstances where this may apply. For example:

- in tropical monsoon areas (QLD, NT, WA) structures such as artificial levees are used to create ‘ponded pastures’ behind structures which support pasture grasses rather than mangrove or tidal marsh species. These ponded pastures may result in a significant loss of soil C_{org} stocks, be significant sources of methane due to the ponding of water and the exclusion of sulphates from marine waters (which otherwise act to inhibit methane production), and possible emission of N_2O in response to fertiliser addition, animal dung and urine and alterations to the soil nitrogen cycle.
- subtropical and temperate estuaries that have been modified for agricultural purposes may include water regulation structures (levees, floodgates, etc.) which aim to exclude tidal waters and promote draining of floodplain areas for agricultural use. Oxidation of soil C_{org} may be occurring in these areas as a result of draining. When flooded by freshwater, areas behind these structures may loose soil C_{org} stock, be significant sources of methane due to the ponding of water and the exclusion of sulphates from marine waters (which otherwise act to inhibit methane production) and a source of N_2O.
- reduced tidal connectivity through creation of roads (with or without culverts), seawalls and levees may also apply in urban areas (including canal estates). Oxidation of soil C_{org} may be occurring in these areas as a result of draining. When flooded by non-tidal sources, areas behind such structures may be significant sources of methane due to the ponding of water and the exclusion of sulphates from marine waters (which otherwise act to inhibit methane production).

Introduction of tidal flow to areas previously not affected could occur in response to the combined effect of removing physical structures limiting tidal flow and sea level rise. Alternatively, it could occur in response to altering surface elevation via earthworks to create new mangrove or tidal marsh habitat.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

The following studies highlight the potential of this abatement activity:

In a study comparing natural and tidally restored wetlands in the Hunter estuary of NSW, Howe et al. (2009) reported a rapid response of soil C_{org} accumulation in tidally restored mangroves and tidal marshes. The increased carbon sequestration rate of the disturbed wetlands was driven by substantially higher rates of vertical accretion (95% higher for mangrove and 345% higher for tidal marsh), relative to the natural reference site.

In a study of drained coastal wetland soils in East Trinity Inlet, Queensland, Hicks et al. (1999) estimated that 45% (or 0.07 million tonnes) of carbon had been lost as a result of oxidation and the dissolution of carbonates in acid sulphate soils (ASS) over a ~20 year period. No quantification of the contribution of carbonates to this estimate was reported, however, an overall average annual CO_2 emission rate for East Trinity Inlet of 33 t C ha^{-1} yr^{-1} was calculated. While estimates of the area affected by drainage were unavailable, Hicks et al. (1999) estimated up to 10 million tonnes of carbon loss annually over 20 years (assuming drainage of 10% of the ~30,000 km^2 of ASS across Australia).

There is also some evidence of subsidence within areas behind artificial water regulation structures (e.g. East Trinity Inlet in Queensland, Hicks et al. (1999)) and in the Hunter Estuary wetlands of NSW (N. Saintilan and J. Kelleway, unpublished data). This suggests either enhanced remineralisation of previously stored carbon and/or reduced sedimentation is occurring as a result of tidal disconnection.

Macklin et al. (2014) investigated the atmospheric flux associated with canal estate developments in southeast QLD. They found that residential canals contributed 46% and 56% of the total flux of CO_2 to the atmosphere during the dry and wet seasons, respectively, across the Gold Coast region. These results imply that areas that were previous atmospheric carbon sinks have become sources of CO_2 to the atmosphere since the development of residential canal estates.

Crooks et al. (2014) estimated the emissions resulting from land use change in the Snohomish Estuary of Washington, USA, at 4.5 million tons of carbon (MtC), of which 1.7 MtC was from draining soils. Of 4,749 ha of converted and drained wetlands, 1,353 ha are currently in planning or construction for restoration and it has been anticipated that rebuilding of soil carbon stocks of 0.32 MtC will occur as wetlands recover to former tidal elevations, and an additional 0.38 MtC with sea level rise of 1 m. Full estuary restoration is anticipated to rebuild soil carbon stocks of 1.2 MtC as tidal marshes build to emergent wetland tidal elevations, and a further 1.2 MtC as they accrete with sea level rise of 1 m. Any recovery of forest biomass would be additional to projected accumulation of soil carbon.

Craft et al. (2003) used a 28-year chronosequence to show that soil carbon accumulation, developed almost instantaneously with the establishment of vegetation in constructed marshes, while similar soil carbon accumulation rates were observed over 10 years in a natural and created marsh (Craft et al. 2002).

Osland et al. (2012) used a 20 year time for space chronosequence to quantify changes in plant and soil variables, including carbon storage in response to mangrove wetland creation in Florida, USA. These results characterize the rate and trajectory of above- and below-ground changes associated with ecosystem development in created mangrove wetlands.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Agricultural, State, Council, Commonwealth and Indigenous landholders on lands which have been previously disconnected from tidal flow. Land ownership and implications of altering high water marks due to changing tidal flow and the implications on property perimeters and who owns the carbon sequestered will need to be considered. Data from the Department of Agriculture and Water Resources – ABARES suggests a large proportion of mangrove habitat is within private lands (35%), leasehold (17%) or unresolved tenure (17%). Such data is not currently available for tidal marshes.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

Unless otherwise stated, the following estimates of potential abatement intensity are based on mean national carbon stock data compiled by the CSIRO Coastal Carbon Cluster and greenhouse gas emissions factors taken from the 2013 IPCC Wetlands Supplement (for range and 95% CI data see Appendix 2):

Scenario A: Tidal introduction to drained, treeless community

Stock change rates:

- estimated increase in mangrove biomass stocks of 6.25 Mg C ha^{-1} yr^{-1} for 20 years

- estimated increase in mangrove soil stocks of 1.26 Mg C ha^{-1} yr^{-1}

- estimated increase in tidal marsh soil stocks of 0.39 Mg C ha^{-1} yr^{-1}

Avoided emission rates:

- estimated CO_2 emission rate for both mangroves and tidal marshes of 7.9 Mg C ha^{-1} y^{-1}

Total abatement intensity for mangroves = 15.41 Mg C ha^{-1} yr^{-1}

Total abatement intensity for tidal marshes = 8.29 Mg C ha^{-1} yr^{-1}

Scenario B: Introduction of saline water to ponded freshwater

Stock change rates:

- estimated increase in mangrove biomass stocks of 6.25 Mg C ha^{-1} y^{-1} for 20 years

- estimated increase in mangrove soil stocks of 1.26 Mg C ha^{-1} yr^{-1}

- estimated increase in tidal marsh soil stocks of 0.39 Mg C ha^{-1} yr^{-1}

Avoided emission rates:

- estimated CH_4 emission rate for both mangroves and tidal marshes of 5.42 Mg C ha^{-1} y^{-1}

- estimated N_2O emission rate – no default value available

Total abatement intensity for mangroves = 12.93 Mg C ha^{-1} yr^{-1}

Total abatement intensity for tidal marshes = 5.81 Mg C ha^{-1} yr^{-1}

Area estimates of potential abatement:

Estimates of the area over which this activity could potentially occur are limited and geographically restricted. The following are the best estimates known to be available:

- Ponded pastures in QLD – up to 35,000 ha of tidal marsh lost (Neldner et al. , Wegscheidl et al. 2015).
- Drained coastal wetlands in northern NSW – 62,000 ha of 'prime fish habitat' lost (inclusive of tidal marshes and mangroves) (Rogers et al. 2015)

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Loss of agricultural income

- Alteration to habitat structure. For example, loss or decline in habitat quality for freshwater dependant species (e.g. frogs), or decline in open vegetation habitat (e.g. for roosting birds) resulting from mangrove afforestation

- Third party impacts in terms of flooding, groundwater and salinity impacts to neighbouring or nearby properties

- Potential for tidal scouring and erosion of sediments in areas associated with enhanced tidal energy

- Loss of visual amenity associated with mangrove afforestation.

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Restoration of tidal connectivity is currently being promoted through fisheries habitat and biodiversity restoration schemes and in some locations through ASS remediation (for drained ASSs). There is the potential for an economic incentive from emissions reduction to help turn potential or planned projects under these other schemes into realised projects.

3. Additionality

3.1 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is unlikely that an agricultural landholder would introduce or re-introduce tidal connectivity to their lands as this may result in loss of production capacity. There is also little to no incentive for the improvement of tidal connection into residential canal estates.

In some instances, there may be other environmental schemes (fisheries habitat restoration, ASS remediation, biodiversity schemes) which promote tidal re-connection, thereby weakening the additionality for this activity.

Table 17. Abatement integrity assessment for re-introduction of tidal flow for mangroves and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not support the restoration of tidal connectivity to areas that have historically been disconnected.
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Research papers have shown that changes in carbon following restoration can be measured, including through monitoring (e.g. Howe et al. (2009) chronosequence (e.g. Osland et al. (2012) and determination of historic subsidence volumes (Crooks et al. 2014).
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited.

Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	There are sufficient examples from the literature to show likely sequestration and emissions benefits of this activity
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	There are methods available to quantify emissions, including any material amounts that may occur.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	1	Based upon mean values reported across multiple species

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	MAN (biomass) = 11 MAN (soil) = 10 TM (soil) = 10	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline: Baseline biomass and soil C_{org} stocks can be measured through field measurements and collection and laboratory analyses of samples prior to the activity. Emissions may be measured using instruments deployed at the site prior to the activity. These data can be compared to suitable, nearby control and reference sites. The duration over which emission assessments are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted on by any particular temporal event.

- Estimation of baseline from literature values: Existing literature can be used to estimate average/median loss of carbon stocks following tidal disconnection to estimate baseline emissions. Where available, regional scale models may be used to determine values or identify landscape variability in values.

- Estimation of baseline from measured literature values and spatial modelling approaches: Existing data quantifying stocks at point locations can be used with a range of covariates to construct models capable of predicting baseline stocks at other locations.

- Estimation of baseline from emissions factors: (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration).

5.2 List and justify the assumptions and uncertainties on which the baseline is based.

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and atmospheric flux. Where baseline measurements can be taken within the project area, this uncertainty can be quantified using approaches similar to those used in the existing "Sequestering carbon in soils in grazing systems" ERF method. Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites. In some instances there may not be suitable reference/control sites to use.

- The use of literature values assumes suitable, relevant information is available. Sources of uncertainty may include differences due to ecosystem age, species composition, intertidal location, soil type and community structure. At present there have been few studies published on this topic from Australian settings, especially in regard to atmospheric flux.

- In cases where drained soils are the baseline scenario, the rate of organic matter decomposition (loss of soil C_{org} as CO_2 will likely vary among sites, according to their climate, soil salinity and type, and the recalcitrance of the organic matter.

- Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration) may underestimate or overestimate baseline values, depending on the specific conditions of the project site.

- Where drained soils represent the baseline condition, IPCC Tier 1 emissions factors are based upon the following assumptions:

  1. Emissions persist as long as the soil remains drained or as long as it takes for soil C_{org} stocks equivalent to those in natural/undrained settings with vegetation to be oxidised.

  2. The drainage condition is characterized by full drainage below the soil surface (i.e. the water table has been changed to 1 m).

5.3 Describe the steps and/or processes involved in undertaking the abatement activity and identify all emissions sources and sinks directly or indirectly affected by the activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

1. Re-introduce tidal flow to an area that was previously under the influence of tides or introduction of tidal flow to an area not previously exposed to tides. This could be done by removing natural and anthropogenic barriers to tidal flow in combination with sea level rise.

2. Passive and/or active revegetation of mangroves or tidal marshes.

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Table 18.Baseline inclusions and exclusions

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	
Project activity sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org}*	Included	

* In many blue carbon estimates belowground biomass and soil C are measured and reported as a single, amalgamated value.

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area that would be inundated by tidal waters by the restoration activity (e.g. removal of walls to a defined elevation). This would need to be modelled prior to commencing the project, most likely through use of digital elevation and/or hydrological models.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

1. Biomass and soil C_{org} stocks can be measured through field collections and laboratory analyses of samples prior to the activity. Biomass measurements may involve the destructive sampling of small, representative plots (often used for tidal marshes and grassland communities), or the combination of field measurements of vegetation structure and allometric equations to estimate biomass non-destructively (often used for mangroves and other forests). Soil samples are often collected as soil cores and require measurement of both bulk density and carbon content. Measurement techniques defined in other ERF methods (e.g. Vegetation Management methods and "Sequestering carbon in soils in grazing systems") would be applicable.

Uncertainties:

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and accumulation rates. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- Uncertainties in field-based biomass quantifications for mangroves may arise from use of allometric equations derived from other locations or for other plant species, which are not suited to the project site. Use of different allometric equations (i.e. from different literature sources) may lead to substantial variation in the biomass estimated for a site. Alternatives include development of site-specific allometric equations (this may require destructive sampling of vegetation within the project site) or use of non-destructive technologies such as LiDAR or Terrestrial Laser Scanner measurements.

- Comparison to reference/control sites assumes suitable site selection. In some instances, there may not be suitable reference/control sites to use.

2. Biomass carbon stocks may be estimated from remotely-sense data (i.e. remote sensing, LiDAR) prior to activity.

Uncertainties:

- Requires data capture of a suitable baseline condition (e.g. prior to establishment of the activity, or of a suitable reference location)

- Remotely-sensed data needs to be of sufficient spatial resolution for the purpose of biomass estimation

- Remotely-sensed data may capture aboveground biomass stocks with adequate accuracy but may not provide a reliable estimation of belowground biomass due to inconsistencies in above versus belowground partitioning of mangrove and tidal marshes in different environmental settings.

3. Emissions may be measured using field-based instruments (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) deployed at the site prior to the activity to determine baseline values.

Uncertainties:

- Wetland atmospheric fluxes may vary substantially across landscapes and climatic gradients. It would therefore be beneficial to develop emissions factors at local scales (e.g. site or estuary scales).

- Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- The quantity and type (CO_2, CH_4, N_2O) of atmospheric flux may involve substantial temporal variability. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night).

4. Estimates of carbon emissions may be made based upon hypsometric determination of a subsided volume below an assumed historic wetland surface elevation and an ascribed conservative soil C_{org} density value derived from the field analysis (Crooks et al. 2014). This does not include loss of carbon pools from living biomass. Annual rates of emission may then be calculated on the basis of time since subsidence began.

<u>Uncertainties</u>:

- Hypsometric determination of subsided volume assumes that subsidence is due to tidal disconnection rather than other causes (e.g. deep subsidence, groundwater changes). This method also require knowledge, or assumption of the historical surface elevation, which may be estimated on the basis of vegetation composition prior to tidal disconnection.

5. Surface accumulation measurements can be used to monitor and measure baseline surface dynamics of mangrove/tidal marsh soils. Soil accumulation rates (in concert with soil C_{org} analyses) can be used to calculate soil C_{org} accumulation rates. Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1cm. Real Time Kinetic (RTK GPS) can be used to determine surface elevation to < ~5cm accuracy. Radiometric dating techniques (e.g. ^{210}Pb, ^{137}Cs and ^{14}C) may also be used to calculate soil accumulation rates which can be used to calculate carbon accumulation rates.

<u>Uncertainties</u>:

- SET and MH techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement may be required to define an accurate baseline. Changes in surface elevation may result from multiple belowground and surface processes, which may or may not be related to carbon dynamics.

- Quantifying carbon accumulation in the surface soils may underestimate C sequestration because root detritus contributes to soil C_{org} throughout the soil profile (Lovelock et al. 2013). For example, mangrove roots tend to grow within older decomposing root structures (McKee 2001). This can be addressed by using analyses which incorporate a deeper section of the soil profile, such as radiometric dating methods.

- Quantifying carbon accumulation in the surface soils may overestimate C sequestration because C concentrations in the top sediment surface layer may be higher than that incorporated into the soil profile (Breithaupt et al. 2012, Lovelock et al. 2013). That is, a large proportion of surface organic matter may be lost through diagenesis within the first year of deposition (Duarte and Cebrian 1996).

- Marker Horizon techniques may prove unreliable due to loss of the marker layer due to bioturbation or disturbance to the soil profile.

6. Use of emissions factors, such as those outlined in the IPCC Wetlands Supplement (2013).

Uncertainties:

- Use of global or regional emissions factors may introduce substantial uncertainty as carbon stocks and greenhouse gas emissions can vary substantially across landscapes, wetland types, and climatic gradients. Use of locally derived emissions factors may help to overcome some of this uncertainty.

- The IPCC Tier 1 level of estimation assumes that:

1. soil C_{org} accumulation is initiated when natural vegetation becomes established

2. the rate of soil C_{org} accumulation is instantaneously equivalent to that in natural settings.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Approaches to calculate project activity emissions are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken. For example, if SET measurement show that the surface elevation has grown 5cm under the project, then the soil C_{org} stock would be measured over 1.05 m soil depth. Similarly, if the SET measurements show a decrease in surface elevation under the project (e.g. elevation loss of 3 cm) then the soil C_{org} sampling depth will be reduced by this amount (i.e. 0.97 m).

A further exception is the hypsometry technique, which would only be used to develop baseline emissions. This approach could be paired with other techniques which provide soil accumulation data after the activity (i.e. SET, MH and radiometric dating data).

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

Calculation of net GHG abatement may be calculated as the difference between the baseline and project activity values for the following methods:

1. Field measurements (biomass) and sample collection with laboratory measurement (soils). Possibly field based soil measurements using infra-red spectroscopic approaches (depending on adequacy of calibration)

2. Biomass carbon stocks estimation using remotely-sense data

3. Emission measurement with field-based instruments (flux towers, continuous measurement chambers, static chambers combined with modelling)

4. Surface accumulation measurements (SETs; MHs; radiometric dating)

5. Use of emissions factors

The hypsometry technique would only be used to develop baseline emissions. This could be paired with other techniques which provide soil accumulation data after the activity (i.e. SET, MH and radiometric dating data).

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

Baseline emissions and removals data may be collected on the basis of:

1) direct or remotely-sensed measurements taken in the project site prior to the activity;

2) via direct or remotely-sensed measurement of suitable reference/control sites;

3) or estimated on the basis of literature values and published emissions factors.

In some instances, there may not be suitable reference/control sites to use and/or there may not be suitable literature values to use. In such instances direct measurement in the project site or reliance upon emissions factors may be required.

Many of the methods outlined require consideration of temporal and spatial variability expected in carbon storage, accumulation and emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radiometric dating is likely to provide the best long term record of soil accumulation rates and may also be used to develop a baseline value of carbon stocks and longer-term accumulation rates using soil cores collected after the commencement of the activity.

The soil C_{org} emission technique based upon hypsometric determination of a subsided volume below an assumed historic wetland surface elevation (Crooks et al. 2014) is one method which is likely to be unique to the current activity (re-introduction of tidal flow). This method may be applied for baseline measurement prior to this activity where prior draining of a wetland has caused measurable subsidence (e.g. Trinity Inlet, Cairns, Hicks et al. (1999)).

8. Double counting

8.1 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream carbon sources that are already being captured in inventory reporting (e.g. carbon that enters the blue carbon ecosystem through river system or catchment area).

Both autochthonous and allochthonous carbon sources may accumulate within the soil C_{org} pool in response to this activity. It is currently being investigated as to whether both autochthonous and allochthonous sources of accumulation will be available for carbon accounting under this activity. This issue is addressed in further detail in the recommendations section.

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the carbon stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of carbon stored:

- Accelerated rates of relative sea level rise may outpace the capacity of mangrove or tidal marsh to build surface elevation, leading to mortality of plants and eventual loss of aboveground biomass carbon pool. Subsidence of a site (including due to belowground extraction of resources) may also act to increase relative sea level. The likelihood of negative effects of sea level rise would be experienced at sites low in the tidal frame, occurring at mean sea level. Higher in the intertidal zone elevation capital may result in wetland persistence even with high rates of sea level rise (Cahoon and Guntenspergen 2010, Lovelock et al. 2015).

- Natural disturbances such as cyclones may cause damage and/or loss of biomass carbon stocks.

- Fire may occur through the aboveground biomass of tidal marshes and mangroves. It is unlikely to cause the remineralisation of belowground biomass and soil C_{org} stocks.

- Dieback of plant biomass, including mangroves (as observed recently in Northern Australia). Causes of such dieback are not well understood at present, but may include drought, prolonged submergence (flooding), temperature stress, insect or other pathogens, among others.

- Foreshore erosion.

- Drainage of soil leading to remineralisation of C as a result of agriculture, runnelling for mosquitoes, alteration of groundwater.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements would need to be measured or estimated and reported in relation to this activity:

- Changes in carbon stocks (biomass and soil pools) on a per unit of area basis. For biomass, this would include the C_{org} associated both above and below ground components – this might be estimated on the basis of either field or remotely-sensed data. For soils this would require definition of an initial depth to be sampled – currently recommended to be 1 m within the IPCC wetlands supplement (Hiraishi et al. 2014) – and a mechanism to quantify the change in soil C_{org} stock above this horizon through time. For soils, monitoring of surface elevation change (e.g. through use of SETs, MHs; RTK GPS) may provide information on surface C_{org} accumulation rates above the baseline horizon. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2).

- Change in CH_4 and N_2O emissions. This will require sufficient temporal coverage including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night). Values could be obtained from direct measurement/monitoring or through the use of approved emission factors.

- A range of measurement options ranging from project specific direct measurement through to the use of IPCC Tier 1 emission factors should be considered. Project specific measurements will be more expensive but should yield more accurate results for that project. Direct measurement techniques defined in current ERF Vegetation Management methods would be applicable to quantify biomass carbon stocks and that outlined in the "Sequestering carbon in soils in grazing systems" ERF method could be adapted for use to monitor soil C_{org} stocks. If emission factors are adopted it will be important to ensure that they are appropriate for Australian conditions and are conservative in their estimate of the magnitude of net abatement achieved.

In general, monitoring on annual or sub-annual timescales may be required in the first years after tidal reintroduction when the ecosystems involved are likely to be most dynamic. Once the restored ecosystems stabilise, monitoring on annual to sub-decadal timescales will likely be appropriate. Existing ERF methodologies require offsets reports to be submitted at least every 5 years for sequestration projects or every 2 years for emissions avoidance projects.

The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The sample size required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b). Based upon global compilation of tidal marsh and mangrove carbon sequestration rates (Chmura et al. 2003), guidance for the VCS suggests sample sizes of approximately 10-20 samples per stratum will likely be required. For measurement of methane fluxes co-efficients of variation are high, requiring about 40 samples (chambers) per stratum (Restore America's Estuaries and Silvestrum 2015a).

- Guidance pertaining to these issues can be obtained from current ERF Vegetation Management and "Sequestering carbon in soils in grazing systems" methods.

11. Land ownership and legal right to carbon

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

The legal right to carbon may vary among jurisdictions if the definition of the seaward boundary of properties varies. In most instances this is the mean high water mark (MHWM), as is the case for example in NSW, however there may be instances where this is not the case. This has particular implications for mangroves which generally occupy elevations between mean sea level (i.e. below MHWM) and the Highest Astronomical Tide (HAT; above MHWM). Further, land that has subsided as a result of decades of tidal disconnection may also occupy elevations below the legislated property limits.

Where land is bounded by water, the legal boundary of the land generally changes to reflect changes in the position of the waters' edge, but only if certain conditions are met (such as changes being 'gradual' and 'natural').

6.4.2 Enhancing sediment supply

Category: Mangrove protection**;** Mangrove establishment/restoration; Tidal marsh protection; Tidal marsh restoration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

Alterations to sediment supply may include any activity which enhances local sedimentation within existing mangrove or tidal marsh ecosystems and enable these ecosystems to survive *in situ* or expand in the face of sea level rise (SLR). This may include direct sedimentation practices such as the discharge of dredge spoil or other sediment spoil to mangroves and tidal marsh substrates or alteration (removal, modification, relocation, installation) of water control structures (dams, natural or artificial levees, seawalls, river diversions, etc.) which either trap sediments or alter hydrodynamic energy. Earthworks or geoengineering works (such as the creation of nearshore oyster reefs or river diversions) might be used to modify the contour of nearby areas and increase local sedimentation.

This activity may have implications for the continued production of biomass carbon pools (sequestration), soil C_{org} pools (sequestration) and avoided emissions which would otherwise occur if these ecosystems drowned under SLR (avoided emissions).

Where there is insufficient sediment supply to a site, the following may occur:

- Insufficient sedimentation to mangrove and tidal marshes may cause an ‘elevation deficit’ whereby the wetlands are unable to keep pace with sea level rise. Consequently, vegetation may die and soils subject to deeper inundation may erode. Loss of vegetation will have consequences for biomass carbon stocks and accumulation rates;

- Loss of vegetation may reduce the trapping capacity of a site to capture allochthonous sources of carbon;

- Potential mobilisation of soil C_{org} stocks once vegetation dies (and hydrodynamic energy increases).

Enhanced sediment supply may have the following carbon benefits:

- Maintenance of elevation in the face of SLR, leading to continued accumulation of biomass and soil C_{org} stocks

- Sedimentation may be a source of allochthonous carbon pool. Increases to sedimentation rates may enhance accumulation of this allochthonous carbon pool.

- Sedimentation may be a source of nutrients supporting enhanced primary productivity

- Rapid sedimentation may bury recently accumulated surface carbon pools, thereby reducing loss of labile carbon through early diagenesis.

- Excessive sedimentation has the potential to smother tidal marsh vegetation and mangrove pneumatophores, leading to declines in productivity or plant mortality.

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Enhancement of sedimentation may be undertaken in a number of circumstances. These may include:

- Where upslope and upstream water control structures act as sediment traps which reduce sediment supply to downstream and downslope areas of existing (or potential) mangrove and tidal marsh. The activity would involve changing the operation of these structures so that more sediment is mobilised and made available to downstream mangroves and tidal marshes. More specifically, this may include:

- dams and weirs on coastal rivers. Examples include the Ord River in the Kimberley region of WA, the estuarine lakes at the mouth of the Murray River in SA, and many coastal rivers in eastern Australia (e.g. Shoalhaven, Hawkesbury and Hunter Rivers in NSW)

- 'ponded pastures' in tropical monsoon areas (QLD, NT, WA) where artificial levees are used to create 'ponded pastures' which support pasture grasses rather than mangrove or tidal marsh species.

- subtropical and temperate estuaries which have been modified for agricultural purposes may include water regulation structures (levees, floodgates, etc.)

- reduced sediment supply through creation of roads (with or without culverts), seawalls and levees may also apply in urban areas.

- This activity may also apply where proponents choose not to act on approvals granted for the construction of new water control structures, including dams, floodgates and levees. This may apply to significant areas of northern Australia where there is interest in the future development of water resources.

- Where dredging operations are currently undertaken or likely to be undertaken in the future. This applies to many ports and estuaries around Australia. The activity would be application of dredge spoil directly to mangrove/tidal marsh ecosystems, or deposition as an offshore sub-tidal berm (allowing tidal/wave action to move the sediment up into the wetland).

- Where nearshore bathymetry and land-use is conducive to restoration and/or installation of features such as oyster reefs which reduce hydrodynamic energy in the intertidal zone and enhance sedimentation there. The activity would be restoration and/or installation of sedimentation enhancement structures.

- Where existing water management structures (such as culverts and floodgates) can be manipulated to alter the deposition dynamics of a site (for example, holding tidal inundation for a longer period than would normally occur).

- Where mangroves and tidal marshes exhibit symptoms or elevation deficit in the face of sea level rise. These symptoms may include erosion of soils, fragmentation of vegetation, drowning/dieback of vegetation and upslope migration of species (including mangrove encroachment upslope into tidal marshes).

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

The following studies highlight the potential of this abatement activity:

In a study comparing natural and tidally restored wetlands in the Hunter estuary of NSW, Howe et al. (2009) reported a rapid response of soil C_{org} accumulation in tidally restored mangroves and tidal marshes which was driven largely by enhanced sediment supply in the restored sites. The 'activity' here was restoration of tidal connection to a wetland, which had the impact of enhancing sedimentation rates. That is there were substantially higher rates of vertical accretion (95% higher for mangrove and 345% higher for tidal marsh), relative to the natural reference site.

There is evidence of subsidence within areas behind artificial water regulation structures (e.g. East Trinity Inlet in Queensland (Hicks et al. 1999) and in the Hunter Estuary wetlands of NSW (N. Saintilan and J. Kelleway, unpublished data). This suggests either enhanced remineralisation of previously stored carbon and/or reduced sedimentation is occurring as a result of tidal disconnection.

Spontaneous vegetation establishment of tidal marsh species has been observed on a range of sediment types, including fine-textured, dredged sediments, sandy sediments, and even landfill sediments (Rozsa 2012), including previously disturbed sediments in Sydney Olympic Park (Kelleway et al. 2007). These studies suggest activities enhancing sedimentation may allow or even promote plant growth and associated carbon pools.

The use of dredge spoil in tidal marsh restoration and elevation management is relatively well established for North American tidal marshes including the Gulf of Mexico (Ford et al. 1999, Slocum et al. 2005) and Atlantic coast (Yozzo et al. 2004). In a definitive study, Slocum et al. (2005) found that sediment enrichment affected plants and soils by two mechanisms:

1) it increased elevation and soil bulk density, leading to increased plant vigour and soil condition over the seven year study period;

2) the sediment slurry also had high nutrient content, which resulted in a pulse of growth, especially in areas receiving the high sediment supply. This nutrient-induced growth spurt was short lived and faded after 3 years.

Osland et al. (2012) used a 20 year time for space chronosequence to quantify changes in plant and soil variables, including carbon storage in response to mangrove wetland creation in Florida, USA. These mangrove creation sites used dredge spoil or upland soils as the new substrate. The results of this study characterize the rate and trajectory of above- and below-ground changes associated with ecosystem development in created mangrove wetlands, showing functional equivalence of aboveground and surface soils with natural references sites within 20 years of creation.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Water management agencies and corporations including dam operators; dredging operators and sediment disposal operators; agricultural, State, Council, Commonwealth and Indigenous landholders of lands which are experiencing or likely to experience elevation deficit.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

Unless otherwise stated, the following estimates of potential abatement intensity are based upon national carbon stock data compiled by the CSIRO Coastal Carbon Cluster and greenhouse gas emissions factors taken from the 2013 IPCC Wetlands Supplement (for range and 95% CI data see Appendix 2):

<u>Stock change rates:</u>

- estimated increase in mangrove soil stocks of 1.26 Mg C ha^{-1} yr^{-1}

- estimated increase in tidal marsh soil stocks of 0.39 Mg C ha^{-1} yr^{-1}

<u>Avoided emission rates:</u>

- no data available

Total abatement intensity for mangroves = 1.26 Mg C ha^{-1} yr^{-1} + avoided emissions (no data)

Total abatement intensity for tidal marshes = 0.39 Mg C ha^{-1} yr^{-1} + avoided emissions (no data)

No estimates are currently available to determine the area over which this activity could occur.

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Removal or modification of water control structures may have impacts in terms of flooding, downstream properties and infrastructure.

- Alteration to habitat structure. For example, loss or decline in habitat quality for subtidal or mudflat dependant species (e.g. shorebirds) resulting from mangrove afforestation or tidal marsh growth in areas of enhanced sedimentation.

- Remobilisation of sediments after extreme events (floods, storms) or unforeseen movement of sediments to unintended areas may have adverse impacts upon subtidal ecosystems (such as seagrasses) and associated industries (oyster production and other aquaculture).

- Inappropriate (excessive) application of sediments may bury existing vegetation structures (whole tidal marsh plants; mangrove aerial roots; seedlings) and cause vegetation die-back.

- Potential for remobilisation of pollutants such as heavy metals and dioxins contained in dredge spoil.

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

While there are numerous measures in place which aim to reduce sediment supply to coastal regions - such as in the agricultural catchments of the Great Barrier Reef; and erosion/sedimentation controls associated with construction activities – there are few measures which specifically promote sedimentation to aquatic environments.

Australia is currently experiencing unprecedented volumes of marine sediment dredging, particularly in QLD and WA. Most of the dredge material produced is typically dealt with by dumping in marine or terrestrial spoil grounds, with negative environmental consequences (Erftemeijer and Lewis 2006). Dredge spoil could be added directly to mangrove/tidal marsh ecosystems to enhance sedimentation, or deposited as an offshore sub-tidal berm (allowing tidal/wave action to move the sediment up into the wetland), thereby providing an economic and environmental opportunity. No specific scheme for such use of dredge spoil is currently in place.

3. Additionality

3.2 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is highly unlikely that active sedimentation would be undertaken in mangroves or tidal marshes as no measures or incentives are currently in place for this. Current practices are likely to avoid sedimentation in mangrove and tidal marsh wetlands due to regulations placed upon development of these and adjacent seagrass and coral ecosystems (e.g. Reef 2050 Long-Term Sustainability Plan for the Great Barrier Reef).

Table 19. Abatement integrity assessment for introduction of sediments to mangrove and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not support enhanced sedimentation to mangroves and tidal marshes.
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	There is substantial research and case studies which outline the successful use of sedimentation and surface elevation monitoring in mangroves and tidal marshes, and the response of vegetation to these surface dynamics.
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited. However, there may be a need to discount any incoming carbon in the sediment, depending on whether the carbon in the sediment was stable in its original location.

Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	There are sufficient examples from the literature to show likely sequestration and emissions benefits of this activity
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	This activity is not expected to lead to material amounts of GHG emission. There are methods available to quantify emissions if they do occur.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	1	Based upon mean values reported across multiple species and aerial extent based upon locations within and outside Australia.

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	MAN (biomass) = 11 MAN (soil) = 10 TM (soil) = 10	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline: Baseline biomass and soil C_{org} stocks can be measured through field measurements and collection and laboratory analyses of samples prior to the activity. Emissions may be measured using instruments deployed at the site prior to the activity. These data can be compared to suitable, nearby control and reference sites. The duration over which emission assessments are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted on by any particular temporal event.

- Estimation of baseline from literature values: Existing literature can be used to estimate average/median loss of carbon stocks prior to the activity to estimate baseline emissions. Where available, regional scale models may be used to determine values or identify landscape variability in values.

- Estimation of baseline from measured literature values and spatial modelling approaches: Existing data quantifying stocks at point locations can be used with a range of covariates to construct models capable of predicting baseline stocks at other locations.

- Estimation of baseline from emissions factors: (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration).

5.2 List and justify the assumptions and uncertainties on which the baseline is based.

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and atmospheric flux. Where baseline measurements can be taken within the project area, this uncertainty can be quantified using approaches similar to those used in the existing "Sequestering carbon in soils in grazing systems" ERF method. Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites. In some instances, there may not be suitable reference/control sites to use.

- The use of literature values assumes suitable, relevant information is available. There is a good monitoring network of mangrove and tidal marsh surface dynamics in SE Australia, but there are geographic gaps elsewhere.

- Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration) may underestimate or overestimate baseline values, depending on the specific conditions of the project site.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity and identify all emissions sources and sinks directly or indirectly affected by the activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

1. Removal of sediment from donor location (either through active methods such as dredging and/or passive methods such as in-stream structures – oyster reef restoration, etc.).

2. Enhance rate of sedimentation to mangrove or tidal marsh.

3. Persistence of mangrove or tidal marsh productivity.

4. Avoidance of mangrove or tidal marsh dieback through ‘drowning’ (avoided emission)

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Table 20. Baseline details

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
Project activity sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area: 1) experiencing removal of sediment (typically an area that is not mangrove or tidal marsh), plus, 2) the area of mangrove or tidal marsh experiencing enhanced sedimentation. The former could be estimated on the basis of proposed removal activity (e.g. dredging operation area and volume) or through use of digital elevation and /or hydrological models. Sedimentation within mangroves and tidal marshes may be estimated *a priori* using the same methods, or measured after the fact by vegetation mapping which shows the maintenance of vegetation structure and vegetation productivity (e.g. NDVI remote sensing). Instrumentation of boundary areas with SETs and/or MHs or other sedimentation methods may also be used to confirm areas of enhanced sedimentation.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

1. Biomass and soil C_{org} stocks can be measured through field collections and laboratory analyses of samples prior to the activity. Biomass measurements may involve the destructive sampling of small, representative plots (often used for tidal marshes and grassland communities), or the combination of field measurements of vegetation structure and allometric equations to estimate biomass non-destructively (often used for mangroves and other forests). Soil samples are often collected as soil cores and require measurement of both bulk density and either C_{org} or organic matter content.

As sediment is being added to the mangrove / tidal marsh substrate as part of this activity deeper sampling will likely be required after the sedimentation event. Reference elevations within the soil depth profile would be required (see discussion of SET method in response 7.4).

Uncertainties:

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and accumulation rates. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- Uncertainties in field-based biomass quantifications for mangroves may arise from use of allometric equations derived from other locations or for other plant species, which are not suited to the project site. Use of different allometric equations (i.e. from different literature sources) may lead to substantial variation in the biomass estimated for a site. Alternatives include development of site-specific allometric equations (this may require destructive sampling of vegetation within the project site); or use of non-destructive technologies such as LiDAR or Terrestrial Laser Scanner measurements.

- Comparison to reference/control sites assumes suitable site selection. In some instances, there may not be suitable reference/control sites to use.

2. Biomass carbon stocks may be estimated from remotely-sense data (i.e. remote sensing, LiDAR) prior to activity. Plant productivity may be estimated remotely through NDVI analysis.

Uncertainties:

- Requires data capture of a suitable baseline condition (e.g. prior to establishment of the activity, or of a suitable reference location).

- Remotely-sensed data needs to be of sufficient spatial resolution for the purpose of biomass estimation.

- Remotely-sensed data may capture aboveground biomass stocks with adequate accuracy but may not provide a reliable estimation of belowground biomass due to inconsistencies in above versus belowground partitioning of mangrove and tidal marshes in different environmental settings.

3. Emissions may be measured using field-based instruments (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) deployed at a reference site which does not receive enhanced sedimentation. Emissions from the donor sediments may also be required, especially if taken from sites of different biogeochemical conditions (such as oxic, anoxic or freshwater sediment donor sites).

Uncertainties:

- Wetland atmospheric fluxes may vary substantially across landscapes and climatic gradients. It would therefore be would be beneficial to develop emissions factors at local scales (e.g. site or estuary scales).

- Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- The quantity and type (CO_2, CH_4, N_2O) of atmospheric flux may involve substantial temporal variability. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night).

4. Surface accumulation measurements can be used to monitor and measure baseline surface dynamics of mangrove/tidal marsh soils via comparison with a reference site not experiencing enhanced sedimentation. Soil accumulation rates (in concert with soil C_{org} analyses) can be used to calculate soil C_{org} accumulation rates. Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1cm. Real Time Kinetic (RTK GPS) can be used to determine surface elevation to

< ~5cm accuracy. Radiometric dating techniques (e.g. ^{210}Pb, ^{137}Cs and ^{14}C) may also be used to calculate soil accumulation rates which can be used to calculate carbon accumulation rates.

Uncertainties:

- SET and MH techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement may be required to define an accurate baseline. Changes in surface elevation may result from multiple belowground and surface processes, which may or may not be related to carbon dynamics.

- Quantifying carbon accumulation in the surface soils may underestimate C sequestration because root detritus contributes to soil C_{org} throughout the soil profile (Lovelock et al. 2013). For example, mangrove roots tend to grow within older decomposing root structures (McKee 2001). This can be addressed by using analyses which incorporate a deeper section of the soil profile, such as radiometric dating methods.

- Quantifying carbon accumulation in the surface soils may overestimate C sequestration because C concentrations in the top sediment surface layer may be higher than that incorporated into the soil profile (Breithaupt et al. 2012, Lovelock et al. 2013). That is, a large proportion of surface organic matter may be lost through diagenesis within the first year of deposition (Duarte and Cebrian 1996).

- Marker Horizon techniques may prove unreliable due to loss of the marker layer due to bioturbation or disturbance to the soil profile.

5. Use of emissions factors, such as those outlined in the IPCC Wetlands Supplement (2013).

Uncertainties:

- Use of global or regional emissions factors may introduce substantial uncertainty as carbon stocks and greenhouse gas emissions can vary substantially across landscapes, wetland types, and climatic gradients. Use of locally derived emissions factors may help to overcome some of this uncertainty.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Approaches to calculate project activity emissions are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken. For example, if SET measurement show that the surface elevation has grown 5 cm under the project, then the soil C_{org} stock would be measured over 1.05 m soil depth. Similarly, if the SET measurements show a decrease in surface elevation under the project (e.g. elevation loss of 3 cm) then the soil C_{org} sampling depth will be reduced by this amount (i.e. 0.97 m).

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

Calculation of net GHG abatement may be calculated as the difference between the baseline and project activity values for each of the methods identified:

1. Field collections and laboratory measurement

2. Biomass carbon stocks estimation and vegetation productivity using remotely-sense data

3. Emission measurement with field-based instruments

4. Surface accumulation measurements (SETs; MHs; radiometric dating)

5. Use of emissions factors

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

Baseline emissions and removals data may be collected on the basis of:

1) direct or remotely-sensed measurements taken in the project site prior to the activity;

2) via direct or remotely-sensed measurement of suitable reference/control sites;

3) or estimated on the basis of literature values and published emissions factors.

In some instances, there may not be suitable reference/control sites to use and/or there may not be suitable literature values to use. In such instances direct measurement in the project site or reliance upon emissions factors may be required.

Many of the methods outlined require consideration of temporal and spatial variability expected in carbon storage, accumulation and emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radiometric dating is likely to provide the best long term record of soil accumulation rates and may also be used to develop a baseline value of carbon stocks and longer-term accumulation rates using soil cores collected after the commencement of the activity.

8. Double counting

8.1 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream carbon sources that are already being captured in inventory reporting (e.g. carbon that enters the blue carbon ecosystem through river system or catchment area).

Both autochthonous and allochthonous carbon sources may accumulate within the soil C_{org} pool in response to this activity. It is currently being investigated as to whether both autochthonous and allochthonous sources of accumulation will be available for counting under this activity. This issue is addressed in further detail in the recommendations section.

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the carbon stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of carbon stored:

- Accelerated rates of relative sea level rise may outpace the capacity of mangrove or tidal marsh to build surface elevation, leading to mortality of plants and eventual loss of aboveground biomass carbon pool. Subsidence of a site (including due to belowground extraction of resources) may also act to increase relative sea level. In some instances, it may be possible to increase rates of artificial sedimentation to combat these changes.

- Natural disturbances such as cyclone may cause damage and/or loss of aboveground biomass and subsequent remineralisation of aboveground biomass carbon.

- Fire may occur through the aboveground biomass of tidal marshes and mangroves. It is unlikely to cause the remineralisation of belowground biomass and soil C_{org} stocks.

- Dieback of plant biomass, including mangroves (as observed recently in Northern Australia). Causes of such dieback are not well understood at present, but may include drought, prolonged submergence (flooding), temperature stress, insect or other pathogens, among others.

- Foreshore erosion (e.g. boat activity).

- Drainage of soil leading to remineralisation of C as a result of agriculture, runnelling for mosquitoes, alteration of groundwater.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in carbon stocks (biomass and soil pools) on a per unit of area basis. For biomass, this would include the C_{org} associated both above and below ground components – this might be estimated on the basis of either field or remotely-sensed data. For soils this would require definition of an initial depth to be sampled - currently recommended to be 1 m within the IPCC wetlands supplement

(Hiraishi et al. 2014)- and a mechanism to quantify the change in soil C_{org} stock above this horizon through time. For soils, monitoring of surface elevation change (e.g. through use of SETs, MHs; RTK GPS) may provide information on surface C_{org} accumulation rates above the baseline horizon. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2).

- Change in CO_2, CH_4 and N_2O emissions. This will require sufficient temporal coverage including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night).

- Extent of influence of enhanced sedimentation. This may change over time due to changes in hydrology (including sea level rise or storm events) or ecogeomorphic response of ecosystems to sediment input (e.g. excessive surface elevation gain may cause areas to rise above elevations of tidal influence).

- The fate of C and N moved with the sediments being deposited as a result of the project. This assessment may focus on whether the new conditions created are appropriate for the preservation of this C and N.

Existing ERF methodologies require offsets reports to be submitted at least every 5 years for sequestration projects or every 2 years for emissions avoidance projects. Monitoring should be undertaken after events of substantial disturbance (such as major storms and flooding events).

The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The sample size required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b). Based upon global compilation of tidal marsh and mangrove carbon sequestration rates (Chmura et al. 2003), guidance for the VCS suggests sample sizes of approximately 10-20 samples per stratum will likely be required. For measurement of methane fluxes co-efficients of variation are high, requiring about 40 samples (chambers) per stratum (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to carbon

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

The legal right to carbon may vary among jurisdictions if the definition of the seaward boundary of properties varies. In most instances this is the mean high water mark (MHWM), as is the case for example in NSW, however there may be instances where this is not the case. This has particular implications for mangroves which generally occupy elevations between mean sea level (i.e. below MHWM) and the Highest Astronomical Tide (HAT; above MHWM). Further, land that has subsided as a result of decades of tidal disconnection may also occupy elevations below the legislated property limits.

Where land is bounded by water, the legal boundary of the land generally changes to reflect changes in the position of the waters' edge, but only if certain conditions are met (such as changes being 'gradual' and 'natural').

6.4.3 Land-use change

Category: Mangrove protection; Mangrove establishment/restoration; Tidal marsh protection; Tidal marsh establishment/restoration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

Land-use change may be undertaken to impact upon mangrove and tidal marsh emissions and removals in two broad number categories: 1) alteration of land-use in existing mangrove and tidal marsh areas; and 2) land-use planning to allow upslope and upstream migration of mangroves and tidal marshes in the face of rising sea level.

Alteration of land-use in existing mangroves and tidal marshes may include changing either the type or intensity of land-use in an area. For example, the type of land-use might be changed from agricultural production (grazing) to environmental protection (grazing removed) OR the intensity of agricultural production may be altered (e.g. stocking densities or time of grazing). Depending on the specific land-uses involved, this activity may have implications for biomass carbon pools (sequestration), soil C_{org} pools (sequestration) and atmospheric flux of greenhouse gases (avoided emissions) within the existing wetland areas.

The most obvious impact of grazing upon carbon sequestration is the partial removal - or in extreme cases complete removal – of the aboveground carbon pool contained in plant biomass. However, grazing may also lead to a shift in biomass distribution whereby grazed plants store more biomass (and therefore carbon) belowground in roots and rhizomes (Elschot et al. 2015). Stock grazing has been shown to substantially change the vegetation composition and structure of tidal marshes (Adam 1990), including through selective grazing (Laegdsgaard et al. 2009). Stock may also act as seed vectors which may encourage weed growth, which may result in an alteration to overall biomass carbon pools. Grazing may also restrict the establishment, expansion or recruitment of plant species on suitable substrates. This may include restriction of mangrove propagule survival and restriction of the development into mature mangroves, which may have substantial implications for local carbon pools.

Land-use planning to accommodate migration of mangroves and tidal marshes in the face of rising sea level would have implications for biomass carbon pools (sequestration) and soil C_{org} pools (sequestration) as new areas of blue carbon ecosystem are created (Traill et al. 2011, Shoo et al. 2014, Mills et al. 2015). Sea level rise has the potential to alter the structure and function of blue carbon ecosystems, with implications for carbon sequestration (Saintilan et al. 2014, Kelleway et al. 2016c).

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

1) Alteration of land-use in existing mangrove and tidal marsh areas:

Due to the limitations imposed by inundation by saline water, land-uses within existing mangrove and tidal marsh areas are largely confined to environmental protection or crown land, and agricultural production (limited primarily to grazing). Mangrove and tidal marshes may occur at the edge of, or adjacent to a broader range of land-uses including residential, industrial and agricultural. Regardless of their classification, existing mangrove and tidal marsh areas may also be subjected to land-uses which are incompatible with their environmental values (including carbon sequestration capacity) such as disturbance from human and vehicle passage (Kelleway 2005, Laegdsgaard et al. 2009).

Land-use changes which are most amenable to carbon abatement activities will include changes in agricultural practices and restrictions on inappropriate land-use such as vehicle passage. These may operate in urban or regional areas across many parts of Australia. These activities may have implications for both sequestration and atmospheric flux (emissions).

2) Land-use planning to allow upslope and upstream migration of mangroves and tidal marshes in the face of rising sea level:

These activities may have implications for sequestration, as mangrove and tidal marsh vegetation (biomass) and biogeochemical conditions (e.g. sulphate rich tidal waters) are allowed to migrate to new areas. Where this avoids the submergence (drowning) of existing mangrove and tidal marsh ecosystems this may also have implications for avoidance of atmospheric flux (emissions).

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

The following studies highlight the potential of this abatement activity:

1) Alteration of land-use in existing mangrove and tidal marsh areas

Grazing management

Elschot et al. (2015) estimated total accumulated C_{org} in European tidal marsh soils and determined how this is affected by long-term grazing by both small and large grazers in relation to age of the ecosystem. They found a limited effect on total accumulated carbon in young marshes (where small grazers such as hare and geese predominate. In mature marshes (where cattle predominate) soil C_{org} content was substantially enhanced. The authors ascribed this to a biomass allocation shift (toward belowground biomass) by the plants, plus trampling effects of cattle enhancing the anoxic conditions of the soil.

Ford et al. (2012) measured soil greenhouse gas emissions from cattle grazed and un-grazed upper tidal marsh in the United Kingdom. They found:

- CO_2 efflux was greater from the ungrazed marsh than the grazed marsh throughout most of the year.

- CH_4 efflux from grazed and un-grazed marsh did not differ significantly although grazing did lead to 'hotspots' of underground CH_4 and CH_4 efflux.

- Grazing was not a significant predictor of N_2O soil emissions.

In a study comparing natural and tidally restored wetlands in the Hunter estuary of NSW, Howe et al. (2009) reported a rapid response of soil C_{org} accumulation in tidally restored mangroves and tidal marshes that had been used for agricultural grazing. The increased carbon sequestration rate of the disturbed wetlands was driven by substantially higher rates of vertical accretion (95% higher for mangrove and 345% higher for tidal marsh), relative to the natural reference site. However, these changes are likely to have been due more to the change in hydrology for the previously grazed site.

Together, these studies highlight the potential for mixed responses in carbon removals and emissions under grazing management. Importantly, no research investigating the direct influence of grazing management on carbon emissions and removals has been conducted in Australian settings.

Runnelling

Breitfuss et al. (2003) showed that runnelling (a form of habitat modification for mosquito control) in SE Australia transports and deposits mangrove propagules to tidal marsh because the runnels carry low-amplitude tides that would not normally inundate higher regions of the marsh. Observations suggest that these propagules can develop into mature mangroves. While this study did not assess carbon implications, other studies e.g., Kelleway et al. (2016c) suggest that mangrove encroachment of tidal marsh may lead to substantial increases in biomass and soil C_{org} pools, though it may take several decades for this increase to become apparent.

Managing inappropriate land-use

An ecological assessment of vehicle impacts on SE Australian tidal marshes (Kelleway 2005) highlighted significant vegetation removal, soil compaction and alteration of surface hydrology associated with unauthorised vehicle passage. This study did not quantify changes in carbon stocks caused by the activity or assess restoration.

2) Sea level rise planning to allow upslope and upstream migration of mangroves and tidal marshes

Rogers et al. (2013) combined vegetation mapping with elevation modelling to estimate the extent of land available for conversion to mangrove and tidal marsh habitat under land-use change and rising sea level in the Hunter River Estuary, NSW. They found approximately 2441 ha of estuarine wetland are located on the Hunter River floodplain, however an additional 6970 ha of land occurs within elevation ranges suitable for estuarine wetlands. These additional areas could support estuarine wetlands if there were management actions which allowed tidal flows to these areas. Modelling using current rates of sea level rise also suggested that by 2050, the Hunter River has the potential to support up to 8069 ha of estuarine wetlands provided that impediments to tidal flow are removed. This study did not quantify or model changes in carbon removals or emissions, however the study of (Howe et al. 2009) in the same area suggests that substantial carbon removals might be expected with these increases in estuarine wetland area.

Kelleway et al. (2016c) used a 70-year time for space chronosequence to quantify changes in carbon storage as mangroves migrated upslope into existing tidal marshes, during a time of known sea level rise in the Sydney region. This study highlighted the capacity of mangrove root growth to enhance soil C_{org} densities and, in some circumstances, to raise surface elevations during a time of sea level rise. These findings suggest that management interventions to curtail mangrove expansion into tidal marsh (such as mangrove seedling removal) may prevent future gains in carbon sequestration.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Agricultural, State, Council, Commonwealth and Indigenous landholders of lands which have been previously disconnected from tidal flow. Land ownership and implications of altering high water marks and the implications on property perimeters and who owns the carbon sequestered will need to be considered. Data from the Department of Agriculture and Water Resources – ABARES suggests a large proportion of mangrove habitat is within private lands (35%), leasehold (17%) or unresolved tenure (17%). Such data is not currently available for tidal marshes.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

Unless otherwise stated, the following estimates of potential abatement intensity are based upon national carbon stock data compiled by the CSIRO Coastal Carbon Cluster and greenhouse gas emissions factors taken from the 2013 IPCC Wetlands Supplement (for range and 95% CI data see Appendix 2):

Scenario A: Land-use change within existing mangrove and tidal marsh areas

No data available. Changes to stocks and/or avoided emissions are likely to vary according to land-use types

Scenario B: Creation of new habitat by land-use change and planning for sea level rise

Stock change rates:

- estimated increase in mangrove biomass stocks of 6.24 Mg C ha^{-1} yr^{-1} for 20 years

- estimated increase in mangrove soil stocks of 1.26 Mg C ha^{-1} yr^{-1}

- estimated increase in tidal marsh soil stocks of 0.39 Mg C ha^{-1} yr^{-1}

Avoided emission rates:

- no data available. Avoided emissions are likely to vary according to initial land-use

Total abatement intensity for mangroves = 7.50 Mg C ha^{-1} yr^{-1} + avoided emissions (no data)

Total abatement intensity for tidal marshes = 0.39 Mg C ha^{-1} yr^{-1} + avoided emissions (no data)

Area estimates of potential abatement

The following is considered an upper national estimate of the area over which sea level rise could allow increases in mangrove and tidal marsh distribution. The area over which land-use planning changes could occur would form an unknown fraction of this estimate:

- National mapping of coastal acid sulfate soil (ASS) extent (Fitzpatrick et al. 2008) was used to estimate the area of supratidal land which may become inundated under higher sea level. This area of supratidal acid sulfate soils likely represents the former distribution of mangrove and tidal marsh ecosystems at a prior elevated sea level. This estimate excludes the area of coastal acid sulfate soil which is within tidal zones.
- Floodplain ASS in coastal settings (6,667 km^2) + Sandplain and dune ASS in coastal settings (9,681 km^2) = 16,348 km^2

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Loss of agricultural income

- Impact upon property values caused by changes to land-use zoning

- Loss of recreational opportunity, including areas where unauthorised access will be impacted as well as the potential for conversion of parklands, golf courses, and other open spaces to be converted to mangrove and tidal marsh migration areas.

- Alteration to habitat structure. For example, loss of habitat for upland species, particularly those reliant upon existing freshwater habitats (e.g. frogs), or decline in open vegetation habitat (e.g. for roosting birds) resulting from mangrove afforestation.

- Increased flood risk including in neighbouring lands, associated with the maintenance of sea level rise accommodation space and preclusion of protective structures such as levees and seawalls. It should be noted more broadly, however, that intact wetlands may act to reduce coastal flooding (Duarte et al. 2013b).

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

1) Alteration of land-use in existing mangrove and tidal marsh areas

Agricultural land-uses may also be regulated by existing legislation. For example, under Fisheries legislation in various states (e.g. NSW Fisheries Management Act 1994; QLD Fisheries Act 1994) any development or activity that may harm mangrove or tidal marshes may need to be referred for approval. Further, the NSW Fisheries Management (General) Regulation 2010 amendments make it illegal for livestock of any type to graze and trample marine vegetation (including tidal marsh and mangroves) on public land (e.g. Crown land or Council land).

Agricultural land-uses may also be subject to existing schemes to manage riparian vegetation, including catchment water quality and nutrient management schemes. These are mostly co-ordinated by catchment management agencies. Activities may include funding for fencing off riparian areas and promoting off-stream water sources to minimise erosion of river banks.

Some unauthorised activities may be illegal under existing legislation, such as damage caused by motor vehicle use in coastal saltmarshes (which are listed as an Endangered Ecological Community under Commonwealth and NSW threatened species legislation).

2) Land-use planning for sea level rise:

There is interest from some coastal resource management agencies in planning for the impacts of sea level rise. This is often associated with flooding risks, but may also include planning for the survival and migration of mangroves and tidal marshes. In NSW estuary management planning by local government is being promoted and funded by the State government. The *Queensland Wetland Buffer Guideline* 2011 provides guidance on buffer areas required around wetlands in QLD, but these are small in scale (e.g. 200 m). The *Queensland Coastal Management Plan* 2013 also included recommendations for planning for migration of wetlands with sea level rise.

There is potential for an economic incentive from emissions reduction to help turn potential or planned projects into realised projects.

3. Additionality

3.1 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

1) Alteration of land-use in existing mangrove and tidal marsh areas

In some instances, there may be other environmental schemes (mostly riparian vegetation protection and restoration schemes) which promote low impact land use in tidal areas, thereby weakening the additionality for this activity. There is the potential for an economic incentive from emissions reduction to help turn potential or planned projects under these other schemes into realised projects.

Unauthorised access activities are likely to be undertaken by people who have no management connection to the land involved, so would be highly unlikely to undertake change for restoration purposes, including any alternate schemes.

2) Land-use planning for sea level rise:

At present there are few legislative requirements for landholders, natural resource managers or government agencies to plan for sea level rise. There is also little to no financial incentive for this to take place at present. Research in Moreton Bay indicates that carbon sequestration could be sufficient to pay for land acquisition for sea level rise, based upon a voluntary carbon market (mean $6.1 AUD Mg C^{-1}) and estimates of the social value of carbon (from $10.94 to $96.94 AUD Mg C^{-1}) (Runting et al. 2016).

Table 21. Abatement integrity assessment for land-use change for mangroves and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	Existing MAN/TM: 1 SLR planning: 2	1) In some regions there may already be incentives which promote land-use change within existing mangrove and tidal marsh areas 2) At present there is little incentive to undertake SLR planning.
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Research papers have shown that changes in carbon following land-use change can be measured, including through monitoring (e.g. Howe et al. (2009), chronosequence (e.g. Osland et al. (2012). Changes in wetland carbon stocks associated with species migration can also be measured (Kelleway et al. 2016c).
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited.

Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	Existing MAN: 2 (Biomass); 1 (Soil) Existing TM: 1 (Soil) SLR planning: 2 (all pools)	1= Evidence is equivocal on the impact of some land-uses (e.g. grazing) on soil sequestration. 2= There are sufficient examples from the literature which show likely sequestration and emissions benefits of mangroves and tidal marshes over terrestrial landscapes.
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	There are methods available to quantify emissions, including any material amounts that may occur.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	1	Based upon mean values reported across multiple species and use of proxies for area estimates.

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	Existing MAN: (biomass) = 10 (soil) = 8 Existing TM: (soil) = 8 SLR planning: MAN (biomass) = 11 MAN (soil) = 10 TM (soil) = 10	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline: Baseline biomass and soil C_{org} stocks can be measured through field measurements and collection and laboratory analyses of samples prior to the activity. Emissions may be measured using instruments deployed at the site prior to the activity. These data can be compared to suitable, nearby control and reference sites. The duration over which emission assessments are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted on by any particular temporal event.

- Estimation of baseline from literature values: Existing literature can be used to estimate average/median loss of carbon stocks prior to the land-use change to estimate baseline emissions. Where available, regional scale models may be used to determine values or identify landscape variability in values.

- Estimation of baseline from measured literature values and spatial modelling approaches: Existing data quantifying stocks at point locations can be used with a range of covariates to construct models capable of predicting baseline stocks at other locations.

- Estimation of baseline from emissions factors: (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration).

5.1 List and justify the assumptions and uncertainties on which the baseline is based.

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and atmospheric flux. Where baseline measurements can be taken within the project area, this uncertainty can be quantified using approaches similar to those used in the existing "Sequestering carbon in soils in grazing systems" ERF method. Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites. In some instances, there may not be suitable reference/control sites to use.

- The use of literature values assumes suitable, relevant information is available. Sources of uncertainty may include differences due to ecosystem age, species composition, intertidal location, soil type and community structure. At present there have been few studies of land-use change upon carbon dynamics in Australian mangrove and tidal marsh settings.

- Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration) may underestimate or overestimate baseline values, depending on the specific conditions of the project site.

5.2 Describe the steps and/or processes involved in undertaking the abatement activity and identify all emissions sources and sinks directly or indirectly affected by the activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

Alteration of land-use in existing mangrove and tidal marsh areas:

1. Alteration of land-use type or intensity

2. Passive and/or active revegetation

Land-use planning for sea level rise:

1. Change to shoreline land-use and barriers to migration

2. Passive and/or active afforestation of new areas

5.3 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Table 22. Baseline details

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
Project activity sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org}*	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

For activities which involve a change in land-use in existing mangrove or tidal marsh area the boundaries would be defined by the area which has been subject to the change in land-use. This may equate to a fenced-off or excluded area, and in some cases may be defined by a property boundary

For activities which involve land-use planning for sea level rise project boundaries may be defined by modelled or observed inundation patterns – for example in Moreton Bay (Traill et al. 2011, Mills et al. 2015, Runting et al. 2016). In this instance digital elevation models and hydrodynamic models might be used to estimate and map the area subject to inundation under a suitable sea level rise scenario. In the longer term, vegetation mapping during the project phase may be used to delineate areas where change in land-use has allowed migration of mangrove or tidal marsh species.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

1. Biomass and soil C_{org} stocks can be measured through field collections and laboratory analyses of samples prior to the activity. Biomass measurements may involve the destructive sampling of small, representative plots (often used for tidal marshes and grassland communities), or the combination of field measurements of vegetation structure and allometric equations to estimate biomass non-destructively (often used for mangroves and other forests). Soil samples are often collected as soil cores and require measurement of both bulk density and either C_{org} or organic matter content.

Uncertainties:

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and accumulation rates. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- Uncertainties in field-based biomass quantifications for mangroves may arise from use of allometric equations derived from other locations or for other plant species, which are not suited to the project site. Use of different allometric equations (i.e. from different literature sources) may lead to substantial variation in the biomass estimated for a site. Alternatives include development of site-specific allometric equations (this may require destructive sampling of vegetation within the project site); or use of non-destructive technologies such as LiDAR or Terrestrial Laser Scanner measurements.

- Comparison to reference/control sites assumes suitable site selection. In some instances, there may not be suitable reference/control sites to use.

2. Biomass carbon stocks may be estimated from remotely-sense data (i.e. remote sensing, LiDAR) prior to activity.

Uncertainties:

- Requires data capture of a suitable baseline condition (e.g. prior to establishment of the activity, or of a suitable reference location).

- Remotely-sensed data needs to be of sufficient spatial resolution for the purpose of biomass estimation.

- Remotely-sensed data may capture aboveground biomass stocks with adequate accuracy but may not provide a reliable estimation of belowground biomass due to inconsistencies in above versus belowground partitioning of mangrove and tidal marshes in different environmental settings.

3. Emissions may be measured using field-based instruments (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) deployed at the site prior to the activity to determine baseline values.

Uncertainties:

- Wetland atmospheric fluxes may vary substantially across landscapes and climatic gradients. It would therefore be would be beneficial to develop emissions factors at local scales (e.g. site or estuary scales).

- Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- The quantity and type (CO_2, CH_4, N_2O) of atmospheric flux may involve substantial temporal variability. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night).

4. Surface accumulation measurements can be used to monitor and measure baseline surface dynamics of mangrove/tidal marsh soils. Soil accumulation rates (in concert with soil C_{org} analyses) can be used to calculate soil C_{org} accumulation rates. Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1cm. Real Time Kinetic (RTK GPS) can be used to determine surface elevation to < ~5cm accuracy. Radiometric dating techniques (e.g. ^{210}Pb, ^{137}Cs and ^{14}C) may also be used to calculate soil accumulation rates which can be used to calculate carbon accumulation rates.

Uncertainties:

- SET and MH techniques are highly susceptible to trampling and disturbance impacts. In sites experiencing grazing or physical disturbance to the sediment this technique may not be reliable.

- SET and MH techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement may be required to define an accurate baseline. Changes in surface elevation may result from multiple belowground and surface processes, which may or may not be related to carbon dynamics.

- Quantifying carbon accumulation in the surface soils may underestimate C sequestration because root detritus contributes to soil C_{org} throughout the soil profile (Lovelock et al. 2013). For example, mangrove roots tend to grow within older decomposing root structures (McKee 2001). This can be addressed by using analyses which incorporate a deeper section of the soil profile, such as radiometric dating methods.

- Quantifying carbon accumulation in the surface soils may overestimate C sequestration because C concentrations in the top sediment surface layer may be higher than that incorporated into the soil profile (Breithaupt et al. 2012, Lovelock et al. 2013). That is, a large proportion of surface organic matter may be lost through diagenesis within the first year of deposition (Duarte and Cebrian 1996).

- Marker Horizon techniques may prove unreliable due to loss of the marker layer due to bioturbation or disturbance to the soil profile.

5. Use of emissions factors, such as those outlined in the IPCC Wetlands Supplement (2013).

Uncertainties:

- Use of global or regional emissions factors may introduce substantial uncertainty as carbon stocks and greenhouse gas emissions can vary substantially across landscapes, wetland types, and climatic gradients. Use of locally derived emissions factors may help to overcome some of this uncertainty.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Approaches to calculate project activity emissions are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken. For example, if SET measurement show that the surface elevation has grown 5cm under the project, then the soil C_{org} stock would be measured over 1.05 m soil depth. Similarly, if the SET measurements show a decrease in surface elevation under the project (e.g. elevation loss of 3 cm) then the soil C_{org} sampling depth will be reduced by this amount (i.e. 0.97 m).

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

Calculation of net GHG abatement may be calculated as the difference between the baseline and project activity values for the following methods:

1. Field collections and laboratory measurement

2. Biomass carbon stocks estimation using remotely-sense data

3. Emission measurement with field-based instruments

4. Surface accumulation measurements (SETs; MHs; radiometric dating)

5. Use of emissions factors

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

Baseline emissions and removals data may be collected on the basis of:

1) direct or remotely-sensed measurements taken in the project site prior to the activity;

2) via direct or remotely-sensed measurement of suitable reference/control sites;

3) or estimated on the basis of literature values and published emissions factors.

In some instances, there may not be suitable reference/control sites to use and/or there may not be suitable literature values to use. In such instances direct measurement in the project site or reliance upon emissions factors may be required.

Many of the methods outlined require consideration of temporal and spatial variability expected in carbon storage, accumulation and emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radiometric dating is likely to provide the best long term record of soil accumulation rates and may also be used to develop a baseline value of carbon stocks and longer-term accumulation rates using soil cores collected after the commencement of the activity.

8. Double counting

8.1 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream carbon sources that are already being captured in inventory reporting (e.g. carbon that enters the blue carbon ecosystem through river system or catchment area).

Both autochthonous and allochthonous carbon sources may accumulate within the soil C_{org} pool in response to this activity. It is currently being investigated as to whether both autochthonous and allochthonous sources of accumulation will be available for counting under this activity. This issue is addressed in further detail in the recommendations section.

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the carbon stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of carbon stored:

- Accelerated rates of relative sea level rise may outpace the capacity of mangrove or tidal marsh to build surface elevation, leading to mortality of plants and eventual loss of aboveground biomass carbon pool on the seaward edge. Subsidence of a site (including due to belowground extraction of resources) may also act to increase relative sea level rise.

- Natural disturbances such as cyclone may cause damage and/or loss of aboveground biomass and subsequent remineralisation of aboveground biomass carbon.

- Fire may occur through the aboveground biomass of tidal marshes and mangroves. It is unlikely to cause the remineralisation of belowground biomass and soil C_{org} stocks.

- Dieback of plant biomass, including mangroves (as observed recently in Northern Australia). Causes of such dieback are not well understood at present, but may include drought, prolonged submergence (flooding), temperature stress, insect or other pathogens, among others.

- Foreshore erosion (e.g. boat activity).

- Drainage of soil leading to remineralisation of C as a result of agriculture, runnelling for mosquitoes, alteration of groundwater.

- Foreshore erosion (e.g. boat activity).

- Drainage of soil leading to remineralisation of C as a result of agriculture, runnelling for mosquitoes, alteration of groundwater.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in carbon stocks (biomass and soil pools) on a per unit of area basis. For biomass, this would include the C_{org} associated both above and below ground components – this might be estimated on the basis of either field or remotely-sensed data. For soils this would require definition of an initial depth to be sampled - currently recommended to be 1 m within the IPCC wetlands supplement (Hiraishi et al. 2014)- and a mechanism to quantify the change in soil C_{org} stock above this horizon through time. For soils, monitoring of surface elevation change (e.g. through use of SETs, MHs; RTK GPS) may provide information on surface C_{org} accumulation rates above the baseline horizon. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2).

- Change in CO_2, CH_4 and N_2O emissions. This will require sufficient temporal coverage including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation (day versus night).

- Monitoring of land-use type/intensity. Has the stated level of land-use change been undertaken effectively and permanently?

- Extent of influence of land-use change. Monitoring of vegetation type and vegetation structure / biomass (through field or remote methods) may offer a relatively simple approach by which to model changes in carbon pools. Monitoring on annual to sub-decadal timescales will likely be appropriate

In general, monitoring on annual or sub-annual timescales may be required in the first years after land-use change when the ecosystems involved are likely to be most dynamic. Once the restored ecosystems stabilise, monitoring on annual to sub-decadal timescales may be appropriate. Existing ERF methodologies require offsets reports to be submitted at least every 5 years for sequestration projects or every 2 years for emissions avoidance projects.

The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The sample size required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b). Based upon global compilation of tidal marsh and mangrove carbon sequestration rates (Chmura et al. 2003), guidance for the VCS suggests sample sizes of approximately 10-20 samples per stratum will likely be required. For measurement of methane fluxes co-efficients of variation are high, requiring about 40 samples (chambers) per stratum (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to carbon

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

The legal right to carbon may vary among jurisdictions if the definition of the seaward boundary of properties varies. In most instances this is the mean high water mark (MHWM), as is the case for example in NSW, however there may be instances where this is not the case. This has particular implications for mangroves which generally occupy elevations between mean sea level (i.e. below MHWM) and the Highest Astronomical Tide (HAT; above MHWM).

There may be land ownership and legal right to carbon issues especially for land-use change for upslope and upstream migration of ecosystems. This may require transfer of property ownership and legal rights, but will also be subject to changes over time in as sea level changes. Where land is bounded by water, the legal boundary of the land generally changes to reflect changes in the position of the waters' edge, but only if certain conditions are met (such as changes being 'gradual' and 'natural').

6.4.4 Avoided clearing and avoided soil disturbance

Category: Mangrove protection**;** Tidal marsh protection.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

The clearing and/or excavation of mangroves and tidal marshes has the potential to impact both upon living and stored biomass carbon pools and may also involve significant disturbance to soil profiles and their carbon pools. This activity could be used by landowners who have mangrove or tidal marsh on their property and who have received consent to clear this vegetation or undertake extraction of soils. Under this proposed activity, landowners could generate credits for not clearing or disturbing this land and maintaining it as mangrove or tidal marsh.

Removal of biomass may have the following implications for carbon storage and cycling in mangroves and tidal marshes:

- removal of aboveground carbon pool

- loss of source of production for belowground biomass carbon pool

- change in trapping capacity of sediment surface

- change in erodibility of soils and soil C_{org} pool

- change in soil microbial community

- changes in macrofaunal community (e.g. bioturbation)

- export of carbon to coastal waters.

Disturbances to soil profile may impact carbon dynamics through:

- oxidation of soil C_{org} stocks

- change in compaction of soils

- change of water infiltration and hydrodynamic energy cause mobilisation of soil C_{org} stocks

- changes in carbon oxidation pathway (e.g. aerobic vs anaerobic, CO_2 vs CH_4).

Therefore, avoidance of clearing/soil disturbance may have implications for the protection of existing carbon stocks in both biomass and soil pools (avoided emissions); continued production of biomass carbon and soil C_{org} pools (sequestration).

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

For mangroves and tidal marshes, avoided clearing may be undertaken where:

- proponents choose not to act on approvals granted for the clearing of mangroves or tidal marsh vegetation, and/or:

- proponents choose not to act on approvals granted for the removal of mangrove seedlings from tidal marsh or mudflat ecosystems (occasionally undertaken for habitat conservation purposes), and/or:

- proponents choose not to act on approvals granted for the disturbance of mangroves or tidal marsh soils.

Biomass clearing and soil disturbance can be associated with dredging used to provide soil for raising the elevation of land, or excavation to enable port, harbour and marina construction; construction of aquaculture ponds; and construction of salt production ponds

While this activity may apply to approvals granted in various locations and jurisdictions around the country, there may be particular application through significant areas of northern Australia where there is interest in the future development of aquaculture, water resources and coastal areas.

Avoided Deforestation is currently a method under the ERF, however it applies specifically to landowners who have received consent to clear forest for the purposes of converting the land to cropland or grassland in perpetuity. Mangrove or tidal marsh conversion to cropland or grassland is an unlikely development pathway (most conversion is historic) and so the current methodology will not apply.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

Similar abatement activities have been developed in regard to avoided clearing or avoided ecosystem conversion in Australia and under the Verified Carbon Standard (VCS):

- ERF method for *Avoided Deforestation*. This methodology however, applies only the carbon stocks within the aboveground biomass, excluding consideration of emissions resulting from disturbance of belowground carbon pools (which may be substantial in mangroves and tidal marshes)

- Verified Carbon Standard (VCS) ‘Methodology for avoided ecosystem conversion’ – this methodology provides a means to quantify emission reductions and removals from project activities that prevent conversion of forest to non-forest and of native grassland and shrubland to a non-native state. It does not, however, make any specific mention of mangrove or tidal marsh ecosystems.

The following studies highlight the potential of this abatement activity in mangroves and tidal marshes, including soil C_{org} pools:

Kauffman et al. (2014) estimated the potential emissions of conversion of tropical mangroves to shrimp ponds in the Dominican Republic using a stock-change approach. They found carbon stocks ranging from 706 to 1131 Mg/ha in mangroves, compared to 95 Mg/ha in abandoned shrimp ponds.

They calculated potential emissions from the conversion of mangroves to shrimp ponds ranging from 2244 to 3799 Mg CO_2e/ha. This is among the largest measured carbon emissions from land use in the tropics.

Sidik and Lovelock (2013) quantified the CO_2 efflux from mangrove soils which had been cleared and converted to shrimp ponds in Bali, Indonesia. Rates of CO_2 efflux within shrimp ponds were 4.37 kg CO_2 m^{-2} yr^{-1} from the pond walls and 1.60 kg CO_2 m^{-2} yr^{-1} from the floors. This study also suggests that higher magnitudes of CO_2 emission may be released to atmosphere where ponds are constructed in newly cleared mangroves.

Kelleway et al. (2016c) used a 70-year time for space chronosequence to quantify changes in carbon storage as mangroves migrated upslope into existing tidal marshes, during a time of known sea level rise in the Sydney region. This study highlighted the capacity of mangrove root growth to enhance soil C_{org} densities and, in some circumstances, to raise surface elevations during a time of sea level rise. These findings suggest that management interventions to curtail mangrove expansion into tidal marsh (such as mangrove seedling removal) may prevent future gains in carbon sequestration.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Any landowner or proponent who has existing approval to clear mangrove or tidal marsh habitat.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

The following estimates of potential abatement intensity are based upon national carbon stock data compiled by the CSIRO Coastal Carbon Cluster (for range and 95% CI data see Appendix 1):

Scenario A: Avoided clearing (biomass only)

Avoided emission:

- estimated one-off avoided emission from cleared mangrove biomass of 124.83 Mg C ha^{-1}

This estimates assumes that: 1) all biomass is removed and decomposes under aerobic conditions; 2) all carbon in this pools is emitted as CO_2 during the year of extraction.

Total one-off abatement intensity for mangroves = 124.83 Mg C ha^{-1} yr^{-1}

Scenario B: Avoided clearing (biomass + soil)

Stock change rates:

- estimated increase in mangrove soil stocks of 1.26 Mg C ha^{-1} yr^{-1}
- estimated increase in tidal marsh soil stocks of 0.39 Mg C ha^{-1} yr^{-1}

Avoided emission:

- Mangrove - estimated one-off avoided emission from cleared mangrove biomass and disturbed soil of 250.57 Mg C ha^{-1}
- Tidal marsh - estimated one-off avoided emission from disturbed soil of 83.95 Mg C ha^{-1}

These estimates assume: 1) full emission of aboveground biomass stock (mangrove only) + emission of 50% of the soil stock (0-1 m); 2) <u>all biomass and soil C is removed and decomposes under aerobic conditions; 3) all carbon in these pools are emitted as CO2 during the year of extraction.</u>

- CH_4 and N_2O emission rate – no data available

Total abatement intensity for mangroves = one-off abatement of 250.57 Mg C ha^{-1} + annual abatement of 1.26 Mg C ha^{-1} yr^{-1}

Total abatement intensity for tidal marshes = one-off abatement of 83.95 Mg C ha^{-1} + annual abatement of 0.39 Mg C ha^{-1} yr^{-1}

No estimates are currently available to determine the area over which this activity could occur. Consequently, no abatement volume estimates have been made.

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Loss of income from development/activity that would otherwise go ahead.

- Loss of community benefit from development/activity that would otherwise go ahead

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

In many Australian jurisdictions there are now strong legislative controls on the clearing or disturbance of mangroves and/or tidal marshes. In QLD and NSW for example, impacts upon mangroves and tidal marshes are regulated by the QLD *Fisheries Act 1994* and NSW *Fisheries Management Act 1994*, respectively. In some states mangrove clearing is also regulated through native vegetation legislation. Throughout sub-tropical Australia, 'coastal saltmarsh' is listed as a Vulnerable Ecological Community under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (and also under the NSW *Threatened Species Conservation Act 1995*).

While the above legislative instruments aim to reduce loss of mangrove and tidal marshes, they do not preclude clearing or disturbance. Instead, they trigger approval processes which require statutory consent. Where this consent has been granted there may be opportunity for the operation of this abatement activity.

3. Additionality

3.3 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

The premise of this activity is that approvals have already been granted and therefore clearing is likely to be enacted as the ordinary course of events. There may, however, be other development roadblocks (such as financial constraints, community opposition) which preclude clearing from taking place, despite clearing approval having already been granted.

Table 23. Abatement integrity assessment for avoided biomass removal and avoided soil disturbance of mangroves and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	The premise of this activity is that approvals have already been granted and therefore clearing is likely to be enacted as the ordinary course of events.
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	There are currently methods in place for analogous terrestrial circumstances – though these do not combine both biomass and soil C_{org} pools, or combine carbon removals (sequestration) with avoided emissions - and under the VCS. There are recognised approaches for quantifying carbon removals and reductions
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited.

Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	There are sufficient examples from the literature to show likely sequestration and emissions benefits of this activity.
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	This activity is not expected to lead to material amounts of GHG emission. There are methods available to quantify emissions if they do occur.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	1	Based upon mean values reported across multiple species.

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	MAN (biomass) = 11 MAN (soil) = 10 TM (soil) = 10	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline: Baseline biomass and soil C_{org} stocks can be measured through field measurements and collection and laboratory analyses of samples prior to the activity. Emissions may be measured using instruments deployed at the site prior to the activity. These data can be compared to suitable, nearby control and reference sites. The duration over which emission assessments are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted on by any particular temporal event.

- Estimation of baseline from existing literature can be used to estimate average/median values from uncleared settings to estimate baseline carbon stocks and accumulation rates. Literature values of emissions from cleared or disturbed wetlands may be used to estimate emissions if clearing had taken place.

- Estimation of baseline from measured literature values and spatial modelling approaches: Existing data quantifying stocks at point locations can be used with a range of covariates to construct models capable of predicting baseline stocks at other locations.

- Estimation of baseline from emissions factors: Suitable emissions factors may be used, such as those outlined in the IPCC Wetlands Supplement (2013) and the VCS Methodology for Tidal Wetland and Seagrass Restoration.

5.2 List and justify the assumptions and uncertainties on which the baseline is based.

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and atmospheric flux. Where baseline measurements can be taken within the project area, this uncertainty can be quantified using approaches similar to those used in the existing "Sequestering carbon in soils in grazing systems" ERF method. Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites. In some instances there may not be suitable reference/control sites to use.

- The use of literature values assumes suitable, relevant information is available. Sources of uncertainty may include differences due to ecosystem age, species composition, intertidal location, soil type and community structure. At present there have been few studies published on this topic from Australian settings, especially in regard to atmospheric flux.

- Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013 and/or VCS Methodology for Tidal Wetland and Seagrass Restoration) may underestimate or overestimate baseline values, depending on the specific conditions of the project site.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity and identify all emissions sources and sinks directly or indirectly affected by the activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

1. Avoidance of emissions associated with vegetation clearing and soil disturbance

2. Continued sequestration by persistence of ecosystem

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Table 24. Baseline details

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
Project activity sources/sinks	CO_2 emission	Mangrove aboveground biomass	Included	
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	Small biomass pool with rapid turnover and variable annual production
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	CH_4 emission	Mangrove aboveground biomass	Excluded	No CH_4 emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No CH_4 emission expected from this pool

Source		Greenhouse gas/ carbon pools	Included or excluded	Justification for exclusion
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	
	N_2O emission	Mangrove aboveground biomass	Excluded	No N_2O emission expected from this pool
		Mangrove belowground biomass*	Included	
		Mangrove soil C_{org} *	Included	
		Tidal marsh aboveground biomass	Excluded	No N_2O emission expected from this pool
		Tidal marsh belowground biomass*	Included	
		Tidal marsh soil C_{org} *	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of ecosystem area for which clearing consent has been foregone.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

1. Biomass and soil C_{org} stocks can be measured through field collections and laboratory analyses of samples prior to the activity. Biomass measurements may involve the destructive sampling of small, representative plots (often used for tidal marshes and grassland communities), or the combination of field measurements of vegetation structure and allometric equations to estimate biomass non-destructively (often used for mangroves and other forests). Soil samples are often collected as soil cores and require measurement of both bulk density and either C_{org} or organic matter content.

Uncertainties:

- Field sampling of biomass and soil C_{org} stocks requires sufficient effort and replication to understand spatial and temporal variability in carbon stocks and accumulation rates. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties.

- Uncertainties in field-based biomass quantifications for mangroves may arise from use of allometric equations derived from other locations or for other plant species, which are not suited to the project site. Use of different allometric equations (i.e. from different literature sources) may lead to substantial variation in the biomass estimated for a site. Alternatives include development of site-specific allometric equations (this may require destructive sampling of vegetation within the project site); or use of non-destructive technologies such as LiDAR or Terrestrial Laser Scanner measurements.

- Comparison to reference/control sites assumes suitable site selection. In some instances, there may not be suitable reference/control sites to use.

2. Biomass carbon stocks may be estimated from remotely-sense data (i.e. remote sensing, LiDAR) prior to activity. Plant productivity may be estimated remotely through NDVI analysis.

Uncertainties:

- Requires data capture of a suitable baseline condition (e.g. prior to establishment of the activity, or of a suitable reference location)

- Remotely-sensed data needs to be of sufficient spatial resolution for the purpose of biomass estimation

- Remotely-sensed data may capture aboveground biomass stocks with adequate accuracy but may not provide a reliable estimation of belowground biomass due to inconsistencies in above versus belowground partitioning of mangrove and tidal marshes in different environmental settings.

3. Use of emissions factors, such as those outlined in the IPCC Wetlands Supplement (2013).

Uncertainties:

- Use of global or regional emissions factors may introduce substantial uncertainty as carbon stocks and greenhouse gas emissions can vary substantially across landscapes, wetland types, and climatic gradients. Use of locally derived emissions factors may help to overcome some of this uncertainty.

- The IPCC Tier 1 methodology makes certain assumptions for extraction (disturbance) activities which may not always be applicable, including that:

1. All biomass, dead organic matter and soil are removed and disposed of under aerobic conditions

2. All carbon in these pools is emitted as CO_2 during the year of extraction.

3. Soil extraction is to a depth of 1 m

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Approaches to calculate project activity emissions are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken. For example, if SET measurement show that the surface elevation has grown 5cm under the project, then the soil C_{org} stock would be measured over 1.05 m soil depth. Similarly, if the SET measurements show a decrease in surface elevation under the project (e.g. elevation loss of 3 cm) then the soil C_{org} sampling depth will be reduced by this amount (i.e. 0.97 m).

A further exception is the following, which may be used to calculate avoided emissions:

1. Avoided emissions may be modelled on the basis of biomass clearing and/or soil disturbances which would have occurred if the clearing permit had been enacted. These values can be determined from the above approaches (1 and 2 in 7.1).

Uncertainties:

- The same uncertainties of the initial data inputs (1 and 2 in 7.1) will apply

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

Calculation of net GHG abatement may be calculated as avoided emissions and continued sequestration associated with avoidance of clearing/disturbance. This may be modelled on the basis of baseline carbon stocks which would be mineralised and accumulation rates that would cease if clearing/disturbance were enacted. These measurements may be derived from:

1. Field collections and laboratory measurement

2. Biomass carbon stocks estimation and vegetation productivity using remotely-sense data

3. Use of literature values or emissions factors

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

Baseline emissions and removals data may be collected on the basis of:

1) direct or remotely-sensed measurements taken in the project site prior to the activity;

2) via direct or remotely-sensed measurement of suitable reference/control sites;

3) or estimated on the basis of literature values and published emissions factors.

In some instances, there may not be suitable literature values to use. In such instances direct measurement in the project site or reliance upon emissions factors may be required.

8. Double counting

8.1 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream carbon sources that are already being captured in inventory reporting (e.g. carbon that enters the blue carbon ecosystem through river system or catchment area).

Both autochthonous and allochthonous carbon sources may accumulate within the soil C_{org} pool in response to this activity. It is currently being investigated as to whether both autochthonous and allochthonous sources of accumulation will be available for counting under this activity. This issue is addressed in further detail in the recommendations section.

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the carbon stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of carbon stored:

- Accelerated rates of relative sea level rise may outpace the capacity of mangrove or tidal marsh to build surface elevation, leading to mortality of plants and eventual loss of aboveground biomass carbon pool. Subsidence of a site (including due to belowground extraction of resources) may also act to increase relative sea level. In some instances it may be possible to increase rates of artificial sedimentation to combat these changes.

- Natural disturbances such as cyclone may cause damage and/or loss of aboveground biomass and subsequent remineralisation of aboveground biomass carbon.

- Fire may occur through the aboveground biomass of tidal marshes and mangroves. It is unlikely to cause the remineralisation of belowground biomass and soil C_{org} stocks.

- Dieback of plant biomass, including mangroves (as observed recently in Northern Australia). Causes of such dieback are not well understood at present, but may include drought, prolonged submergence (flooding), temperature stress, insect or other pathogens, among others.

- Foreshore erosion (e.g. boat activity).

- Drainage of soil leading to remineralisation of C as a result of agriculture, runnelling for mosquitoes, alteration of groundwater.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in carbon stocks (biomass and soil pools) on a per unit of area basis. For biomass, this would include the C_{org} associated both above and below ground components – this might be estimated on the basis of either field or remotely-sensed data. For soils this would require definition of an initial depth to be sampled - currently recommended to be 1 m within the IPCC wetlands supplement (Hiraishi et al. 2014)- and a mechanism to quantify the change in soil C_{org} stock above this horizon through time. For soils, monitoring of surface elevation change (e.g. through use of SETs, MHs; RTK GPS) may provide information on surface C_{org} accumulation rates above the baseline horizon. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2).

- Monitoring of vegetation type and vegetation structure / biomass (through field or remote methods) may offer a relatively simple approach by which to model changes in carbon pools. Monitoring on annual to sub-decadal timescales will likely be appropriate

- Monitoring of surface elevation change (e.g. through use of SETs, MHs; RTK GPS) may provide information on any changes in carbon accumulation rates.

Existing ERF methodologies require offsets reports to be submitted at least every 5 years for sequestration projects or every 2 years for emissions avoidance projects. Monitoring may be necessary after events of substantial disturbance (such as major storms, flooding events, fire) or any land-use change.

The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The sample size required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b). Based upon global compilation of tidal marsh and mangrove carbon sequestration rates (Chmura et al. 2003), guidance for the VCS suggests sample sizes of approximately 10-20 samples per stratum will likely be required. For measurement of methane fluxes co-efficients of variation are high, requiring about 40 samples (chambers) per stratum (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to carbon

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

The legal right to carbon may vary among jurisdictions if the definition of the seaward boundary of properties varies. In most instances this is the mean high water mark (MHWM), as is the case for example in NSW, however there may be instances where this is not the case. This has particular implications for mangroves which generally occupy elevations between mean sea level (i.e. below MHWM) and the Highest Astronomical Tide (HAT; above MHWM).

Where land is bounded by water, the legal boundary of the land generally changes to reflect changes in the position of the waters' edge, but only if certain conditions are met (such as changes being 'gradual' and 'natural').

6.4.5 Change in species composition

Category: Mangrove establishment/restoration; Tidal marsh restoration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

The distribution of mangrove and tidal marsh vegetation is driven largely by climatic and geomorphic factors, however, may also be influenced directly or indirectly by human influence. Shifts in species composition may alter the above- and below-ground carbon stocks, depending on the biomass of the species involved. Active management of species composition (e.g. selective removal of mangroves or introduced species) may have implications for carbon storage. Planting of unvegetated areas may also occur.

Global data compilations have shown that there may be differences in biomass stocks among different species of mangrove (Komiyama et al. 2008) and tidal marsh (Ouyang and Lee 2014) vegetation. Recent evidence from SE Australia and sites near the latitudinal limit of mangroves in the northern hemisphere show that replacement of tidal marsh species by mangrove species can also increase carbon removal rates and increase biomass and soil C_{org} stocks (Doughty et al. 2015, Kelleway et al. 2016c).

Any intervention which promotes species with higher carbon removal rates relative to the existing species composition (but is not considered business as usual) may be included under this activity. This may include direct manipulation of species composition through addition or replacement of species or cessation of activities which remove species with potential for high biomass and high carbon removal rates. One example here is the removal of mangrove seedlings to prevent mangrove growth (often for the purpose of maintaining open habitat structure for roosting birds).

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Direct manipulation of mangrove and tidal marsh species composition could potentially be undertaken in any jurisdiction (though mangroves do not occur in Tasmania). The expansion of mangroves into areas previously dominated by tidal marsh vegetation has been documented in Queensland, New South Wales, Victoria and South Australia. Recent observations suggest it is also occurring in the Northern Territory. Mangroves do not currently occur in Tasmania, though anecdotally there may be opportunity for their expansion there. Therefore, activities which promote the expansion of mangrove over other ecosystem types with lower carbon removal rates could potentially be undertaken in any of these jurisdictions.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

The following studies highlight the potential of this abatement activity and the limitation of findings in regard to this activity:

Osland et al. (2012) used a 20-year time for space chronosequence to quantify changes in plant and soil variables, including carbon storage in response to mangrove wetland creation in Florida, USA. The restoration process of this study involved the succession from tidal marsh vegetation to mangrove vegetation, using dredge spoil or upland soils as the new substrate. The results of this study characterize the rate and trajectory of above- and below-ground changes associated with ecosystem development in created mangrove wetlands, showing increase in carbon stocks as mangroves replaced tidal marsh vegetation and showing functional equivalence with natural references sites within 20 years of creation.

Kelleway et al. (2016c) used a 70-year time for space chronosequence to quantify changes in carbon storage as mangroves migrated upslope into existing tidal marshes, during a time of known sea level rise in the Sydney region. This study highlighted the capacity of mangrove root growth to enhance soil C_{org} densities and, in some circumstances, to raise surface elevations during a time of sea level rise. These findings suggest that management interventions to curtail mangrove expansion into tidal marsh (such as mangrove seedling removal) may prevent future gains in carbon sequestration.

Atwood et al. (In Review) found that mangrove stands of mixed species composition had 17% higher soil C stocks per unit area than monotypic stands. However, there was not a linear increase in soil C stocks per unit area with increasing genera richness. Instead, the distribution was an inverted U-shaped curve with mangrove stands containing four genera having 40-117% higher C stocks per unit area than all other richness levels. This study did not did not explicitly test the effects of species composition and data on stands containing three or more genera were rare.

Kelleway et al. (2016a) specifically tested whether belowground carbon stocks (0-1 m depth) varied between rush (high biomass) and succulent/grass (lower biomass) tidal marsh stands in SE Australia. They found no difference in carbon stocks between these vegetation types, but instead found significant variability in carbon stocks according to geomorphic and sedimentary factors.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Private, State, Council, Commonwealth and Indigenous landholders of lands where mangroves currently exist or where mangrove may encroach into in the future (including current tidal marsh area). Planning consent for the disturbance or removal of marine vegetation (mangrove, tidal marsh) may be a constraint in some locations.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

Scenario A: Direct manipulation of mangrove species composition

No data available.

Scenario B: Enabling mangrove encroachment of tidal marsh

The following estimates of potential abatement intensity are based upon a study of temperate zone mangrove encroachment into tidal marshes (Kelleway et al. 2016c) (for range and 95% CI data see Appendix 1):

Stock change rates:

- estimated increase in biomass stocks of 0.41 Mg C ha^{-1} yr^{-1} over 70 years

- estimated increase in soil stocks of 2.30 Mg C ha^{-1} yr^{-1}

Avoided emission rates:

No data available.

Total abatement intensity = 2.71 Mg C ha^{-1} yr^{-1} + avoided emissions (no data)

No reliable estimates are currently available to determine the area over which this activity could occur. Consequently, no abatement volume estimates have been made.

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Change in plant species richness. This may have implications for habitat diversity as well as ecosystem resilience to disturbance or disease;

- Alteration to habitat structure. For example, loss or decline in habitat quality for species requiring open or low vegetation habitat (e.g. for roosting birds) or aquatic species which utilise aerial roots of certain mangrove species as habitat.

- Loss of visual amenity associated with mangrove afforestation

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Direct manipulation of mangrove species composition is unlikely to be promoted, except in cases of transplantation of rare species for conservation purposes (which is likely to be very rare).

Mangrove encroachment into tidal marsh or other areas is occurring as a natural phenomenon. At present, legislation in many jurisdictions allows for this encroachment to occur and may even limit alternate courses of action (e.g. the removal of encroaching plants).

3. Additionality

3.1 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is highly unlikely that active manipulation of mangrove composition would be undertaken as no measures or incentives are currently in place for this.

In contrast, mangrove encroachment is a near ubiquitous trend in many parts of Australia. While the drivers of this trend are not completely understood changes in sea level rise and climatic factors and atmospheric CO_2 concentrations are all considered potential drivers. With future changes in these factors likely it is likely that mangrove encroachment into tidal marsh and unvegetated flats may represent the ordinary course of events.

Table 25. Abatement integrity assessment for change of species composition of mangroves and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	Direct manipulation: 2 Mangrove Encroachment: 0	There is little to no incentive to directly manipulate species composition of mangroves Mangrove encroachment is a near ubiquitous trend in many parts of Australia
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	Direct manipulation: 2 Mangrove Encroachment: 2	May utilise existing approaches for determining carbon stocks and carbon stock change
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited.

Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	Direct manipulation: 0 Mangrove Encroachment: 1	There is limited research to support increases in carbon from manipulating mangrove species composition. Studies investigating carbon change under mangrove encroachment are limited to a small number of settings
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	1	This may depend on the methods used to manipulate species composition including any disturbances to physical characteristics of the site.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	Direct manipulation: 0 Mangrove Encroachment: 1	There are no data currently available to support this activity Based upon a small number of studies

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	Direct manipulation: MAN (biomass) = 7 MAN (soil) = 6 TM (soil) = 6 Mangrove Encroachment: MAN (biomass) = 7 MAN (soil) = 6 TM (soil) = 6	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

6.4.6 Offsite management options to impact site processes

Category: Mangrove restoration; Tidal marsh restoration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous carbon from autochthonous carbon.

Offsite nutrient management:

Nutrients are required for the growth of biomass carbon pools and maintenance of primary productivity. Enhanced nutrient input may alter biomass allocation (increase in aboveground : belowground biomass) (Lovelock et al. 2009), however this may not occur in all settings (Saintilan 2004). Excessive nutrient input can cause mortality and subsequent loss of mangrove and tidal marsh, especially during arid periods (Lovelock et al. 2009, Deegan et al. 2012). Enhanced nutrient concentrations may stimulate rates of microbial decomposition of C stocks.

Nutrient sources may include diffuse sources such as fertiliser use across an agricultural catchment and/or point sources such as sewerage treatment plants which discharge into or adjacent to wetlands.

Offsite salinity management:

Modifications to natural pathways of tidal water (brackish and saline water) and catchment runoff (freshwater) may alter the salinity dynamics of mangroves and tidal marshes. Management of freshwater, brackish and saline water sources could potentially be used to increase carbon storage capacity and reduce emissions through:

- altering biomass allocation of existing species (aboveground v belowground): mangroves characteristically increase allocation of carbon to growth of roots relative to shoots with increase in salinity, with this pattern being amplified with decreasing humidity (Ball 1988);

- crossing salinity thresholds which dictate types of emissions from wetlands (CO_2 v CH_4), with IPCC Wetlands Supplement stating salinity of 18ppt as the upper threshold at which CH_4 production is effectively suppressed (Hiraishi et al. 2014). However, high water column CH_4 concentrations have also been reported under hypersaline conditions in a mangrove driven by tidal pumping (Call et al. 2015).

1.2 List the circumstances or conditions under which the activity is to be implemented.

- If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Offsite nutrient management:

Enhanced nutrient concentrations are likely to occur from diffuse sources in most estuaries around the country which have urban and/or agricultural development within their catchments (i.e. in all jurisdictions).

Point source nutrient enhancement may occur adjacent to or downstream of land uses such as:

- Waste Treatment Plants

- Cane farms (dissolved inorganic nitrogen)

- Agricultural properties under fertiliser application.

Offsite salinity management

May apply in all coastal areas and jurisdictions, but would have particular application in:

- High rainfall areas

- Cane farming areas

- Ponded pasture freshwaters (QLD, NT, WA)

- Flood prone catchments

- Highly impounded estuarine areas/coastal catchments

In both nutrient and salinity management scenarios, ensuring net gains in carbon abatement may be difficult to achieve. This is because in each circumstance there may be positive and negative abatement outcomes from the same management intervention. For example, reducing the salinity of a site may increase biomass productivity and increase biomass carbon stocks, but limiting the influence of saline, sulphate-rich waters may also increase the production of CH_4.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

Offsite nutrient management

In a study of sediment enrichment, Slocum et al. (2005) found that the applied sediment slurry also had high nutrient content, which resulted in a pulse of growth, especially in areas receiving the high sediment supply. However, this nutrient-induced growth spurt was short lived and faded after 3 years.

There are numerous studies which investigate the influence of direct nutrient addition to mangrove and tidal marsh soils on plant growth, biomass partitioning and ecosystem response. The outcomes of these studies highlight the complexity and variability of implications for carbon removals and emissions - for example, nutrient addition may increase plant growth rates, but may also increase microbial activity and remineralisation rates). Further, we are not aware of any studies which specifically link offsite nutrient management to changes in carbon removals or emissions from mangroves or tidal marshes.

Offsite salinity management

Poffenbarger et al. (2011) used published and unpublished field data to investigate the relationships between tidal marsh methane emissions, salinity, and porewater concentrations of methane and sulfate. They found that polyhaline tidal marshes (salinity >18) had significantly lower methane emissions than other marshes, and can be expected to decrease radiative forcing when created or restored. In contrast, methane emissions were higher from fresh (salinity=0–0.5) and mesohaline (5–

18) marshes, while oligohaline (0.5–5) marshes had the highest and most variable methane emissions. Annual methane emissions can be modelled using a linear fit of salinity against log-transformed methane flux:

$Log(CH_4) = -0.056 \times salinity + 1.38$ ($r^2 = 0.52$; $p < 0.0001$).

The authors concluded that managers interested in using marshes as greenhouse gas sinks can assume negligible methane emissions in polyhaline systems, but need to estimate or monitor methane emissions in lower-salinity marshes.

We are not aware of any studies which specifically link catchment based salinity management to changes in carbon removals or emissions from mangroves or tidal marshes.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

Water management agencies and corporations including dam operators; landowners and industry groups responsible for nutrient inputs to catchment waterways; agricultural, State, Council, Commonwealth and Indigenous landholders of lands which are: 1) experiencing or likely to experience elevated nutrient inputs; and/or 2) show signs of suppressed biomass production and high salinity stress.

2.2 Estimate the potential volume of abatement for the blue carbon enhancement activity, taking into account scale of abatement over land mass area.

At present there are insufficient data and case studies from which to derive estimates of potential abatement intensity.

No estimates are currently available to determine the area over which this activity could occur. Consequently, no abatement volume estimates have been made.

2.3 Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Removal or modification of water control structures may have impacts in terms of flooding, downstream properties and infrastructure.

- Alteration to habitat structure. For example, loss or decline in habitat quality for subtidal or mudflat dependant species (e.g. shorebirds) resulting from mangrove afforestation or tidal marsh growth in areas of altered salinity and/or nutrient status.

- Nutrient impacts upon other areas as a result of bypassing of mangroves and tidal marshes which might otherwise filter some of the nutrient load.

2.4 Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

In Queensland the *Environmental Protection Act 1994* regulates operation of point sources of nutrients. A voluntary market-based mechanism now exists which provides an alternative investment option for licensed point source operators to meet their water emission discharge requirements under the Act, while delivering an improvement in water quality in the receiving environment. This mechanism allows environmental authority holders, such as sewage treatment plants and aquaculture operations, to use alternative nutrient reduction actions to counterbalance nitrogen and phosphorous loads contained in water emissions. Alternative nutrient reduction actions may come from another point source, or may be achieved through diffuse actions such as bank stabilisation, improved fertiliser application and constructed wetlands.

For example, in the agricultural catchments of the Great Barrier Reef, reef protection requirements under the Environmental Protection Act 1994 and the Chemical Usage (Agricultural and Veterinary) Control Act 1988 and associated regulations require all cane farmers in the Wet Tropics, Burdekin and Mackay-Whitsundays to keep records of their use of fertilisers and agricultural chemicals; and undertake soil tests and use results of soil tests, and the regulated method, to calculate and apply no more than the optimum amount of fertiliser (nitrogen and phosphorus).

While there may be instances where other environmental schemes (fisheries habitat restoration, ASS remediation, biodiversity schemes) promote tidal restoration to mangrove and tidal marshes, it is unlikely that such schemes would apply specifically in circumstances where freshwater inputs to a site are increased.

3. Additionality

3.1 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is unlikely that freshwater inputs would be actively managed for the purpose of mangrove and tidal marsh ecosystems in the ordinary course of events as there are no legislative requirements or financial incentives to do so. Further, alteration of freshwater management may result in loss of production capacity elsewhere in the catchment.

There are current and potentially future circumstances where nutrient management may be undertaken in the ordinary course of events, thereby weakening additionality of this activity.

Table 26. Abatement integrity assessment for offsite management options for mangroves and tidal marshes. Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in carbon abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	1	There has been increasing effort and numerous mechanisms to reduce nutrient concentrations in many coastal catchments and this trend is likely to continue
4.2. Estimating the activity's carbon removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine carbon removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	0	It is possible to measure nutrient and soil C_{org} rates in mangroves and tidal marshes, however demonstrating a link with catchment activity is not yet validated.
4.3. Carbon abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible carbon abatement in accordance with the approach outlined in footnote 2.	0- Carbon abatement from the activity is not eligible carbon abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if carbon abatement from the activity is eligible carbon abatement. It is uncertain whether the carbon can be counted towards Australia's national greenhouse gas inventory. 2 - Carbon abatement from the activity is eligible carbon abatement and can be counted	MAN: 2 (Biomass); 1 (Soil) TM: 1 (Soil)	Mangrove biomass carbon may be included under current forest carbon inventory. For soils, if we can track and count it now then there is potential for it to be credited.

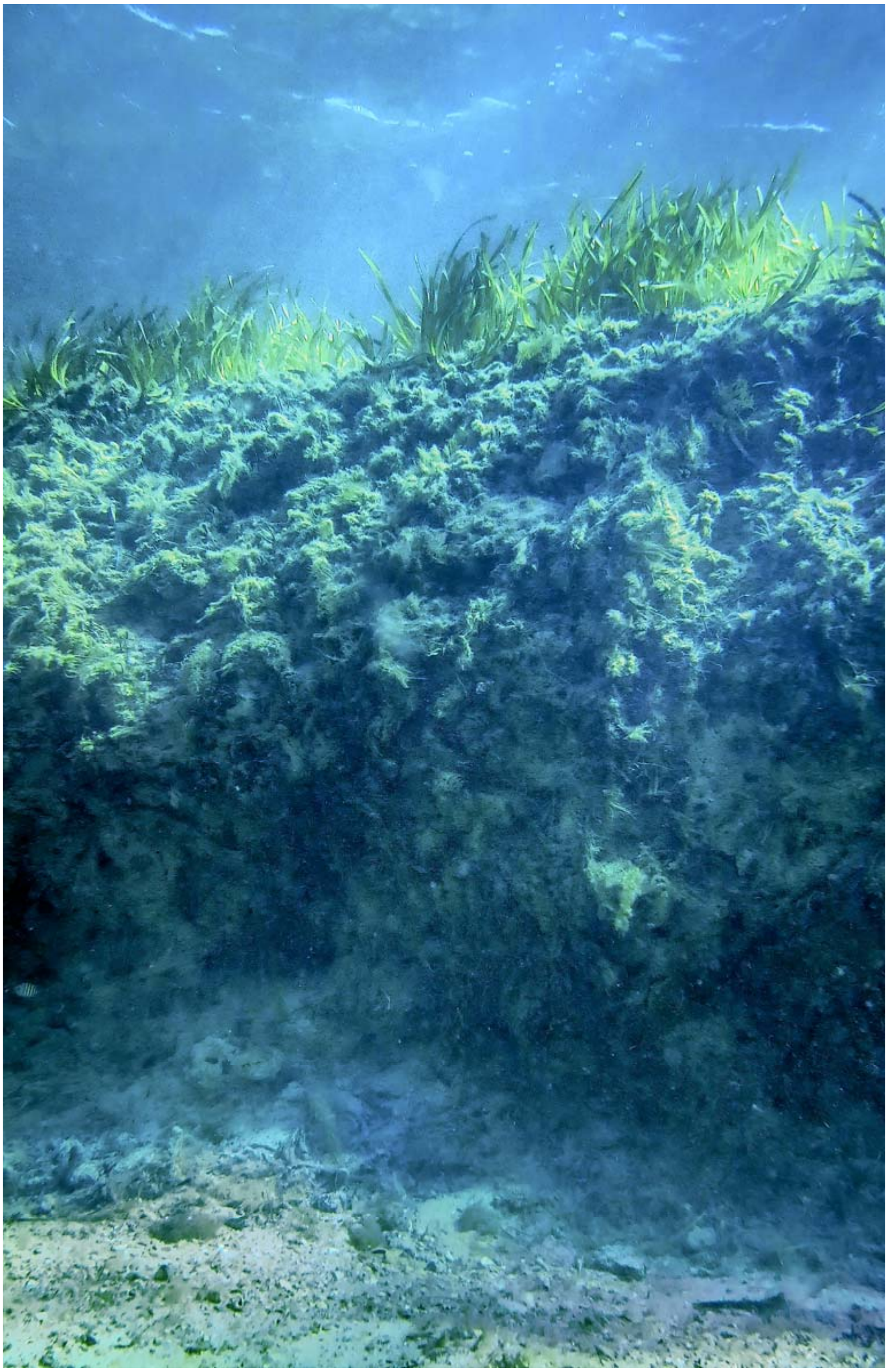
Integrity requirement	Scoring criteria	Score	Score Justification
	towards Australia's national greenhouse gas inventory.		
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	1	Research linking nutrient supply and/or salinity management to blue carbon enhancement are currently limited. Outcomes to date are largely equivocal.
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	There are methods available to quantify emissions in mangroves and tidal marshes, including any material amounts that may occur.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative.	1	Data are limited and in many cases findings are equivocal so it cannot be determined whether estimates, projections or assumptions are conservative.

Integrity requirement	Scoring criteria	Score	Score Justification
	2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.		
	Total score	MAN (biomass) = 7 MAN (soil) = 6 TM (soil) = 6	

Footnote 2: *To be eligible carbon abatement, the abatement needs to be able to be captured* in *Australia's nationally reported greenhouse gas emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

7 SEAGRASSES



SECTION A: FACTORS INFLUENCING EMISSIONS AVOIDANCE AND SEQUESTRATION IN AUSTRALIAN SEAGRASSES.

7.1 Introduction to Influencing Factors relevant to seagrasses

There are several natural and anthropogenic factors that can influence the fluxes of C_{org} in seagrass ecosystems. In this section the relevant *influencing factors* driving C_{org} sequestration and CO_2-e emissions in seagrasses and those most amenable to modification through anthropogenic management are identified and discussed.

Thematically, the influencing factors have been divided into physical, biological and chemical categories; however, a high degree of interaction among influencing factors in these three categories can exist. For example, a change to the hydrology within a catchment (physical factor) through reducing riverine inputs and increasing nutrient fluxes into blue carbon ecosystems may also influence the primary productivity of a seagrass site (biological factors) whilst also altering the salinity or nutrient status (chemical factors). For this reason, some overlap exists in the subsequent information reported across the different influencing factors.

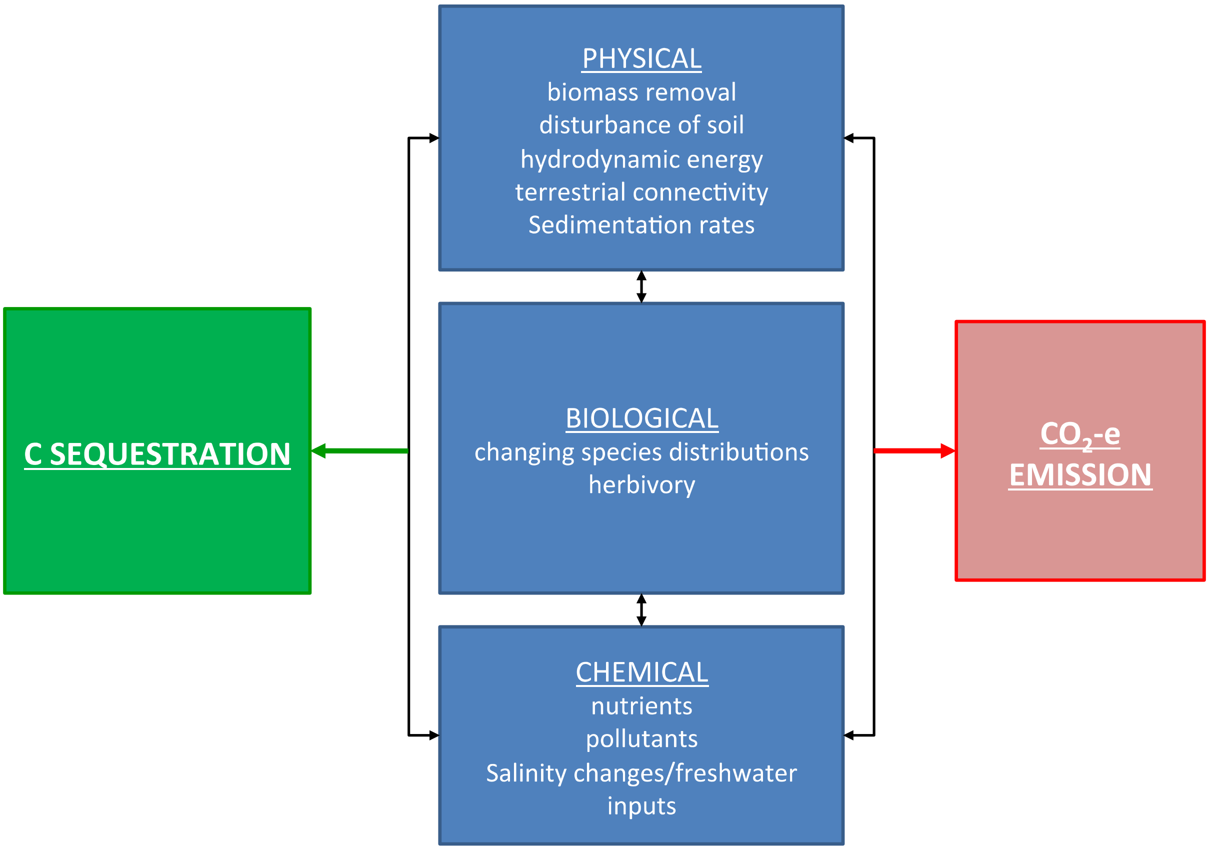


Figure 7: List of important physical, biological and chemical influencing factors for C_{org} sequestration and emission in seagrasses that are amenable to human intervention.

7.2 National and State legislation relevant to management of seagrasses

Most of the influencing factors listed in this section are regulated under legislations (federal/state/local) that protect seagrass ecosystems. Hamdorf and Kirkman (1995) presented a State-by-State assessment of legislative protection for seagrass, updated by Butler et al. (1999). Here we present a summary of the legislation affecting seagrass habitats in Australia (based on Butler et al. (1999)), which provides more details linked to the information provided in the tables below. Seagrass legislation can be in the form of the following Acts.

7.2.1 Acts that include specific protection for seagrasses

Source: NSW Fish habitat protection plan no 2 seagrasses

Searches of the Australasian Legal Information Institute's databases of Australian legislation (www.austlii.edu.au) revealed that, in relation to fisheries and environmental interests, direct reference to seagrass/es occurs in only seven acts or regulations. These are:

- Commonwealth Federal Airports Corporation Regulations — Schedule 1 1993 (deals specifically with environmental management in Botany Bay for Sydney Airport)

- New South Wales Environmental Planning and Assessment Regulation 1994

- New South Wales Fisheries Management Act 1994

- New South Wales Fisheries Management (General) Regulation 1995

- Territory Fisheries Act

- South Australian Environment Protection (Marine) Policy 1994

- Reg 4 South Australian Fisheries Act 1982

A second way of protecting seagrasses specifically though legislation is to zone particular areas as protected, by inclusion within Marine Parks, Aquatic Reserves and in fishing closures. Such areas are set aside under conservation legislation (as national parks for example), planning legislation (by being zoned under council planning schemes) or under fisheries legislation (in marine protected areas). In general, any activity, which may directly affect seagrasses, would be prohibited, as would indirect activities occurring within the protected area. For activities occurring outside the protected area, which may affect seagrasses inside, coercion and pressure may be used, although these tactics may not necessarily be successful. The Great Barrier Reef Marine Park Authority is just one agency that has problems dealing with activities outside the park boundaries that affect the park itself.

7.2.2 Acts that address activities that may affect seagrasses

Source: Butler et al. (1999)

Other legislation, refers more generally to marine plants or to fish habitat but does not refer to seagrass specifically:

- Fisheries Act 1994 (e.g. QLD and NSW): The *Fisheries Management Act 1994* states that "A person must not cut, remove, damage or destroy marine vegetation on public water land or an aquaculture lease, or on the foreshore of any land or lease, except under the authority of a permit issued by the

Minister under this Part (205) or of an aquaculture permit". Seagrass may also be protected under other sections of the Act by placing appropriate conditions on permits granted for dredging and reclamation, for the commercial collection of marine vegetation, for aquaculture, and scientific collections and on commercial fishing licences. Some fisheries acts (amongst others) include provisions for the control of activities such as dredging and reclamation, which may affect seagrasses.

- Other agencies also influence seagrass management; for example, the Department of Land and Water Conservation, the National Parks and Wildlife Service, the Sydney Ports Corporation and the Marine Ministerial Holdings Corporation all have control of the substratum of some sub-tidal and intertidal lands which support seagrasses.

- A number of Commonwealth and State Departments may also have legislation (e.g. *Environmental Planning and Assessment Act*) that permits them to generate policies or plan impacts of activities on seagrasses. A large number of pieces of legislation are included in this category. Most of the pollution control legislation, for example, aims to ensure that water quality in waterways is sufficient to maintain plants and animals. In South Australia, loss of seagrass is included in the definition of environmental harm.

- Legislation providing for land use planning and protected areas can protect seagrasses in several ways. For example, it may provide for the protection of all seagrasses wherever they occur, making it the responsibility of anyone who may affect seagrasses to seek a permit. An example is Habitat Protection Plan Number 2, which was promulgated under the NSW Fisheries Management Act, 1994. The Queensland Fisheries Act (1996) also provides strong legislation specific to protection of all seagrasses and other marine plants (Appendix 5.2 of their publication).

In general these acts are reactive in that they are triggered by a particular development or activity proposal. Practitioners' administering such acts need to be aware of the existence and needs of seagrasses in the area affected by the proposal in order to invoke protective or impact amelioration mechanisms.

7.2.3 National and State specific legislation related to creation of protected zones

The following is a summary of the provisions of Australian legislation that affect seagrass within the Commonwealth and each State. The name of the primary organisation that administers the act is in parentheses following the title of the act (Source: Butler et al. (1999).

Commonwealth

Water Act 2007 – regulates water management and infrastructure.

Environment Protection and Biodiversity Conservation Act 1999 – requires environmental approvals process to consider impacts of a development or activity upon 'Matters of national environmental significance'. These include the Commonwealth conservation estate, Ramsar wetlands and listed threatened species and ecosystems.

New South Wales

Fisheries Management Act 1994 (NSW Fisheries) – it is an offence to cut, remove, damage or destroy marine vegetation (including seagrass) without a permit. Permits are also required for dredging and reclamation. Provides for the declaration of seagrass as threatened species and creation of aquatic reserves. A small number of existing aquatic reserves contain some seagrass. Fish Habitat Protection Plan Number 2, created under this act, deals with seagrass management.

National Parks and Wildlife Act 1974 (National Parks and Wildlife Service) – provides for creation of nature reserves and national parks; a few of which contain seagrass.

Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS) – provides for creation of marine parks: Jervis Bay and Solitary Islands have been declared and management plans are in preparation and will provide for seagrass protection.

Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning) –provides for land use planning through State Environmental Planning Policies, Regional Environmental Plans and Local Environmental Plans. Provides for impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass).

Clean Waters Act 1970 (Environment Protection Authority) – a licence is required to place any material in waterways. Water quality objectives are currently being developed for NSW waterways.

Environmental Offences and Penalties Act 1991 (Environment Protection Authority) –provides for control over actions that cause environmental damage. Allows for enforcement of clean up and restoration programs.

Catchment Management Act 1989 – establishes a State Catchment Management Coordinating Committee. Provides for creation of Catchment Management Committees for specific geographic areas that function to, inter alia: 1) promote and coordinate the implementation of total catchment management policies and programs; 2) advise on and coordinate the natural resource management activities of authorities, groups and individuals; 3) provide a forum for resolving natural resource conflicts and issues; and 4) facilitate research into the cause, effect and resolution of natural resource issues.

Water Management Act 2000 – regulates water management and infrastructure.

State Environmental Planning Policy No 14 Coastal Wetlands —places restrictions on development within designated wetlands, including the requirement for consent for restoration works. Does not apply to wetlands outside mapped boundaries.

NSW Coastal Planning Guideline: Adapting to Sea Level Rise – local Councils are encouraged to give local sea level rise projections due and proper consideration. Strategic planning to accommodate the effects of sea level rise on wetland' landward migration and their recognition in development applications.

Northern Territory

Fisheries Act (Dept. of Primary Industries and Fisheries) – provides for creation of aquatic reserves; no existing reserves contain seagrass. Provides for control of harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants without a permit.

Parks and Wildlife Conservation Act (Parks and Wildlife Commission) – provides for creation of marine parks. Draft plan of management for Coburg Marine Park specifies protection of seagrasses.

Water Act 1992 – regulates water management and infrastructure.

Water Act 1996 – sets standards for effluents such as sewage and requires that effluents do not cause degradation of water quality in fresh and marine systems.

Queensland

Fisheries Act 1994 (Department of Primary Industries) – refers to 'marine plants' and 'fisheries habitats' which includes mostly mangroves, seagrasses, algae, saltmarshes and other tidally influenced wetlands. Provides for declaration of Fish Habitat Areas, management of declared Fish Habitat Areas, protection of fisheries resources in declared Fish Habitat Areas, protection of marine plants, and executive powers to request rehabilitation or restoration of fisheries habitat or restore land or waters. Developers, government agencies and authorities, extractive industries and researchers, etc., require permits to remove, damage or destroy marine plants.

Environment Protection Act 1994 (Department of Environment) – used in regulating any point source discharge (e.g., volumes, composition and method of discharges) from shipyards, resorts, farms, waste treatment plants.

Nature Conservation Act 1992 (Department of Environment) – provides the basis for conservation of species of particular conservation value, e.g., dugongs and sea turtles. Conservation of these species requires protection of their seagrass feeding habitats.

Harbours Act 1955 – provides for enforcement and regulation of works in tidal waters, e.g., dredging, construction of walls, or other structures, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed.

Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA) – provide for identification and zoning of areas which require special protection from human impacts or use. Marine Park permits are required for activities which may affect seagrasses, conservation of other flora and fauna, or have impacts on the physical environment (e.g., water quality) in a marine park. Impacts from outside marine parks can also be regulated (e.g., prawn farm runoff, dredge operations and spoil dumps, structures which could cause shading.) Deeds of Agreement can be written into Marine Park permits as conditions or obligations on impact mitigation, habitat compensation or habitat recovery. Bonds may be held in trust to help ensure these conditions/obligations can be fulfilled. These are not often used and there appears to be no formal policy within the Queensland Department of Environment on revegetation or replenishment of seagrass habitat.

Coastal Protection and Management Act 1995 – allows for development of a Statewide coastal management plan as well as regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations.

Integrated Planning Act 1997 – intends to provide a State-wide planning system for dealing with developments which affect coastal habitats. Includes obligations to set Desired Environment Outcomes and to monitor selected performance indicators. Developments to be assessed by all relevant management agencies (Integrated Development Assessment System).

Water Act 2000 and Sustainable Planning Act 2009 – regulate water management and infrastructure

Coastal Management Plan – Impacts of climate variability, including sea level rise are considered in managing the coast.

South Australia

Fisheries Act 1982 (Primary Industries and Resources - Fisheries) – provides for control of fisheries (including commercial harvesting of seagrass), aquatic reserves, marine parks and disturbance of the sea floor and associated biota*.* Flora can be protected in marine parks. A person must not engage in an operation involving or resulting in removal of or interference with aquatic or benthic flora and fauna of any waters.

Native Vegetation Act 1991 – limits the destruction of any native vegetation including seagrass Delegates responsibility for marine vegetation to Director of Fisheries.

Local Government Act 1934 – empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores.

Development Act 1993 – controls planning and approvals for developments.

Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency) – under this Act, the Environment Protection (Marine) Policy 1994 sets out transitional licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria which are derived from national guidelines, and, for nutrients, requires specifically that no discharge will cause loss of seagrass after March 2001. Dredging is also licensed under this Act. Operations must use best available technology in dredging and monitor their effects during operations. The policy requires that spoil be brought ashore, unless exempted. No exemptions have been granted to date. The Act provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan.

Natural Resources Management Act 2004 – regulates water management and infrastructure.

Fisheries Management Act 2007 – mangroves, but not seagrasses, are explicitly identified. The objective is to protect and conserve aquatic habitats.

Tasmania

Living Marine Resources Management Act 1995 – generally regulates and protects the living marine environment, including seagrasses.

Marine Farming Planning Act 1995 – aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture.

Environmental Management and Pollution Control Act 1996 –the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste.

State Policies and Projects Act 1993 – the State Coastal Policy is a policy created under this Act. The central objective of any State policy is sustainable development. This means that it must address the use, development and protection of natural and physical resources together with the objectives relating to public involvement and the sharing of responsibility in resource management and planning as well as those relating to economic development. The policy establishes the State Coastal Advisory Committee, which is supported by the Coastal and Marine Program in the Department of Environment and Land Management. Seagrass will be considered for inclusion in protected environmental values under the State Water Quality Management Policy.

Land Use Planning and Approvals Act 1993 – provides for land use planning and development control. To ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries), the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application.

Water Management Act 1999 – regulates water management and infrastructure.

Coastal Policy Statement – areas subject to significant risk from coastal processes and hazards, including sea level rise, will be identified and managed. Retreat pathways for natural ecosystems prioritised when planning new infrastructure.

Victoria

Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division) – one of the objectives (Section 3(b)) is to protect and conserve fisheries habitats and ecosystems: this includes seagrass. This can be done two ways: i) declaration of an area as a Fisheries Reserve under Part 5, Division 3; and ii) list seagrass as protected aquatic biota under Part 5, Division 1. Provides for creation of marine parks in areas that support seagrasses. Management plans for these protected areas can specify actions designed to protect seagrass.

Environment Protection Act 1970 (Environment Protection Authority) – provides for creation of State Environment Protection Policies (SEPPs) that identify environmental segments to be protected and can identify attainments program to prevent environmental damage or restore systems, including seagrass. SEPPs relevant to seagrass protection are: Waters of Victoria (maintenance of natural aquatic ecosystems and associated wildlife); and Waters of Western Port Bay and Catchment (maintenance and conservation of marine ecosystems and wildlife habitats, including seagrasses). In assessing works approvals and developing license conditions it is mandatory to include SEPP requirements. While not specifically prohibiting resource use activities in an area, SEPPs ensure that activities are undertaken in a manner that prevents impacts or likely impacts on beneficial uses.

Planning and Environment Act 1987

Water Act 1989 – regulates water management and infrastructure.

Coastal Management Act 1995 and associated *Victorian Coastal Strategy 2014* – apply to private and Crown land in the intertidal zone and within 200 m of the high water mark. Aims to protect coastal areas of environmental significance. Actions proposed that facilitate retreat of coastal ecosystems under sea level rise.

Western Australia

NOTE – water legislation in WA is currently under review.

Fisheries Resources Management Act 1994 (Fisheries WA) – seagrasses are included in the definition of fish. The objectives of the act are to conserve, develop and share the fish resources of the State for the benefit of present and future generations. Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.

Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management) – provides for creation of Marine Nature Reserves and multiple use Marine Parks. Certain aquatic species are protected under this Act. It could affect the collection of source material for transplantation or any activities affecting listed species (e.g. *Posidonia* ecosystems). The Act is also relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities.

Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection) – provides for protection of the environment through the prevention, control and abatement of pollution. Requires environmental impact assessment of proposed activities. The EPA has developed environmental protection policies with a strong focus on seagrass (Cockburn Sound) and has provided a number of non-statutory guidelines for assessing potential impacts on marine ecosystems, including seagrass. Most of the legislations to protect seagrasses are biased towards direct mechanical damage, as opposed to more diffuse or indirect causes of disturbance, such as runoff. Even in the case of direct mechanical damage, it is a wonder how many direct impacts (e.g. propeller scarring and boat mooring) go ahead unregulated.

Environmental Assessment Guideline (EAG) No. 3 Protection of Benthic Primary Producer Habitats in Western Australia's Marine Environment (2009) provides the basis for the EPA's evaluation of, and advice on, proposals or schemes subject to EIA and which relate to Benthic Primary Producer Habitats (BPPH) – which includes seabed communities within which seagrass and mangroves are prominent components. It provides a framework for assessing the environmental impact of proposals that have potential to result in loss or serious damage to these habitats in Western Australia's marine environment.

Water Resources Acts – the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act. These include the: Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947. These would influence any activities that involved changes to the use of water.

Water Agencies (Powers) Act 1984, *Country Areas Water Supply Act 1947, Metropolitan Water Supply, Sewerage and Drainage Act 1909* and *Waterways Conservation Act 1976* - also relate to the management of water.

7.3 Influencing factors for seagrasses

7.3.1 Removal of living biomass and disturbance of soil profile

Table 27. Influencing factors for carbon sequestration and emission in seagrasses: Physical: Removal of living biomass and disturbance of soil profile.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Physical disturbance: Removal of living biomass and disturbance of soil structure. Associated causes: Numerous, including but not limited to: moorings, fishing (trawling), bait/shell digging and collection, harvesting seagrass fibres, dredging, beach restoration, construction of coastal infrastructure, boating and anchoring, construction and operation of aquaculture facilities, seismic testing, scientific collections, reclamation, and walking through seagrass areas.	**Bourque et al.** (2015) **Macreadie et al.** (2014) **Macreadie et al.** (2015) **Ricart et al.** (2015) **Serrano et al.** (2016a) **Serrano et al.** (2016c) Baltais (2014) Demers (2013) Hastings et al. (1995) Pitcher (2007) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) (Walker 1992) Waycott et al. (2009) Larkum (1989)
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Physical disturbance can result in the removal of living biomass and exposure of soil C_{org}, leading to reduced sequestration and altered conditions conducive to C_{org} remineralisation and GHG emissions. The loss of the seagrass canopy reduces net primary production and the trapping of organic particles from the water column, thereby reducing C_{org} sequestration. Canopy loss also exposes the soil to oxic conditions, entailing a change in microbial activity and sediment biogeochemistry, which can enhance C_{org} remineralisation. Loss of the	**Bourque et al.** (2015) **Macreadie et al.** (2014) **Macreadie et al.** (2015) **Ricart et al.** (2015) **Serrano et al.** (2016a)

Question	Response	References
	canopy also exposes the soils to erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to the release of GHG.	Serrano et al. (2016c)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	*(additional context provided in section 7.2.3 above)* Commonwealth *Water Act 2007* *Environment Protection and Biodiversity Conservation Act 1999* New South Wales *Fisheries Management Act 1994 (NSW Fisheries):* controls the removal, damage or destruction of marine vegetation (including seagrass). *National Parks and Wildlife Act 1974 (National Parks and Wildlife Service):* provides for creation of reserves that may contain seagrass and associated management plans. *Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS):* provides for creation of marine parks which may contain seagrass and associated management plans for seagrass protection. *Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning):* provides for land use planning and impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass). *Clean Waters Act 1970 (Environment Protection Authority):* controls the placement of materials into water, which may include materials released by physical disturbance. *Environmental Offences and Penalties Act 1991 (Environment Protection Authority):* control over actions that cause environmental damage, clean up and restoration programs. *Catchment Management Act 1989* *Water Management Act 2000* *State Environmental Planning Policy No 14 Coastal Wetlands* *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* Northern Territory *Fisheries Act (Dept. of Primary Industries and Fisheries):* provides for creation of aquatic reserves that may contain seagrass, harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants. *Parks and Wildlife Conservation Act (Parks and Wildlife Commission):* provides for creation of marine parks that may protect seagrasses. *Water Act 1992*	Fish habitat protection plan no 2: Seagrasses (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/202744/Fish-habitat-protection-plan-2---Seagrass.pdf) Butler et al. (1999)

Question	Response	References
	Water Act 1996: sets standards for effluents and requires that effluents do not cause degradation of water quality in fresh and marine systems – materials released by disturbance might constitute an effluent. Queensland *Fisheries Act 1994 (Department of Primary Industries):* refers to 'marine plants' and 'fisheries habitats', which includes seagrasses. Provides for management and protection of declared Fish Habitat Areas, protection of marine plants, and powers to request rehabilitation or restoration of fisheries habitat. Require permits to remove, damage or destroy marine plants *Environment Protection Act 1994 (Department of Environment):* provides for protection of the environment, including seagrasses, and for protection from contaminants, which could include materials released through physical disturbance. *Nature Conservation Act 1992 (Department of Environment):* provides the basis for conservation of species, including seagrasses. Conservation of other species may require protection of their seagrass habitats. *Harbours Act 1955:* regulation of works in tidal waters, including dredging, and construction, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed. *Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA):* provide for identification and zoning of areas requiring special protection from human impacts. Permits are required for activities that may affect seagrasses or impact the physical environment (e.g., water quality) in a marine park. Can regulate physical disturbance from outside marine parks (e.g., dredge operations and spoil dumps) to protect the park. *Coastal Protection and Management Act 1995:* allows for Statewide and regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations. *Integrated Planning Act 1997: provide for State-wide planning for developments affecting coastal habitats through an Integrated Development Assessment System.* *Water Act 2000 and Sustainable Planning Act 2009* *Coastal Management Plan* South Australia *Fisheries Act 1982 (Primary Industries and Resources – Fisheries):* provides for control of fisheries, including commercial harvesting of seagrass. Controls removal of or interference with aquatic or benthic flora of any waters. *Native Vegetation Act 1991:* limits the destruction of any native vegetation including seagrass. *Local Government Act 1934:* empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores. *Development Act 1993:* controls planning and approvals for developments, including those that could physically disturb seagrass.	

Question	Response	References
	Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency): sets out licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria for nutrients and requires that no discharge will cause loss of seagrass. Dredging is also licensed under this policy. Provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan. *Natural Resources Management Act 2004* *Fisheries Management Act 2007* Tasmania *Living Marine Resources Management Act 1995:* generally regulates and protects the living marine environment, including seagrasses. *Marine Farming Planning Act 1995:* aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture. *Environmental Management and Pollution Control Act 1996:* the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste. *State Policies and Projects Act 1993:* allows for the creation of State Policies, including the State Coastal Policy, addressing the development and protection of natural resources. Seagrass are considered in protected environmental values under the State Water Quality Management Policy which provides a framework for the development of water quality objectives and the management and regulation of emissions to coastal waters. *Land Use Planning and Approvals Act 1993:* provides for land use planning and development control to ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application. *Water Management Act 1999* *Coastal Policy Statement* Victoria *Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division):* provides for protection of fisheries habitats, including seagrass through declaration Fisheries Reserves or listing seagrass as protected. *Environment Protection Act 1970 (Environment Protection Authority):* provides for creation of State Environment Protection Policies (SEPPs). While not specifically prohibiting resource use activities, SEPPs	

Question	Response	References
	ensure that activities are undertaken in a manner that prevents impacts. For operations such as dredging it must be demonstrated that there would not be significant impacts. *Planning and Environment Act 1987* *Water Act 1989* *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* Western Australia *Fisheries Resources Management Act 1994 (Fisheries WA): seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resource. Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.* *Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management):* provides for creation of Marine Nature Reserves and multiple use Marine Parks. Aquatic species, including seagrasses, are protected under this Act. The Act is relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities. *Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection):* provides for protection of the environment through the prevention, control and abatement of pollution, which includes discharge of materials through physical disturbance activities. Environmental Protection Policies and Environmental Assessment Guidelines (EAGs) are provided for under this Act. EAG No. 3 (Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment, 2009) provides non-statutory guidance on protection of seagrass habitat in relation to EIA. EAG7 provides non-statutory guidance on dredging activities in relation to EIA. *Environmental Assessment Guideline (EAG) No. 3 Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment (2009)* *Water Resources Acts:* the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act (Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947). These Acts relate to activities that involved the changes to the use of water. Including the additional of materials through physical disturbance. *Water Agencies (Powers) Act 1984* *Country Areas Water Supply Act 1947* *Metropolitan Water Supply and Sewage and Drainage Act 1909* *Waterways Conservation Act 1976*	

Question	Response	References
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all coastal jurisdictions, but particularly in coastal protected areas such as estuaries and embayments. - Walker et al. (1989) determined the effect of moorings on seagrass beds near Perth. - Larkum and West (1990) reported that the decline of seagrass occurred during a period of industrial and residential development in the catchment (i.e. a history of poor catchment management) of Botany Bay (Sydney), which involved dredging. - Demers (2013) assessed the impacts of "seagrass-friendly" boat mooring systems on seagrass meadows at Jervis Bay, and concluded that different types of "seagrass-friendly" moorings incur different impact on seagrass cover. - (Long et al. 1996) detected that dredging had a negative impact of seagrass ecosystems in Deception Bay, decreasing its biomass. - McMahon et al. (2011) reported that light reduction after dredging activities has a severe impact on seagrass meadows. - Fyfe and Davis (2007) reported impacts on seagrass (e.g. decrease in shoot density) following pier construction in an embayment in south-eastern Australia. - Turner and Lewis III (1996) reported that fishing results in the degradation or loss of seagrass ecosystem. - Ralph and Moore (2006) reported that growth of human populations along coastal environments (e.g. beach restoration, construction of marinas, ramps and pontoons) result in loss of seagrass meadows. - Short and Wyllie-Echeverria (1996) reported that certain fishing practices can impact seagrass meadows.	Walker et al. (1989) Larkum and West (1990) Demers (2013) Long et al. (1996) McMahon et al. (2011) Fyfe and Davis (2007) Turner and Lewis III (1996) Ralph and Moore (2006) Short and Wyllie-Echeverria (1996)
Is the influencing factor historic, current or anticipated?	Historic: The physical removal of living biomass and disturbance of soil structure has occurred since European settlement in Australia, and increased exponentially until present (peaking by 1950 and being maintained to 2000s). Current: Australia is experiencing a demographic expansion in coastal areas and estuaries, incurring physical removal of living biomass and disturbance of soil, as well as unprecedented levels of dredging for industrial development, especially in WA and QLD. Anticipated: Future developments in coastal areas and estuaries are predicted to occur in Australia, including maintenance of existing infrastructures.	Walker et al. (1989) Larkum and West (1990) Demers (2013) Long et al. (1996) McMahon et al. (2011) Fyfe and Davis (2007) Turner and Lewis III (1996) Ralph and Moore (2006) Short and Wyllie-Echeverria (1996)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: moorings, construction of coastal infrastructure, construction and operation of aquaculture facilities. Harvesting seagrass fibres and dredging could have permanent effects if the post-activity habitat is unsuitable for seagrass recovery (e.g. too deep). Causes with a temporary effect: fishing, bait/shell digging and collection, beach restoration, boating and anchoring, seismic testing, scientific collections, reclamation and walking through seagrass areas.	Bourque et al. (2015) Macreadie et al. (2014) Macreadie et al. (2015) Ricart et al. (2015) Serrano et al. (2016a)

Question	Response	References
		Serrano et al. (2016c)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- Larkum and West (1990) reported 2.6 km^2 loss in Botany Bay, NSW (erosion, coastal works, eutrophication and sea urchin grazing). - Kirkman (1997) reported 70 km^2 loss in Gulf St. Vincent (sewage and stormwater discharge; coastal works). - Kirkman (1997) reported 178 km^2 loss in Western Port Bay (siltation linked to coastal development). - Kirkman (1997) reported 4 km^2 loss in Birch Point (unknown but most probably a combination of physical and chemical factors). - Kirkman (1997) reported 4.3 km^2 loss in Ralphs Bar (unknown but most probably a combination of physical and chemical factors). - Kirkman (1997)reported 12 km^2 loss in Pittwater (unknown but most probably a combination of physical and chemical factors). - Kirkman (1997) reported 2.1 km^2 loss in Norfolk Bar (unknown but most probably a combination of physical and chemical factors). - Kirkman (1997) reported 7 km^2 loss in Lake Macquarie (increased turbidity partially due to coastal development). - Kirkman (1997) reported 4.5 km^2 loss in Clarence River (increased turbidity and decline in water quality, partially due to coastal development). - Kirkman (1997) reported >100 km^2 loss in Torres Strait (flooding). - Kirkman (1997) reported 183 km^2 loss in West Island – Limmen Bight (damage from cyclone). - Serrano et al. (2016a) report at least 0.02 km^2 of seagrass loss due to mooring at Rottnest Island, WA and report the associated C_{org} loss.	Larkum and West (1990) Kirkman (1997) and references therein. Serrano et al. (2016a)

7.3.2 Hydrodynamic energy

Table 28. Influencing factors for carbon sequestration and emission in seagrasses: Physical: Hydrodynamic energy (waves, currents, tides).

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Physical disturbance: Hydrodynamic energy (waves, currents, tides) Associated causes: storms, boating, flooding, changes in sea level; alteration of hydrodynamics through coastal development (e.g. the hydrodynamic effects of artificial reefs, groynes, breakwaters, jetties, wharves, bridges, ramps and pontoons, dredging, beach restoration, shellfish reefs, mangrove and riparian vegetation degradation, alterations of river run-off and urban stormwater discharge, controlled water flow and tidal connectivity).	**Bourque et al. (2015)** **Macreadie et al. (2014)** **Macreadie et al. (2015)** **Ricart et al. (2015)** **Serrano et al. (2016a)** **Serrano et al. (2016c)** **Marbà et al. (2015)** **Samper-Villarreal et al. (2016)** Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Increased hydrodynamic energy (pulse events or continued) can result in i) the removal of living biomass (deforestation), exposing soil C_{org} to oxic conditions, entailing a change in microbial community and soil biogeochemistry conducive to C_{org} remineralisation and GHG emissions. The loss of seagrass canopy results in the loss of C_{org} production and accumulation and exposes the soils to erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to the release of GHG. Reduced hydrodynamic energy can also facilitate soil accumulation and increase C_{org} accumulation and storage, including the regeneration and/or creation of new habitat for seagrasses, though if it is too extreme it may result in reduced seagrass abundance and C_{org} sequestration and enhanced GHG emissions.	**Bourque et al. (2015)** **Macreadie et al. (2014)** **Macreadie et al. (2015)** **Ricart et al. (2015)** **Serrano et al. (2016a)** **Serrano et al. (2016c)** **Marbà et al. (2015)** **Samper-Villarreal et al. (2016)**

Question	Response	References
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	*(additional context provided in section 7.2.3 above)* Commonwealth *Water Act 2007* *Environment Protection and Biodiversity Conservation Act 1999* New South Wales *Fisheries Management Act 1994 (NSW Fisheries):* controls the removal, damage or destruction of marine vegetation (including seagrass). *National Parks and Wildlife Act 1974 (National Parks and Wildlife Service):* provides for creation of reserves that may contain seagrass and associated management plans. *Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS):* provides for creation of marine parks which may contain seagrass and associated management plans for seagrass protection. *Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning):* provides for land use planning and impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass). *Clean Waters Act 1970 (Environment Protection Authority):* controls the placement of materials into water, which may include materials released by physical disturbance. *Environmental Offences and Penalties Act 1991 (Environment Protection Authority):* control over actions that cause environmental damage, clean up and restoration programs. *Catchment Management Act 1989* *Water Management Act 2000* *State Environmental Planning Policy No 14 Coastal Wetlands* *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* Northern Territory *Fisheries Act (Dept. of Primary Industries and Fisheries):* provides for creation of aquatic reserves that may contain seagrass, harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants. *Parks and Wildlife Conservation Act (Parks and Wildlife Commission):* provides for creation of marine parks that may protect seagrasses. *Water Act 1992*	Fish habitat protection plan no 2: Seagrasses (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/202744/Fish-habitat-protection-plan-2---Seagrass.pdf) Butler et al. (1999)

Question	Response	References
	Water Act 1996: sets standards for effluents and requires that effluents do not cause degradation of water quality in fresh and marine systems – materials released by disturbance might constitute an effluent. Queensland *Fisheries Act 1994 (Department of Primary Industries):* refers to 'marine plants' and 'fisheries habitats', which includes seagrasses. Provides for management and protection of declared Fish Habitat Areas, protection of marine plants, and powers to request rehabilitation or restoration of fisheries habitat. Require permits to remove, damage or destroy marine plants *Environment Protection Act 1994 (Department of Environment):* provides for protection of the environment, including seagrasses, and for protection from contaminants, which could include materials released through physical disturbance. *Nature Conservation Act 1992 (Department of Environment):* provides the basis for conservation of species, including seagrasses. Conservation of other species may require protection of their seagrass habitats. *Harbours Act 1955:* regulation of works in tidal waters, including dredging, and construction, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed. *Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA):* provide for identification and zoning of areas requiring special protection from human impacts. Permits are required for activities that may affect seagrasses or impact the physical environment (e.g., water quality) in a marine park. Can regulate physical disturbance from outside marine parks (e.g., dredge operations and spoil dumps) to protect the park. *Coastal Protection and Management Act 1995:* allows for Statewide and regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations. *Integrated Planning Act 1997: provide for State-wide planning for developments affecting coastal habitats through an Integrated Development Assessment System.* *Water Act 2000 and Sustainable Planning Act 2009* *Coastal Management Plan* South Australia *Fisheries Act 1982 (Primary Industries and Resources – Fisheries):* provides for control of fisheries, including commercial harvesting of seagrass. Controls removal of or interference with aquatic or benthic flora of any waters. *Native Vegetation Act 1991:* limits the destruction of any native vegetation including seagrass.	

Question	Response	References
	Local Government Act 1934: empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores. *Development Act 1993:* controls planning and approvals for developments, including those that could physically disturb seagrass. *Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency):* sets out licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria for nutrients and requires that no discharge will cause loss of seagrass. Dredging is also licensed under this policy. Provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan. *Natural Resources Management Act 2004* *Fisheries Management Act 2007* Tasmania *Living Marine Resources Management Act 1995:* generally regulates and protects the living marine environment, including seagrasses. *Marine Farming Planning Act 1995:* aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture. *Environmental Management and Pollution Control Act 1996:* the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste. *State Policies and Projects Act 1993:* allows for the creation of State Policies, including the State Coastal Policy, addressing the development and protection of natural resources. Seagrass are considered in protected environmental values under the State Water Quality Management Policy which provides a framework for the development of water quality objectives and the management and regulation of emissions to coastal waters. *Land Use Planning and Approvals Act 1993:* provides for land use planning and development control to ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application. *Water Management Act 1999* *Coastal Policy Statement*	

Question	Response	References
	Victoria *Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division):* provides for protection of fisheries habitats, including seagrass through declaration Fisheries Reserves or listing seagrass as protected. *Environment Protection Act 1970 (Environment Protection Authority):* provides for creation of State Environment Protection Policies (SEPPs). While not specifically prohibiting resource use activities, SEPPs ensure that activities are undertaken in a manner that prevents impacts. For operations such as dredging it must be demonstrated that there would not be significant impacts. *Planning and Environment Act 1987* *Water Act 1989* *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* Western Australia *Fisheries Resources Management Act 1994 (Fisheries WA): seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resource. Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.* *Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management):* provides for creation of Marine Nature Reserves and multiple use Marine Parks. Aquatic species, including seagrasses, are protected under this Act. The Act is relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities. *Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection):* provides for protection of the environment through the prevention, control and abatement of pollution, which includes discharge of materials through physical disturbance activities. Environmental Protection Policies and Environmental Assessment Guidelines (EAGs) are provided for under this Act. EAG No. 3 (Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment, 2009) provides non-statutory guidance on protection of seagrass habitat in relation to EIA. EAG7 provides non-statutory guidance on dredging activities in relation to EIA. *Environmental Assessment Guideline (EAG) No. 3 Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment (2009)* *Water Resources Acts:* the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act (Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947). These Acts relate	

Question	Response	References
	to activities that involved the changes to the use of water. Including the additional of materials through physical disturbance. *Water Agencies (Powers) Act 1984* *Country Areas Water Supply Act 1947* *Metropolitan Water Supply and Sewage and Drainage Act 1909* *Waterways Conservation Act 1976*	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	All States and jurisdictions. - Larkum and West (1990) reported that the decline of seagrass occurred due to a history of poor catchment management at Botany Bay (Sydney), which involved dredging and subsequent increase in wave height and deterioration and erosion of seagrass beds. - Loneragan et al. (2013) reported that cyclones in Exmouth Gulf (WA) impacted seagrass ecosystems (seagrass area), followed by seagrass recovery after 4 years. - Short and Wyllie-Echeverria (1996) reported that changes in hydrodynamic energy can impact seagrass meadows.	Larkum and West (1990) Loneragan et al. (2013) Short and Wyllie-Echeverria (1996)
Is the influencing factor historic, current or anticipated?	Historic: Coastal development since European settlement in Australia entailed alteration of hydrodynamic energy in coastal areas, in particular human activities during 1950 - 2000. Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, including activities that could alter the hydrodynamic energy within seagrass ecosystems or coastal and estuarine areas. Anticipated: Future developments in coastal areas, estuaries and catchments affecting hydrology and hydrodynamic energy are predicted to occur in Australia. Future global change scenarios predict and increase in the magnitude and frequency of extreme climatic events such as storms.	Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: alteration of hydrodynamics (artificial reef, construction groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons, shellfish reefs). Causes with a temporary effect: storms, alteration of hydrodynamics (river discharge, flooding, dredging, beach restoration, boating, control water flow, tidal connectivity and river run-off, groundwater use), temporary changes to stormwater discharges, mangrove and riparian vegetation degradation and global change.	Bourque et al. 2015 Macreadie et al. 2014 Macreadie et al. 2015 Ricart et al. 2015 Serrano et al. 2016a and 2016c Marbà et al. 2015 Samper-Villareal et al. 2016 Duarte et al. (2013a) Pendleton et al. (2012)

Question	Response	References
		Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- Sergeev (1988) reported 8 km^2 loss in Holdfast Bay, SA (sediment instability induces blowout expansion). - Larkum and West (1990) reported 2.6 km^2 loss in Botany Bay, NSW (erosion, coastal works, eutrophication and sea urchin grazing). - Kirkman (1997) reported 70 km^2 loss in Gulf St. Vincent (sewage and stormwater discharge; coastal works). - Kirkman (1997) reported 178 km^2 loss in Western Port Bay (siltation). - Kirkman (1997) reported 18.3 km^2 loss in West Island – Limmen Bight (damage from cyclone).	Sergeev (1988) Larkum and West (1990) Kirkman (1997) and references therein.

7.3.3 Sediment loading

Table 29. Influencing factors for carbon sequestration and emission in seagrasses: Physical: Sediment loading.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Physical disturbance: Sediment loading Associated causes: Land-use change (agriculture, coastal development) and associated run-off, fire, dredging; alteration of hydrodynamics (e.g. artificial reef, construction groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons, shellfish reefs, river discharge, dredging, beach restoration, boating, storms, aquaculture, storms, cyclones) and hydrology (e.g. control water flow, tidal connectivity, river run-off, flooding, point source stormwater).	Marbà et al. (2015) Macreadie et al. (2012) Duarte et al. (2013a) Greiner et al. (2013) Rozaimi et al. (2016) Dahl et al. (2016) Liu et al. (2016) Reynolds (2016) Serrano et al. (2014) Ribaudo et al. (2016) Watanabe and Kuwae (2015) Serrano et al. (2016b) Serrano et al. (2016c) Samper-Villarreal et al. (2016) Short and Wyllie-Echeverria (1996) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)

Question	Response	References
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Changes in sediment loading can result in either enhanced or reduced C_{org} accumulation in seagrass meadows: i) Increased suspended sediments result in reduced irradiance and reduced C_{org} production. Accumulation as a result of excess sediment loading and sedimentation could result in asphyxia or sulphide toxicity and the loss of living biomass (deforestation) followed by exposure of soil C_{org} to oxic conditions conducive to C_{org} remineralisation and GHG emissions. The loss of seagrass canopy also results in the loss of C_{org} accumulation and expose soils to erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to the release of GHG. ii) Changes in sediment loading and sedimentation below detrimental thresholds can enhance C_{org} accumulation in seagrass ecosystems linked to increased fluxes of sediments by delivering more sediment-associated C_{org} to potentially be sequestered and by enhancing the soil accumulation rates which increase the C_{org} accumulation and preservation potential. iii) Changes in sediment loading and sedimentation can also result in the reduction of sediment fluxes (and associated C_{org}) into coastal areas, which can lead to the erosion of living biomass and associated remineralisation of soil C_{org} stocks in seagrass meadows and GHG emissions. iv) Changes in sediment loading and sedimentation can also result in the creation of new habitat suitable for seagrass growth (e.g. by forming shallower habitat with higher irradiance availability, or by changing hydrodynamic energy), resulting in an increase in C_{org} sequestration.	Marbà et al. (2015) Macreadie et al. (2012) Duarte et al. (2013a) Greiner et al. (2013) Rozaimi et al. (2016) Dahl et al. (2016) Liu et al. (2016) Reynolds (2016) Serrano et al. (2014) Ribaudo et al. (2016) Watanabe and Kuwae (2015) Kuwae et al. (2016) Serrano et al. (2016b) Serrano et al. (2016c) Samper-Villarreal et al. (2016) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	*(additional context provided in section 7.2.3above)* Commonwealth *Water Act 2007* *Environment Protection and Biodiversity Conservation Act 1999* New South Wales *Fisheries Management Act 1994 (NSW Fisheries):* controls the removal, damage or destruction of marine vegetation (including seagrass).	Fish habitat protection plan no 2: Seagrasses (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/202744/Fish-habitat-protection-plan-2---Seagrass.pdf) Butler et al. (1999)

Question	Response	References
	National Parks and Wildlife Act 1974 (National Parks and Wildlife Service): provides for creation of reserves that may contain seagrass and associated management plans. *Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS):* provides for creation of marine parks which may contain seagrass and associated management plans for seagrass protection. *Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning):* provides for land use planning and impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass). *Clean Waters Act 1970 (Environment Protection Authority):* controls the placement of materials into water, which may include materials released by physical disturbance. *Environmental Offences and Penalties Act 1991 (Environment Protection Authority):* control over actions that cause environmental damage, clean up and restoration programs. *Catchment Management Act 1989* *Water Management Act 2000* *State Environmental Planning Policy No 14 Coastal Wetlands* *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* Northern Territory *Fisheries Act (Dept. of Primary Industries and Fisheries):* provides for creation of aquatic reserves that may contain seagrass, harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants. *Parks and Wildlife Conservation Act (Parks and Wildlife Commission):* provides for creation of marine parks that may protect seagrasses. *Water Act 1992* *Water Act 1996: sets standards for effluents and requires that effluents do not cause degradation of water quality in fresh and marine systems – materials released by disturbance might constitute an effluent.* Queensland *Fisheries Act 1994 (Department of Primary Industries):* refers to 'marine plants' and 'fisheries habitats', which includes seagrasses. Provides for management and protection of declared Fish Habitat Areas, protection of marine plants, and powers to request rehabilitation or restoration of fisheries habitat. Require permits to remove, damage or destroy marine plants *Environment Protection Act 1994 (Department of Environment):* provides for protection of the environment, including seagrasses, and for protection from contaminants, which could include materials released through physical disturbance. *Nature Conservation Act 1992 (Department of Environment):* provides the basis for conservation of species, including seagrasses. Conservation of other species may require protection of their seagrass habitats.	

Question	Response	References
	Harbours Act 1955: regulation of works in tidal waters, including dredging, and construction, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed. *Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA):* provide for identification and zoning of areas requiring special protection from human impacts. Permits are required for activities that may affect seagrasses or impact the physical environment (e.g., water quality) in a marine park. Can regulate physical disturbance from outside marine parks (e.g., dredge operations and spoil dumps) to protect the park. *Coastal Protection and Management Act 1995:* allows for Statewide and regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations. *Integrated Planning Act 1997: provide for State-wide planning for developments affecting coastal habitats through an Integrated Development Assessment System.* *Water Act 2000 and Sustainable Planning Act 2009* *Coastal Management Plan* South Australia *Fisheries Act 1982 (Primary Industries and Resources – Fisheries):* provides for control of fisheries, including commercial harvesting of seagrass. Controls removal of or interference with aquatic or benthic flora of any waters. *Native Vegetation Act 1991:* limits the destruction of any native vegetation including seagrass. *Local Government Act 1934:* empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores. *Development Act 1993:* controls planning and approvals for developments, including those that could physically disturb seagrass. *Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency):* sets out licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria for nutrients and requires that no discharge will cause loss of seagrass. Dredging is also licensed under this policy. Provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan. *Natural Resources Management Act 2004* *Fisheries Management Act 2007* Tasmania *Living Marine Resources Management Act 1995:* generally regulates and protects the living marine environment, including seagrasses. *Marine Farming Planning Act 1995:* aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture.	

Question	Response	References
	Environmental Management and Pollution Control Act 1996: the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste. *State Policies and Projects Act 1993:* allows for the creation of State Policies, including the State Coastal Policy, addressing the development and protection of natural resources. Seagrass are considered in protected environmental values under the State Water Quality Management Policy which provides a framework for the development of water quality objectives and the management and regulation of emissions to coastal waters. *Land Use Planning and Approvals Act 1993:* provides for land use planning and development control to ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application. *Water Management Act 1999* *Coastal Policy Statement* Victoria *Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division):* provides for protection of fisheries habitats, including seagrass through declaration Fisheries Reserves or listing seagrass as protected. *Environment Protection Act 1970 (Environment Protection Authority):* provides for creation of State Environment Protection Policies (SEPPs). While not specifically prohibiting resource use activities, SEPPs ensure that activities are undertaken in a manner that prevents impacts. For operations such as dredging it must be demonstrated that there would not be significant impacts. *Planning and Environment Act 1987* *Water Act 1989* *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* Western Australia *Fisheries Resources Management Act 1994 (Fisheries WA): seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resource. Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.* *Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management):* provides for creation of Marine Nature Reserves and multiple use Marine Parks. Aquatic species, including seagrasses,	

Question	Response	References
	are protected under this Act. The Act is relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities. *Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection):* provides for protection of the environment through the prevention, control and abatement of pollution, which includes discharge of materials through physical disturbance activities. Environmental Protection Policies and Environmental Assessment Guidelines (EAGs) are provided for under this Act. EAG No. 3 (Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment, 2009) provides non-statutory guidance on protection of seagrass habitat in relation to EIA. EAG7 provides non-statutory guidance on dredging activities in relation to EIA. *Environmental Assessment Guideline (EAG) No. 3 Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment (2009)* *Water Resources Acts:* the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act (Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947). These Acts relate to activities that involved the changes to the use of water. Including the additional of materials through physical disturbance. *Water Agencies (Powers) Act 1984* *Country Areas Water Supply Act 1947* *Metropolitan Water Supply and Sewage and Drainage Act 1909* *Waterways Conservation Act 1976*	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all jurisdictions, in particular in coastal protected areas such as estuaries and embayments. - Larkum and West (1990) reported that the decline of seagrass occurred during a period of industrial and residential development in the catchment (i.e. a history of poor catchment management) of Botany Bay (Sydney), which involved changes in terrestrial connectivity and sedimentation patterns. - Daniell et al. (2008) linked the migration of bedforms to the disappearance of seagrass meadows at Torres Strait. - Ralph and Moore (2006) reported that growth of human populations along coastal environments and associated activities increasing sedimentation in coastal areas resulted in loss of seagrass meadows. - Short and Wyllie-Echeverria (1996) reported that human activities modifying sediment loading can impact seagrass meadows. - Preen et al. (1995) and Campbell and McKenzie (2004) reported the loss seagrass throughout different parts of the Queensland coast as the result of persistent sediment plumes following storms and cyclones.	Larkum and West (1990) Daniell et al. (2008) Ralph and Moore (2006) Short and Wyllie-Echeverria (1996) Preen et al. (1995) Campbell and McKenzie (2004)
Is the influencing factor historic, current or anticipated?	Historic: Coastal development since European settlement in Australia impacted sediment loading and sedimentation, mostly between 1950 until 2000s.	Duarte et al. (2013a) Pendleton et al. (2012)

Question	Response	References
	Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, including activities that could alter sediment loading and sedimentation within seagrass ecosystems or coastal and estuarine areas. The volume of dredging has increased dramatically resulting in large areas of seagrass being impacted, particularly in QLD and WA. Anticipated: Future developments in coastal areas, estuaries and catchments affecting sediment loading and sedimentation in coastal areas and estuaries occupied by seagrasses are predicted to occur in Australia. Future global change scenarios predict an increase in the magnitude and frequency of extreme climatic events such as storms, which can influence sediment loading and sedimentation within seagrass ecosystems.	Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989) Short and Wyllie-Echeverria (1996)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: Land-use change (agriculture, coastal development) and associated run-off, alteration of hydrology (e.g. artificial reef, construction groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons, shellfish reefs). For some of these, permanence assumes maintenance of the current situation into the future. Causes with a temporary effect: fire, dredging, alteration of hydrology (river discharge, control water flow and tidal connectivity, point source stormwater), altered hydrodynamics (artificial reefs, construction of coastal infrastructure, dredging, beach restoration, boating, river run-off, groundwater use, flooding, beach restoration, point source stormwater, storms and cyclones, aquaculture).	Marbà et al. (2015) Macreadie et al. (2012) Duarte et al. (2013a) Greiner et al. (2013) Rozaimi et al. (2016) Dahl et al. (2016) Liu et al. (2016) Reynolds (2016) Serrano et al. (2014) Ribaudo et al. (2016) Watanabe and Kuwae (2015) Kuwae et al. (2016) Serrano et al. (2016b) Serrano et al. (2016c) Samper-Villarreal et al. (2016) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)

Question	Response	References
		Short and Wyllie-Echeverria (1996)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- Sergeev (1988) reported 178 km^2 loss in Westernport, Victoria (fine muds settles on leaf-blade). - Bulthuis (1983) reported 1 km^2 loss in South of Outer Harbour, Holdfast Bay, South Australia (accretion of sediment). - Kirkman (1978) reported seagrass loss in Moreton Bay (smothering by sediment). - Larkum and West (1990) reported 2.6 km^2 loss in Botany Bay, NSW (erosion, coastal works, eutrophication and sea urchin grazing). - Kirkman (1997) reported 7.2 km^2 loss in Oyster Harbour (eutrophication and farm run-off). - Kirkman (1997) reported 70 km^2 loss in Gulf St. Vincent (sewage and stormwater discharge; coastal works). - Kirkman (1997) reported 17.8 km^2 loss in Western Port Bay (siltation). - Kirkman (1997) reported 100 km^2 loss in Hervey Bay (increased turbidity from flooding rivers). - Kirkman (1997) reported >100 km^2 in loss Torres Strait (flooding). - Kirkman (1997) reported 11.3 km^2 loss of seagrass loss in Port Macquarie (increased turbidity). Preen et al. (1995) and Campbell and McKenzie (2004) reported the loss of 1,000 km^2 seagrass throughout different parts of the Queensland coast (persistent sediment plumes following storms and cyclones).	Bulthuis (1983) Sergeev (1988) Kirkman (1978) Larkum and West (1990) Kirkman (1997) (and references therein) Preen et al. (1995) Campbell and McKenzie (2004)

7.3.4 Nutrient enrichment

Table 30. Influencing factors for carbon sequestration and emission in seagrasses: Chemical: nutrient enrichment.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Chemical disturbance: nutrient enrichment Associated causes: Land-use change (agriculture, use of fertilizers and pesticides, coastal development and associated run-off and nutrient inputs into coastal and estuarine areas), livestock, dredging and nutrient resuspension, alteration of hydrology, industry (e.g. superphosphate plants), atmospheric dust, aquaculture, construction of coastal infrastructure (e.g. groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons), river discharge, beach restoration, fire, control water flow, tidal connectivity and river run-off; groundwater use), beach restoration, tidal influence modification, point source stormwater and sewage/wastewater.	**Marbà et al. (2015)** **Macreadie et al. (2012)** **Duarte et al. (2013a)** **Greiner et al. (2013)** **Armitage and Fourqurean (2016)** **Rozaimi et al. (2016)** **Howard et al. (2014a)** **Dahl et al. (2016)** **Liu et al. (2016)** **Reynolds (2016)** **Serrano et al. (2014)** **Ribaudo et al. (2016)** **Watanabe and Kuwae (2015)** **Kuwae et al. (2016)** Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Samper-Villarreal et al. (2016) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)

Question	Response	References
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Changes in nutrient loading can result in: i) Enhanced run-off and higher fluxes of nutrients into coastal areas, resulting in reduced irradiance through phytoplankton and epiphyte growth, and death of seagrass meadows through irradiance starvation and hypoxia. Eutrophication could result in the loss of living biomass (deforestation). The loss of seagrass canopy could reduce C_{org} accumulation; expose the soil C_{org} to greater oxygen exposure; permit enhanced soil erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org}. All of these consequences are conducive to C_{org} remineralisation and emissions of GHG. ii) Changes in nutrient loading below detrimental thresholds may result in enhanced seagrass productivity resulting in increased C_{org} sequestration. iii) Nutrient enrichment can lead to organic-enriched sediments with high respiratory demand. As well as increased GHG emissions, this can also result in high sulphide concentrations in the soils, which can be toxic to seagrasses, resulting in deforestation. iv) Nutrient enrichment may also lead to a loss of seagrass canopy which can enhance the potential for soils to erode, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to further oxygen exposure, remineralisation and release of GHG.	Marbà et al. (2015) Macreadie et al. (2012) Duarte et al. (2013a) Greiner et al. (2013) Armitage and Fourqurean (2016) Rozaimi et al. (2016) Howard et al. (2014a) Dahl et al. (2016) Liu et al. (2016) Reynolds (2016) Serrano et al. (2014) Ribaudo et al. (2016) Watanabe and Kuwae (2015) Kuwae et al. (2016) Serrano et al. (2016b)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	*(additional context provided in section 7.2.3 above)* Commonwealth *Water Act 2007* *Environment Protection and Biodiversity Conservation Act 1999* New South Wales *Fisheries Management Act 1994 (NSW Fisheries):* controls the removal, damage or destruction of marine vegetation (including seagrass). *National Parks and Wildlife Act 1974 (National Parks and Wildlife Service):* provides for creation of reserves that may contain seagrass and associated management plans. *Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS):* provides for creation of marine parks which may contain seagrass and associated management plans for seagrass protection. *Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning):* provides for land use planning and impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass).	Fish habitat protection plan no 2: Seagrasses (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/202744/Fish-habitat-protection-plan-2---Seagrass.pdf) Butler and Jernakoff (1999)

Question	Response	References
	Clean Waters Act 1970 (Environment Protection Authority): controls the placement of materials into water, which may include materials released by physical disturbance. *Environmental Offences and Penalties Act 1991 (Environment Protection Authority):* control over actions that cause environmental damage, clean up and restoration programs. *Catchment Management Act 1989* *Water Management Act 2000* *State Environmental Planning Policy No 14 Coastal Wetlands* *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* Northern Territory *Fisheries Act (Dept. of Primary Industries and Fisheries):* provides for creation of aquatic reserves that may contain seagrass, harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants. *Parks and Wildlife Conservation Act (Parks and Wildlife Commission):* provides for creation of marine parks that may protect seagrasses. *Water Act 1992* *Water Act 1996: sets standards for effluents and requires that effluents do not cause degradation of water quality in fresh and marine systems – materials released by disturbance might constitute an effluent.* Queensland *Fisheries Act 1994 (Department of Primary Industries):* refers to 'marine plants' and 'fisheries habitats', which includes seagrasses. Provides for management and protection of declared Fish Habitat Areas, protection of marine plants, and powers to request rehabilitation or restoration of fisheries habitat. Require permits to remove, damage or destroy marine plants *Environment Protection Act 1994 (Department of Environment):* provides for protection of the environment, including seagrasses, and for protection from contaminants, which could include materials released through physical disturbance. *Nature Conservation Act 1992 (Department of Environment):* provides the basis for conservation of species, including seagrasses. Conservation of other species may require protection of their seagrass habitats. *Harbours Act 1955:* regulation of works in tidal waters, including dredging, and construction, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed. *Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA):* provide for identification and zoning of areas requiring special protection from human impacts. Permits are required for activities that may affect seagrasses or impact the physical environment (e.g., water	

Question	Response	References
	quality) in a marine park. Can regulate physical disturbance from outside marine parks (e.g., dredge operations and spoil dumps) to protect the park. *Coastal Protection and Management Act 1995:* allows for Statewide and regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations. *Integrated Planning Act 1997: provide for State-wide planning for developments affecting coastal habitats through an Integrated Development Assessment System.* *Water Act 2000 and Sustainable Planning Act 2009* *Coastal Management Plan* South Australia *Fisheries Act 1982 (Primary Industries and Resources – Fisheries):* provides for control of fisheries, including commercial harvesting of seagrass. Controls removal of or interference with aquatic or benthic flora of any waters. *Native Vegetation Act 1991:* limits the destruction of any native vegetation including seagrass. *Local Government Act 1934:* empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores. *Development Act 1993:* controls planning and approvals for developments, including those that could physically disturb seagrass. *Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency):* sets out licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria for nutrients and requires that no discharge will cause loss of seagrass. Dredging is also licensed under this policy. Provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan. *Natural Resources Management Act 2004* *Fisheries Management Act 2007* Tasmania *Living Marine Resources Management Act 1995:* generally regulates and protects the living marine environment, including seagrasses. *Marine Farming Planning Act 1995:* aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture. *Environmental Management and Pollution Control Act 1996:* the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste. *State Policies and Projects Act 1993:* allows for the creation of State Policies, including the State Coastal Policy, addressing the development and protection of natural resources. Seagrass are considered in protected	

Question	Response	References
	environmental values under the State Water Quality Management Policy which provides a framework for the development of water quality objectives and the management and regulation of emissions to coastal waters. *Land Use Planning and Approvals Act 1993:* provides for land use planning and development control to ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application. *Water Management Act 1999* *Coastal Policy Statement* Victoria *Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division):* provides for protection of fisheries habitats, including seagrass through declaration Fisheries Reserves or listing seagrass as protected. *Environment Protection Act 1970 (Environment Protection Authority):* provides for creation of State Environment Protection Policies (SEPPs). While not specifically prohibiting resource use activities, SEPPs ensure that activities are undertaken in a manner that prevents impacts. For operations such as dredging it must be demonstrated that there would not be significant impacts. *Planning and Environment Act 1987* *Water Act 1989* *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* Western Australia *Fisheries Resources Management Act 1994 (Fisheries WA): seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resource. Seagrass is protected by creating areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established.* *Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management):* provides for creation of Marine Nature Reserves and multiple use Marine Parks. Aquatic species, including seagrasses, are protected under this Act. The Act is relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities. *Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection):* provides for protection of the environment through the prevention, control and abatement of pollution, which includes discharge of materials through physical disturbance activities. Environmental Protection Policies and Environmental Assessment Guidelines (EAGs) are provided for under this Act. EAG No. 3 (Protection Of	

Question	Response	References
	Benthic Primary Producer Habitats In Western Australia's Marine Environment, 2009) provides non-statutory guidance on protection of seagrass habitat in relation to EIA. EAG7 provides non-statutory guidance on dredging activities in relation to EIA. *Environmental Assessment Guideline (EAG) No. 3 Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment (2009)* *Water Resources Acts:* the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act (Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947). These Acts relate to activities that involved the changes to the use of water. Including the additional of materials through physical disturbance. *Water Agencies (Powers) Act 1984* *Country Areas Water Supply Act 1947* *Metropolitan Water Supply and Sewage and Drainage Act 1909* *Waterways Conservation Act 1976*	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all jurisdictions, in particular in coastal protected areas such as estuaries and embayments. - Haynes et al. (2000) assessed the effect of herbicide exposure in seagrass species and concluded that herbicide concentrations present in nearshore Queensland sediments present a potential risk to seagrass functioning. - Neverauskas (1987) reported severe impacts to seagrass beds at Gulf St. Vincent (South Australia) linked to the discharge of digested sludge (1900 ha), followed by a partial recovery due to improved management. - (Longstaff 1999) reported that seagrass has a limited tolerance to light deprivation, resulting in death. - McMahon et al. (2011) reported that light reduction have a severe impact on seagrass leaf biomass, ultimately resulting in death. - Ralph et al. (2006) reported that growth of human populations along coastal environments and associated activities increasing nutrients and pollution in coastal areas resulted in loss of seagrass meadows. - Short and Wyllie-Echevarria (1996) reported that human activities modifying terrestrial connectivity, nutrient loading can impact seagrass meadows. - Cambridge et al. (1986) and Kendrick et al. (2002) reported that increased nutrient loading resulted in loss of seagrass meadows.	McMahon et al. (2005) Haynes et al. (2000) Neverauskas (1987) Ralph and Burchett (1998) Longstaff (1999) McMahon et al. (2011) Ralph and Moore (2006) Short and Wyllie-Echeverria (1996) Haynes et al. (2000)
Is the influencing factor historic, current or anticipated?	Historic: changes in nutrient loads constitute the main cause of seagrass loss in Australia, in particular in estuarine ecosystems around 1970-1990s. Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, with associated activities that could alter nutrient delivery to seagrass ecosystems or coastal and estuarine areas. Anticipated: Future developments in coastal areas, estuaries and catchments affecting terrestrial connectivity and eutrophication in coastal areas and estuaries occupied by seagrasses are predicted to occur in Australia.	Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) McLeod et al. (2011)

Question	Response	References
		Waycott et al. (2009) Larkum (1989) Samper-Villarreal et al. (2016) Cambridge et al. (1986) Kendrick et al. (2002)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: construction of coastal infrastructure. Causes with a temporary effect: Land-use change (agriculture, use of fertilizers and pesticides, coastal development and associated run-off and nutrient inputs into coastal and estuarine areas), livestock, dredging and nutrient resuspension, alteration of hydrology, industry (e.g. superphosphate plants), aquaculture, river discharge, beach restoration, fire, control water flow, tidal connectivity and river run-off; groundwater use), beach restoration, tidal influence modification, point source stormwater and sewage/wastewater. Many of these causes are temporary in the sense that the effect could be reversed if the disturbance is removed.	Marbà et al. (2015) Macreadie et al. (2012) Duarte et al. (2013a) Greiner et al. (2013) Armitage and Fourqurean (2016) Rozaimi et al. (2016) Howard et al. (2014a) Dahl et al. (2016) Liu et al. (2016) Reynolds (2016) Serrano et al. (2014) Ribaudo et al. (2016) Watanabe and Kuwae (2015) Kuwae et al. (2016) Serrano et al. (2016b) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Samper-Villarreal et al. (2016) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)

Question	Response	References
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- West (1983) reported 50% loss of area in numerous estuaries of NSW (light reduction). - King and Hodgson (1986) reported 7 km^2 loss in Lake Macquarie NSW (light reduction). - King and Hodgson (1986) reported13 km^2 loss in Tuggerah Lakes (light reduction). - Cambridge and McComb (1984), Cambridge et al. (1986) and Silberstein et al. (1986) reported 33 km^2 loss in Cockburn Sound, WA (increased epiphytism blocking light). - Bastyan (1986) reported 15.3 km^2 loss in Princess Royal Harbour and Oyster Harbour in WA (decreased light and increased epiphyte loads). - Neverauskas (1985a,b) reported 52.8 km^2 loss in Holdfast Bay and off Bolivar, SA (increased epiphytism blocking light, and other contributing factors). - Larkum and West (1990) reported 2.6 km^2 loss in Botany Bay, NSW (poor catchment management, uncontrolled effluent disposal and widespread dredging). - Kirkman (1997) reported 8.1 km^2 loss in Princess Royal Harbour (eutrophication, factories and sewage). - Kirkman (1997) reported 7.2 km^2 loss in Oyster Harbour (eutrophication and farm run-off). - Kirkman (1997) reported 70 km^2 loss in Gulf St. Vincent (sewage and stormwater discharge; coastal works). - Kirkman (1997) reported 4 km^2 loss in Birch Point (unknown, but most probably related to chemical and physical factors). - Kirkman (1997) reported 4.3 km^2 loss in Ralphs Bar (unknown, but most probably related to chemical and physical factors). - Kirkman (1997) reported 12 km^2 loss in Pittwater (unknown, but most probably related to chemical and physical factors). - Kirkman (1997) reported 21.5 km^2 loss in Norfolk Bar (unknown, but most probably related to chemical and physical factors). - Kirkman (1997) reported 7 km^2 loss in Lake Macquarie (increased turbidity, partially linked to eutrophication). - Kirkman (1997) reported 4.5 km^2 loss in Clarence River (increased turbidity and decline in water quality). - Kirkman (1997) reported 1,000 km^2 loss in Hervey Bay (increased turbidity from flooding rivers). - Kirkman (1997) reported >100 km^2 loss in Torres Strait (flooding). - Kirkman (1997) reported 11.3 km^2 loss of seagrass loss in Port Macquarie (increased turbidity) Cambridge et al. (1986) & Kendrick et al. (2002) reported 2.3 km^2 loss in Cockburn Sound (increased nutrient loading)	West (1983) King and Hodgson (1986) Cambridge and McComb (1984) Cambridge et al. (1986) Silberstein et al. (1986) Bastyan (1986) Neverauskas (1985b) Neverauskas (1985a) Larkum and West (1990) Kirkman (1997) and references therein.

7.3.5 Salinity changes/freshwater inputs

Table 31. Influencing factors for carbon sequestration and emission in seagrasses: Chemical: salinity changes/freshwater inputs.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Chemical: salinity changes/freshwater inputs Associated causes: alteration of water flow and tidal connectivity; stormwater discharge, flooding, disposal of hypersaline brine.	Lapointe and Matzie (1996) Preen et al. (1995) Campbell and McKenzie (2004) Roberts et al. (2010) Ralph and Moore (2006)
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Changes in salinity (either excessive increases or decreases) can result in the death of seagrasses (deforestation) and exposure of soil C_{org} to oxic conditions conducive to C_{org} remineralisation and GHG emissions. Indeed, the loss of seagrass canopy entails the loss of C_{org} accumulation and expose soils to erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to the release of GHG.	Lapointe and Matzie (1996) Preen et al. (1995) Campbell and McKenzie (2004) Roberts et al. (2010) Ralph and Moore (2006) Fernandez-Torquemada et al. (2005) Gacia et al. (2007) Sánchez-Lizaso et al. (2008) Chesher (1975) Latorre (2005)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	*(additional context provided in section 7.2.3 above)* Commonwealth *Water Act 2007* *Environment Protection and Biodiversity Conservation Act 1999*	Fish habitat protection plan no 2: Seagrasses (http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0019/202744/Fish-habitat-

Question	Response	References
	New South Wales *Fisheries Management Act 1994 (NSW Fisheries):* controls the removal, damage or destruction of marine vegetation (including seagrass). *National Parks and Wildlife Act 1974 (National Parks and Wildlife Service):* provides for creation of reserves that may contain seagrass and associated management plans. *Marine Parks Act 1997 (Marine Parks Authority/NSW Fisheries/NPWS):* provides for creation of marine parks which may contain seagrass and associated management plans for seagrass protection. *Environmental Planning and Assessment Act 1979 (Dept. Urban Affairs & Planning):* provides for land use planning and impact assessment of development proposals and activities (an environmental impact statement is generally required for dredging in seagrass). *Clean Waters Act 1970 (Environment Protection Authority):* controls the placement of materials into water, which may include materials released by physical disturbance. *Environmental Offences and Penalties Act 1991 (Environment Protection Authority):* control over actions that cause environmental damage, clean up and restoration programs. *Catchment Management Act 1989* *Water Management Act 2000* *State Environmental Planning Policy No 14 Coastal Wetlands* *NSW Coastal Planning Guideline: Adapting to Sea Level Rise* Northern Territory *Fisheries Act (Dept. of Primary Industries and Fisheries):* provides for creation of aquatic reserves that may contain seagrass, harvesting of aquatic life (including seagrasses) and for protection of fish habitat from release of organisms or pollutants. *Parks and Wildlife Conservation Act (Parks and Wildlife Commission):* provides for creation of marine parks that may protect seagrasses. *Water Act 1992* *Water Act 1996: sets standards for effluents and requires that effluents do not cause degradation of water quality in fresh and marine systems – materials released by disturbance might constitute an effluent.* Queensland *Fisheries Act 1994 (Department of Primary Industries):* refers to 'marine plants' and 'fisheries habitats', which includes seagrasses. Provides for management and protection of declared Fish Habitat Areas, protection of marine plants, and powers to request rehabilitation or restoration of fisheries habitat. Require permits to remove, damage or destroy marine plants	protection-plan-2---Seagrass.pdf) Butler et al. (1999)

Question	Response	References
	Environment Protection Act 1994 (Department of Environment): provides for protection of the environment, including seagrasses, and for protection from contaminants, which could include materials released through physical disturbance. *Nature Conservation Act 1992 (Department of Environment):* provides the basis for conservation of species, including seagrasses. Conservation of other species may require protection of their seagrass habitats. *Harbours Act 1955:* regulation of works in tidal waters, including dredging, and construction, where direct and indirect impacts on seagrasses may occur. Permits are required for works to proceed. *Marine Park Act 1982 (Department of Environment) and Great Barrier Reef Marine Parks Act 1975 (GBRMPA):* provide for identification and zoning of areas requiring special protection from human impacts. Permits are required for activities that may affect seagrasses or impact the physical environment (e.g., water quality) in a marine park. Can regulate physical disturbance from outside marine parks (e.g., dredge operations and spoil dumps) to protect the park. *Coastal Protection and Management Act 1995:* allows for Statewide and regional coastal management plans, and can include measures to protect seagrass habitats necessary for dugong and sea turtle populations. *Integrated Planning Act 1997: provide for State-wide planning for developments affecting coastal habitats through an Integrated Development Assessment System.* *Water Act 2000 and Sustainable Planning Act 2009* *Coastal Management Plan* South Australia *Fisheries Act 1982 (Primary Industries and Resources – Fisheries):* provides for control of fisheries, including commercial harvesting of seagrass. Controls removal of or interference with aquatic or benthic flora of any waters. *Native Vegetation Act 1991:* limits the destruction of any native vegetation including seagrass. *Local Government Act 1934:* empowers councils to make by-laws regulating, controlling or prohibiting the removal of sand, shells, seaweed or other material from foreshores. *Development Act 1993:* controls planning and approvals for developments, including those that could physically disturb seagrass. *Environment Protection Act 1993 (Dept. for Environment, Heritage and Aboriginal Affairs, Environment Protection Agency):* sets out licensing arrangements, defines environmental harm to include loss of seagrass, sets water quality criteria for nutrients and requires that no discharge will cause loss of seagrass. Dredging is also licensed under this policy. Provides for licensing of ports, marinas, and similar boating facilities, which are required to have an environment management plan. *Natural Resources Management Act 2004* *Fisheries Management Act 2007*	

Question	Response	References
	Tasmania *Living Marine Resources Management Act 1995:* generally regulates and protects the living marine environment, including seagrasses. *Marine Farming Planning Act 1995:* aims to integrate marine farming activities with other marine users and to minimise any adverse impacts of aquaculture. *Environmental Management and Pollution Control Act 1996:* the primary environment protection and pollution control legislation in Tasmania, based on the prevention, reduction and remediation of environmental harm (including to seagrasses), particularly from pollution and waste. *State Policies and Projects Act 1993:* allows for the creation of State Policies, including the State Coastal Policy, addressing the development and protection of natural resources. Seagrass are considered in protected environmental values under the State Water Quality Management Policy which provides a framework for the development of water quality objectives and the management and regulation of emissions to coastal waters. *Land Use Planning and Approvals Act 1993:* provides for land use planning and development control to ensure integration between planning schemes and other plans affecting the coastal zone, the Coastal Policy requires all planning authorities (including local councils, Marine Boards, the Secretary of the Department of Primary Industry and Fisheries and other agencies developing plans which cover all or any part of the coastal zone) to consult with the Marine Resources Division (Department of Primary Industry and Fisheries) the Marine Board responsible for the area subject to the plan and the Department of Environment and Land Management. The assessment of impacts on seagrass is required for coastal development application. *Water Management Act 1999* *Coastal Policy Statement* Victoria *Fisheries Act 1995 (Dept. of Natural Resources and Environment, Fisheries Division):* provides for protection of fisheries habitats, including seagrass through declaration Fisheries Reserves or listing seagrass as protected. *Environment Protection Act 1970 (Environment Protection Authority):* provides for creation of State Environment Protection Policies (SEPPs). While not specifically prohibiting resource use activities, SEPPs ensure that activities are undertaken in a manner that prevents impacts. For operations such as dredging it must be demonstrated that there would not be significant impacts. *Planning and Environment Act 1987* *Water Act 1989* *Coastal Management Act 1995* and associated *Victorian Coastal Strategy 2014* Western Australia *Fisheries Resources Management Act 1994 (Fisheries WA): seagrasses are included in the definition of fish. The objects of the act are to conserve, develop and share the fish resource. Seagrass is protected by creating*	

Question	Response	References
	areas closed to trawling and by prohibiting aquaculture above seagrass beds. Fish Habitat Protection Areas are established. *Conservation and Land Management Act 1984 (Dept. of Conservation and Land Management):* provides for creation of Marine Nature Reserves and multiple use Marine Parks. Aquatic species, including seagrasses, are protected under this Act. The Act is relevant to management of any activity on land and marine, parks and reserves, which may be the location of some of the activities. *Environmental Protection Act 1986 (Environmental Protection Authority/Dept. of Environmental Protection):* provides for protection of the environment through the prevention, control and abatement of pollution, which includes discharge of materials through physical disturbance activities. Environmental Protection Policies and Environmental Assessment Guidelines (EAGs) are provided for under this Act. EAG No. 3 (Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment, 2009) provides non-statutory guidance on protection of seagrass habitat in relation to EIA. EAG7 provides non-statutory guidance on dredging activities in relation to EIA. *Environmental Assessment Guideline (EAG) No. 3 Protection Of Benthic Primary Producer Habitats In Western Australia's Marine Environment (2009)* *Water Resources Acts:* the use of water resources is managed under a number of Acts that are currently being merged into a single Water Act (Rights in Water and Irrigation Act 1914; the Metropolitan Water Supply, Sewerage and Drainage Act 1909; the Waterways Conservation Act 1976; the Environmental Protection Act 1986; the Soil and Land Conservation Act 1945; the Country Areas Water Supply Act 1947). These Acts relate to activities that involved the changes to the use of water. Including the additional of materials through physical disturbance. *Water Agencies (Powers) Act 1984* *Country Areas Water Supply Act 1947* *Metropolitan Water Supply and Sewage and Drainage Act 1909* *Waterways Conservation Act 1976*	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all jurisdictions, in particular in coastal protected areas such as estuaries and embayments. Roberts et al. (2010) and Ralph et al. (2006) reported that changes in salinity linked to freshwater inputs and desalination plants can impact seagrass meadows, resulting in death. In several estuaries and wetlands around Australia, modification of tidal flow can result in changes in salinity and freshwater inputs, thereby impacting seagrass ecosystems (e.g. Peel-Harvey and Vasse Wonnerup in WA).	Roberts et al. (2010) Ralph and Moore (2006) Lapointe and Matzie (1996) Preen et al. (1995) Campbell and McKenzie (2004)
Is the influencing factor historic, current or anticipated?	Historic: changes in salinity and freshwater inputs constitute a significant cause of seagrass loss in Australia, in particular in estuarine ecosystems around 1970-1990s.	Lapointe and Matzie (1996)

Question	Response	References
	Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, including activities that could alter salinity and freshwater inputs to seagrass ecosystems or coastal and estuarine areas. **Anticipated**: Future developments in coastal areas, estuaries and catchments affecting freshwater inputs and salinity in coastal areas and estuaries occupied by seagrasses are predicted to occur in Australia.	Preen et al. (1995) Campbell and McKenzie (2004) Roberts et al. (2010) Ralph and Moore (2006)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	**Causes with a permanent effect:** manipulate water flow and tidal connectivity **Causes with a temporary effect:** manage stormwater discharge and flooding, stormwater discharge, flooding, disposal of hypersaline brine.	Lapointe and Matzie (1996) Preen et al. (1995) Campbell and McKenzie (2004) Roberts et al. (2010) Ralph and Moore (2006)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	There are no specific studies in Australia documenting the extent of seagrass loss due to salinity changes. However, numerous studies have documented negative effect of salinity changes in field monitoring programs, field experimental studies and laboratory studies (see above (row 2 of this Table).	Roberts et al. (2010) Ralph and Moore (2006)

7.3.6 Change in species distribution

Table 32. Influencing factors for carbon sequestration and emission in seagrasses: Biological: change in species distribution.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Biological disturbance: change in species composition <u>Associated causes:</u> change in chemical (nutrient dynamics) or physical condition (e.g. water depth), hydrodynamic energy, removal of vegetation) that facilitate increased or decreases competitiveness of species or trigger a successional change.	**Dahl et al.** (2016) **Trevathan-Tackett et al.** (2015) **Serrano et al.** (2016a) **Fourqurean et al.** (2012) **Lavery et al.** (2013) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Samper-Villarreal et al. (2016) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989) Hyndes et al. (2016)
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Changes in species composition can result in either enhanced or reduced soil C_{org} accumulation depending on the effect of the new species on the balance between C_{org} sequestration and accumulation in soils versus losses via decomposition and/or erosion. The C_{org} storage capacity of seagrasses largely vary between seagrass species as a function of their productivity, organic chemistry and particle trapping capacity.	**Dahl et al.** (2016) **Trevathan-Tackett et al.** (2015) **Serrano et al.** (2016c) **Fourqurean et al.** (2012) **Lavery et al.** (2013)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	No	

Question	Response	References
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all jurisdictions.	Hyndes et al. (2016)
Is the influencing factor historic, current or anticipated?	Historic: changes in species composition have been reported in Australia, in particular in estuarine ecosystems around 1970-1990s. Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, including activities that could alter plant species composition within seagrass ecosystems or coastal and estuarine areas. Anticipated: Future developments in coastal areas, estuaries and catchments affecting plant species composition in coastal areas and estuaries occupied by seagrasses are predicted to occur in Australia.	Larkum and West (1990) Aragones and Marsh (1999) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Hyndes et al. (2016) Larkum (1989)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: change in physical condition (e.g. water depth) or hydrodynamic energy within the ecosystem. Causes with a temporary effect: change in nutrient dynamics.	Dahl et al. (2016) Trevathan-Tackett et al. (2015) Serrano et al. (2016c) Fourqurean et al. (2012) Lavery et al. (2013) Aragones and Marsh (1999) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Larkum (1989)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	Tropical and sub-tropical seagrass meadows are highly dynamic and species composition can change naturally. Climate change is causing a tropicalisation of temperate seagrass meadows and a shift in species composition.	*Some key publications:* Hyndes et al. (2016)

7.3.7 Herbivory

Table 33. Influencing factors for C_{org} sequestration and emission in seagrasses: Biological: Herbivory.

(References in bold showed direct relationships among the influencing factor and enhanced C_{org} sequestration and/or avoided emissions)

Question	Response	References
Identify the influencing factor and associated cause	Biological disturbance: Herbivory Associated causes: Overfishing of predators. Increase in nutrient loading or other change in environmental condition (e.g. seawater temperature). Increased density of herbivores due to loss of habitat in adjacent ecosystems.	**Atwood et al.** (2015) **Dahl et al.** (2016) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Samper-Villarreal et al. (2016) McLeod et al. (2011) Waycott et al. (2009) Larkum (1989)
How does the influencing factor affect either the C_{org} sequestered in the ecosystem or the greenhouse gases released by the ecosystem?	Herbivory results in consumption of seagrass matter, resulting in reduced C_{org} sequestration (as the C_{org} is removed from the system), and/or death of seagrass meadows. Excess herbivory can result in the death of seagrasses (deforestation) and exposure of soil C_{org} to oxic conditions conducive to C_{org} remineralisation and GHG emissions. Indeed, the loss of seagrass canopy entails the loss of C_{org} accumulation and expose soils to erosion, which can resuspend fine-grained (mud) sediments and associated soil C_{org} leading to the release of GHG.	**Atwood et al.** (2015) **Dahl et al.** (2016)
Is the influencing factor regulated under any legislation (federal/state/local)? If yes, provide the context.	No	
In what Australian location/s and jurisdiction/s does the influencing factor occur?	In all jurisdictions. - Larkum and West (1990) assessed the impact of grazing by sea urchins and reported that the decline of seagrass occurred during a period of industrial and residential development in the catchment (i.e. a history of poor catchment management) of Botany Bay (Sydney). - Aragones and Marsh (1999) reported that dugong grazing and turtle cropping in tropical Queensland resulted in an improvement of seagrass ecosystems. - Eklf et al. (2009) assessed the impact of grazing by Black Swans on seagrass in temperate WA (Swan River Estuary) and reported 23% removal of net primary productivity.	*Some key publications:* Larkum and West (1990) Aragones and Marsh (1999) (Eklf et al. 2009)

Question	Response	References
Is the influencing factor historic, current or anticipated?	Historic: changes in herbivory have been reported in Australia, in particular in estuarine ecosystems around 1970-1990s. Current: Australia is experiencing a demographic explosion in coastal areas and estuaries, including activities that alter food webs and herbivory patterns within seagrass ecosystems or coastal and estuarine areas. Anticipated: Future developments in coastal areas, estuaries and catchments affecting herbivory patterns in coastal areas and estuaries occupied by seagrasses are predicted to occur in Australia.	Larkum and West (1990) Aragones and Marsh (1999) Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Larkum (1989)
Is the influencing factor permanently or temporarily affecting the blue carbon ecosystem?	Causes with a permanent effect: n/a Causes with a temporary effect: overfishing of predators, increase in nutrient loading or change in environmental condition (e.g. seawater temperature).	Atwood et al. (2015) Dahl et al. (2016) Aragones and Marsh, 1999 Duarte et al. (2013a) Pendleton et al. (2012) Kilminster et al. (2015) Larkum (1989)
Where data exists, what is the recognised extent of the affected areas (km^2), and where do these occur? (This could be demonstrated with assistance of a map)	- Larkum and West (1990) reported 2.6 km^2 lost in Botany Bay, NSW (erosion, coastal works, eutrophication and sea urchin grazing). - In Noormamunga MPA, an urchin plague is causing ‘significant’ seagrass decline, acknowledged by state authorities (Parks Victoria, DELWP). The exact area has not been reported.	*Some key publications:* Larkum and West (1990)

SECTION B: ERF suitability assessment of blue carbon ecosystem enhancement activities for seagrasses

7.4 Introduction to seagrass activities

Anthropogenic activities in coastal areas have the potential to affect C_{org} sequestration by seagrasses. Around 95% of the Australian population live within 50 km of the coastline which can have direct and indirect impacts on seagrasses. Many natural and anthropogenic induced events create disturbances in seagrasses in Australia.

An activity, natural or human-induced, is defined as any event that measurably alters C_{org} storage in seagrasses. Natural disturbances that are most commonly responsible for seagrass loss include cyclones, earthquakes, disease, and grazing by herbivores. Anthropogenic activities most affecting seagrasses are those that disturb the plants or soil or alter water quality or clarity (e.g. nutrient and sediment loading from run-off and sewage disposal, dredging and filling, pollution, upland development, and certain fishing practices). Seagrasses depend on an adequate degree of water clarity to sustain productivity and C_{org} storage in their submerged environment. Although natural events have been responsible for both large-scale and local losses of seagrass ecosystem, our evaluation suggests that human population expansion is now the most serious cause of seagrass ecosystem loss and, specifically, that increasing anthropogenic inputs to the coastal oceans is primarily responsible for the worldwide decline in seagrasses (Short and Wyllie-Echeverria 1996, Waycott et al. 2009).

About 98% of C_{org} stocks in seagrass ecosystems are found in their soils (Lovelock et al. 2016). Furthermore, the C_{org} pool in living biomass is relatively labile and less likely to be sequestered in the long-term. Therefore, the C_{org} associated with living seagrass biomass is not considered in this assessment. Activities with the potential to sequester C_{org} or avoid GHG emissions against the business as usual scenario within seagrasses are summarised in Table 33.

Table 33. Summary table of activities with the potential to sequester additional C_{org} or avoid CO_2-e emissions against the business as usual scenario within seagrasses

Seagrass meadows
Avoidance of seagrass loss through direct physical disturbance by: • management of moorings, dredging, trawling, beach restoration and other activities.

Re-establishment of seagrasses by:
• direct revegetation (transplanting, seedling),
• passive revegetation (in situ and/or offsite activities) by
  o alteration of hydrodynamics (through the use of or amendment of artificial structures, alteration of tidal connectivity or other processes),
  o alteration of water quality (through reduction of suspended sediments, nutrients and pollutant loads, or by alteration of salinity).

Creation of new seagrasses by:
• creation of suitable habitat if required through alteration of hydrodynamics (artificial structures; alteration of tidal connectivity, water flow), water quality (suspended sediments, nutrient and pollutant loads), sediment stability and composition, and water column depth (by enhanced sediment deposition or in-filling the seabed), coupled with:
  o direct revegetation (transplanting, seedling) or
  o passive revegetation

Avoidance of seagrass loss through water quality changes by: • management of catchment area (terrestrial and off-shore) to avoid detrimental changes to water quality; and • management of point-source pollutants (e.g. sewage, dredging sites) to avoid detrimental changes to water quality.

7.4.1 Avoidance of seagrass loss through direct physical disturbance

Category: Avoided emissions and enhanced sequestration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous C_{org} from autochthonous C_{org}.

Physical disturbance of seagrasses can result in a loss of existing soil C_{org} stocks, a loss of future sequestration potential and emission of non CO_2 GHG. Physical disturbance to seagrasses includes that caused by moorings, fishing, bait/shell digging and collection, harvesting seagrass fibres, dredging, beach restoration, construction of groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons, boating and anchoring, construction and operation of aquaculture facilities, seismic testing, scientific collections, reclamation, walking through seagrass areas, and alteration of hydrology and/or hydrodynamic energy.

Abatement activities linked to the avoidance of physical disturbance can preserve seagrass C_{org} sequestration capacity and/or avoid emissions of GHG to the atmosphere, by avoiding the removal of living biomass and the exposure of soil C_{org} to oxic conditions conducive to GHG emissions. Scientific studies support the hypotheses that this abatement activity can enhance C_{org} sequestration and/or avoid emissions of GHG to the atmosphere, but little information is available on CH_4 and/or N_2O fluxes in natural or disturbed seagrasses. Given the presence of sulphate in seagrass soils, CH_4 production is likely low under baseline conditions but it is unknown whether physical disturbance would enhance CH_4 production. The production of N_2O is limited to oxic soil horizons, typically found within the top 10 cm of seagrass soils and around seagrass rooting systems. Therefore, N_2O baseline production in seagrasses is probably low; however, physical disturbance will likely result in enhanced N_2O emissions as a result of nitrification and denitrification occurring in oxic/semi-oxic disturbed soils. Actively avoiding disturbance will therefore prevent N_2O emissions.

1.2 List the circumstances or conditions under which the activity is to be implemented.
If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Avoiding physical disturbance of seagrasses can be carried out in any area in which activities causing direct physical disturbance of seagrasses are planned and approved. While the avoidance of physical disturbance can be implemented in all seagrass ecosystems, those with higher C_{org} stocks have larger potential for avoided GHG emissions.

Examples of avoiding physical disturbance that could result in either an avoided emission or both an avoided emission and enhanced sequestraton against the business as usual position include:

- Avoiding dredging of seagrasses.
- Avoiding the placement of moorings that cover the soil surface, kill existing seagrass and do not allow recolonization.
- Installing environmental-friendly moorings instead of traditional swing moorings.
- Avoiding fishing techniques that disturb seagrass ecosystems (e.g. trawling).
- Avoiding bait/shell digging and collection in seagrass ecosystems.

- Avoiding harvesting seagrass fibres for commercial and/or recreational activities.
- Avoiding the construction of groynes and breakwaters, construction of jetties, wharves, bridges, ramps and pontoons in seagrass ecosystems.
- Avoiding anchoring in seagrass ecosystems.
- Avoiding boating across shallow seagrass beds in order to minimise the potential for propeller damage.
- Avoiding seismic testing in seagrass ecosystems.
- Avoiding reclamation or conversion of seagrass ecosystems.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

There is peer-reviewed evidence showing that physical disturbance of seagrasses (plants and soil) results in reduced C_{org} sequestration capacity and enhanced GHG emissions:

- Serrano et al. (2016a) demonstrated that boat moorings threaten seagrasses and the mechanical destruction they cause also trigger the loss of soil C_{org} stocks. This study, in Rottnest Island, Western Australia, sampled seagrasses and from bare but previously vegetated soils underneath moorings and adjacent unaffected segrasses. The soil C_{org} stocks had been compromised by the mooring deployment from the 1930s onwards, through both the erosion of existing C_{org} stocks and the lack of further accumulation of C_{org} over time. On average, undisturbed meadows contained ~64 Mg C_{org} ha^{-1} in the upper 50 cm accumulating at a rate of 0.34 Mg C_{org} ha^{-1} yr^{-1}. The comparison of C_{org} stocks between unaffected seagrasses and mooring scars indicated a net loss of 48 Mg C_{org} ha^{-1} to a depth of 50 cm as a result of mooring deployments.

- Bourque et al. (2015) demonstrated that soil disturbance was a key contributor to degradation in seagrass ecosystems, leading to long-term changes in ecosystem function, including C_{org} storage, in Florida (USA). The authors used a chronosequence of vessel grounding disturbances of different ages (0 to 5+ yr) as a model for soil disturbance to test the hypotheses that disturbance alters primary producer communities, soil properties, biogeochemical processes, and infauna communities in seagrass ecosystems. Disturbance resulted in long-term loss of seagrass and C_{org} stocks. Disturbed sites were characterized by reductions in variables related to C_{org} content. These impacts persisted in study sites for >5 yr after the disturbance, likely because of physical and chemical soil modification accompanied by slow development of the seagrass community. It was estimated that disturbance from 0.4 m deep excavations led to losses of 60 Mg C_{org} ha^{-1} from the disturbed areas

- (Ricart et al. 2015) evaluated the influence of the spatial configuration of seagrasses at small scales (metres) on C_{org} stocks in seagrass soils. They intensively studied C_{org} stocks and other geochemical properties across seagrass–sand edges in a patchy *Zostera muelleri* seagrass landscape. Stocks of C_{org}, mostly from allochthonous sources, were significantly higher (ca. 20%) inside seagrass patches than at seagrass–sand edges and bare sediments. Patch-level attributes (e.g. edge distance) were important determinants of the spatial heterogeneity of C_{org} stocks within seagrass ecosystems. This study showed that fragmentation of seagrass ecosystems due to physical disturbance impacts seagrass soil C_{org} stocks.

- Macreadie et al. (2015) reported that a seagrass ecosystem that had been disturbed 50 years ago earlier showed a 72% decline in soil C_{org} stocks which, according to radiocarbon dating, had taken hundreds to thousands of years to accumulate. Isotopic fingerprinting of the C_{org} suggested that the contribution of autochthonous C_{org} to the soil C_{org} pool was less in disturbed areas compared with seagrass and recovered areas. Seagrass areas that had recovered from disturbance had slightly lower (35%) C_{org} stocks than undisturbed, but more than twice as much as the disturbed areas, which is encouraging for restoration efforts. Slow rates of seagrass recovery imply that transplanting seagrass may provide benefit over waiting for recovery via natural processes. This study empirically demonstrated that disturbance to seagrass ecosystems caused release of stored C_{org}.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

State, Council, Commonwealth and Indigenous landholders or Australians with a pre-existing right to cause physical disturbance to seagrass meadows.

2.2. Estimate the potential intensity of abatement for the blue carbon enhancement activity.

The following estimates of potential intensity of abatement are based upon mean data of national C_{org} stocks and accumulation rates for seagrasses compiled by the CSIRO Coastal Carbon Cluster, and assuming that 25-75% soil C_{org} stocks in 1 m soil deposits are remineralised after disturbance. For the range of estimates and 95% Confidence Intervals (CI) see Appendix 1. The loss and fate of C_{org} stocks after disturbance is variable (e.g. it can range from 0 to 100% loss and the fate is assumed to be 100% remineralisation even though part of the C_{org} could be preserved elsewhere). As a result, the general applicability of individual estimates of the magnitude of avoided emission presented in the subsequent lists for Australian seagrasses as a whole remains uncertain. Additionally, the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates (e.g. as a function of species composition and geomorphology) contribute uncertainty to calculations of the potential intensity of abatement. Estimates of the potential intensity of abatement for non-CO_2 GHG emissions (i.e. CH_4 and N_2O) are not provided because of a lack of data.

Change in soil C_{org} storage:

- Estimated increase in soil C_{org} sequestration (enhanced sequestration by avoiding loss of living biomass):
    - average 0.36 Mg C_{org} ha^{-1} yr^{-1} (1.32 Mg CO_2-e ha^{-1} yr^{-1})

Avoided emission rates:

- Estimated soil C_{org} avoided emissions (avoided emissions by avoiding loss of canopy and remineralisation of soil C_{org} stocks):
    - ranging from 28 to 84 Mg C_{org} ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised after disturbance).
- Estimated CO_2 avoided emissions from soil C_{org} (avoided CO_2 emissions by avoiding loss of canopy and remineralisation of soil C_{org} stocks):
    - ranging from 103 to 308 Mg CO_2 ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised after disturbance) (conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Area estimates of potential abatement:

Estimates of the area over which this activity could potentially occur are unknown.

2.3. Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Social impacts through exclusion or restriction of recreational use of seagrasses.
- Economic cost of removing the stress that disturbed seagrasses initially.
- Economic cost of deploying infrastructure to preserve seagrasses.
- Economic cost through exclusion or restriction of commercial fishing over seagrasses.
- Economic cost through exclusion or restriction of coastal development activities where seagrasses exist and would be adversely affected.

2.4. Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Conservation of seagrasses is currently being promoted through legislation. However, physical damage to seagrasses occurs frequently (e.g. direct impact by propeller and anchors, or indirect impacts by dredging activities). There is the potential for an economic incentive from emissions reduction to help fund conservation activities and communication strategies leading to enhanced C_{org} sequestration and avoided GHG emissions against a business as usual condition.

3. Additionality

3.1 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is unlikely that the activities currently resulting in physical threats to seagrass ecosystems will be excluded or restricted in the future and therefore these disturbances and the associated emissions are likely to continue without the introduction of activities. Little to no incentives are in place to modify or abandon existing practices in order to reduce direct physical impacts on soil C_{org} stocks or GHG emissions from affected seagrasses. It is unlikely that current rates of seagrass ecosystem loss due to physical disturbances will diminish.

Table 34. Abatement integrity assessment for "Avoidance of seagrass ecosystem loss through direct physical disturbance". Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in C_{org} abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not exclude or restrict current or historic physical disturbance to seagrass meadows.
4.2. Estimating the activity's C_{org} removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine C_{org} removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Peer-reviewed literature support measurable change in soil C_{org} stock as a result of avoided physical disturbances.
4.3. C_{org} abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible C_{org} abatement in accordance with the approach outlined in footnote 2.	0- C_{org} abatement from the activity is not eligible C_{org} abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if C_{org} abatement from the activity is eligible C_{org} abatement. It is uncertain whether the C_{org} can be counted towards Australia's national greenhouse gas inventory. 2 - C_{org} abatement from the activity is eligible C_{org} abatement and can be counted towards Australia's national greenhouse gas inventory.	1	If we can track and count it now there is potential for it to be credited.
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	Peer-reviewed literature support change in soil C_{org} stock as a result of avoided physical disturbances.

Integrity requirement	Scoring criteria	Score	Score Justification
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	Demonstrable processes exist (direct measurement techniques and IPCC wetlands supplement emission factors) to account for emissions of other GHG in addition to changes in C_{org} stocks for a project.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative. 2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.	1	Based on a probability of exceedance >50% rather than mean values. The range of abatements are large, and thus illustrate that the C_{org} sequestration capacity of seagrasses largely differ between ecosystems, and thereby their potential for abatement.
	Total score	10	

Footnote 2: *To be eligible C_{org} abatement, the abatement needs to be able to be captured* in *Australia's nationally reported GHG emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 - *AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands).*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline prior to activity: Baseline seagrass soil C_{org} stocks and sequestration rates can be measured through field soil coring and C_{org} analyses in the laboratory, through the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) throughout applied potential project area. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates (Mg C ha^{-1} y^{-1}) prior to the implementation of any project management activities.

Emissions of non-CO_2 GHG fluxes may be measured using instruments deployed at the site prior to implementing the proposed management activity.

The duration over which assessments of GHG fluxes are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event.

- Estimation of baseline from literature values: Despite the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates, it is possible to use peer-reviewed literature values to estimate average/median C_{org} stocks and accumulation rates within a seagrass project. Modelling approaches are also capable of estimating C_{org} sequestration rates and stocks at a study site, using a range of covariates from other locations to construct models capable of predicting baseline stocks and C_{org} storage at the study site. Suitable emissions factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013).

5.2. List and justify the assumptions and uncertainties on which the baseline is based.

Field sampling of soil C_{org} stocks and accumulation rates, and fluxes of GHG requires sufficient effort and replication to understand spatial and temporal variability. Statistical approaches to sampling design and data analyses exist to allow quantification of the uncertainty associated with measured values.

Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites. Global emissions factors, such as those in the IPCC Wetlands Supplement 2013 could also be used.

In moving from project specific measurements through to global emission factors, it must be recognised that the uncertainty associated with calculated changes in Corg sequestration and/or avoided emissions of GHGs will become greater. In some instances there may not be suitable reference/control sites to use because of the large uncertainties involved.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

Undertaking the abatement activity will involve: i) delineation of the areal extent over which the activity (avoiding physical disturbance) would be applied (i.e. the project area); ii) determination of baseline C_{org} stocks and GHG emissions; iii) implementing actions that will avoid a planned disturbance; and iv) monitoring of temporal changes to C_{org} stocks and GHG emissions within the project area over time through repeated measurement or modelling. The C_{org} stocks determined in the baseline assessment as well as that accumulated over time would represent an avoided emission against a business as usual condition. This accumulation would be amended with the change in GHG emissions to provide the net carbon abatement resulting from the avoided disturbance.

The GHG assessment boundaries will be easy to define for activities resulting in avoidance of physical disturbances if direct affects are considered.

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Source		Greenhouse gas/ C_{org} pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	
Project activity sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area that would have been directly affected by the physical disturbance and activity and would be fixed prior to commencement of the project.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

<u>Measurement of baseline prior to activity:</u>

- Baseline soil C_{org} stocks can be measured through coring and laboratory analyses of samples prior to the activity. Soil samples (e.g. 1 m long) would need to be collected throughout the project area using a robust statistical design. The samples should be processed in the laboratory to estimate soil C_{org} content. Soil accumulation rates combined with C_{org} analyses of surface soils can be used to monitor and measure baseline C_{org} sequestration rates in seagrass ecosystems. Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1 cm and could be applied in seagrass ecosystems. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. These data can be used as a control to determine baseline C_{org} stocks and sequestration rates prior to avoiding the activity. GHG fluxes may be measured using instruments deployed at the site prior to the activity (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) to determine baseline GHG fluxes. Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates within the study site, probably reducing the replication needs.

- Existing literature can be used to estimate average/median C_{org} stocks and sequestration rates prior to the activity (i.e. baseline). Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates at the study site, using a range of covariates from other locations to construct models capable of predicting baseline C_{org} stocks and sequestration rates at the study sites. Emission factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013) or those available in peer-reviewed literature.

<u>Measurement of avoided emissions (i.e. by preserving soil C_{org} stocks) and enhanced sequestration (i.e. by preserving C_{org} accumulation):</u>
Estimating avoided emissions can rely on limited peer-reviewed literature or IPCC factors. Enhanced sequestration can be based on baseline data or literature estimates of C_{org} sequestration in seagrass ecosystems.

Approaches to calculate avoided emissions and enhanced sequestration are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method or radioisotopes can be used to determine the depth at which project measurements should be taken to assess gains (CO_2-C) or losses (CO_2-e) after the activity. For example, if SET measurements show that the surface elevation has grown 5 cm under the project, then the soil C_{org} stock would be measured from 5 to 105 cm soil depth. The top 5 cm of soil accumulated will constitute additional sequestration of soil C_{org} (gain in C_{org} sequestration). Similarly, if the SET or radioisotope measurements show a decrease in surface elevation (i.e. erosion) under the project (e.g. elevation loss of 3 cm) then the soil C_{org} stock estimates will be reduced by the top 97 cm of soil as a result of soil erosion and lack of C_{org} accumulation.

<u>Uncertainties</u>:
A. The inter- and intra-ecosystem variability in C_{org} stocks and sequestration within seagrass ecosystems (i.e. a potential ERF project area) can be large (up to 18-fold; up to 18-fold (Lavery et al. 2013, Serrano et al. 2014). Therefore, the sampling design would need to include physical and biogeochemical ecosystem variability and enough replication to ensure that baseline estimates of C_{org} stock and sequestration rates are representative of the project. The use of a probability of exceedance (e.g. >50%) instead of mean or median values is recommended to avoid bias by large/small C_{org} stock and sequestration rates values measured within the GHG assessment boundary, as currently used in the “Sequestering carbon in soils in grazing systems” ERF method.

B. The use of peer-reviewed literature values to determine baseline C_{org} stocks and accumulation rates within the GHG assessment boundary (i.e. instead of direct measurements) would entail larger uncertainties. However, considering the amount of peer-reviewed data available, statistical approaches could be used to quantify uncertainties and develop approaches that are conservative and meet the requirements of ERF methods.

C. The duration over which assessments of GHG fluxes are completed would require further consideration to ensure that measured values are indeed indicative of true temporal trends and not aberrations due to an abnormal event or condition. GHG fluxes may vary substantially across landscapes (e.g. intertidal versus subtidal seagrass meadows, and water depth) and climatic gradients. It would therefore be beneficial to develop emissions factors at local and regional scales (e.g. site or estuary scales). Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties. The quantity and type of GHG fluxes (CO_2, CH_4, N_2O) could by temporally variable. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation.

D. Modelling approaches are also capable of estimating C_{org} stocks and sequestration rates, and avoided emissions over spatial scales. A range of covariates could be used to construct models capable of predicting measured baseline stocks and sequestration rates and then models could be applied, with some validation, to other locations.

E. SETs and MHs techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement to define an accurate baseline. Marker Horizon techniques may prove unreliable due to loss of the marker layer through bioturbation or disturbance to the soil profile.

F. Despite the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates, it is possible to use peer-reviewed literature values to determine average/median C_{org} stocks and accumulation rates at the study site combined with emissions factors (e.g. IPCC Wetlands Supplement, 2013) to estimate emissions' avoidance. Although, the use of literature-derived stocks and accumulation rates and global or regional emissions factors may introduce substantial uncertainty, the statistical approaches can be applied to ensure estimates obtained are conservative. . Use of locally derived stocks, accumulation rates and emission factors may help to overcome some of this uncertainty.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Howard et al. (2014) and IPCC (2013) provide guidelines on how to estimate gains and/or avoided emissions in blue carbon ecosystems. The uncertainties involved in each of the approaches are listed, and are the same as described in Section 7.1. Modelling could be used in all approaches described below to improve the accuracy (i.e. reduce uncertainties) of estimates.

The steps required for estimating project activity emissions and removals are described below:

Approach 1 *(Accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG project boundaries and mapping of seagrass meadows prior to activity.

b. Collection of 1 m long soil cores throughout the study area and analyses of C_{org} concentration throughout the cores (e.g. at 0-5, 5-20, 20-50, 50-100 cm; in homogenised samples).

c. Deployment of SETs and MHs throughout the study area and measurement of soil surface elevation (i.e. based on the SETs and MHs deployed throughout the study area) (e.g. after 5, 10, 15 and 20 years).

d. Measurement of GHG fluxes.

e. Estimate enhanced soil GHC sequestration (i.e. by preserving C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of avoided disturbance, based on GHG sequestration rates measured at the study site (i.e. baseline estimates of soil accumulation and C_{org} accumulation and N_2O) and CH_4 fluxes in top 5 cm of soil); and estimate avoided GHG emissions (i.e. by preserving soil C_{org} stocks) based on existing peer-reviewed evidence linking change in soil C_{org} and the activity at the study site (possible in a few number of cases only).

Uncertainties: **A**, **C**, **D**, **E** and **F** listed in Section 7.1.

Approach 2 *(Accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG project boundaries and mapping of seagrass meadows prior to activity.

b. Estimate soil C_{org} stocks (e.g. at 0-5, 5-20, 20-50, 50-100 cm), C_{org} sequestration rates (e.g. surface soils) and GHG fluxes within the GHG assessment boundary based on existing peer-reviewed literature for similar ecosystems or global values.

c. Estimate enhanced soil GHC sequestration (i.e. by preserving C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of avoided disturbance, based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

Uncertainties: **A**, **B**, **C**, **D**, **E** and **F** listed in Section 7.1.

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

The approaches to calculate net GHG abatement have been specified in section 7.2. There is a need to propagate uncertainties and specify a confidence required. It is suggested that emission avoidance and sequestration results be expressed as the magnitude associated with a defined probability of exceedance.

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

The data collection methods have been briefly described in sections 7.1 and 7.2. A more comprehensive description of methods follows:

- Mapping of seagrass ecosystem can be performed by direct observations or remote sensing in shallow areas, or based on existing peer-reviewed literature. Most methods of mapping seagrass have significant limitations (e.g. limited by water clarity) and therefore mapping of sub-tidal seagrass meadows will often have larger uncertainties than those associated with other blue carbon ecosystems.
- Soil cores could be collected by means of manual percussion using PVC or aluminium coring pipes, 75 mm internal diameter. Soil compression (i.e. 'shortening') should be measured in

the field to allow normalisation of soil C_{org} stocks and sequestration rates to a predefined soil depth. In the laboratory, the core samples should be cut lengthwise, and the soil contained in the cores sliced at desired intervals. The soil samples should be homogenised and processed to measure C_{org} concentrations. There are several methods to estimate C_{org} concentration in costal sediments, including loss on ignition (and subsequent assumptions of the OM:OC ratio), elemental analyser, mass spectrometer, infra-red spectroscopy, etc. (see Howard et al. 2014) for further details. Estimates of C_{org} content can differ between methods, and it is important to establish standard methods for ERF eligibility. Scaling of C_{org} estimates to a certain soil depth should be consistent too.

- Methods for the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) are well known.
- Many of the methods outlined require consideration of temporal and spatial variability expected in C_{org} storage, accumulation and GHG emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be estimated over a certain soil depth (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radioisotope dating is likely to provide long-term records of soil accumulation rates, and may also be used to develop a baseline value of C_{org} stocks and longer-term accumulation rates (e.g. annual to millennial scales) using soil cores collected prior or after the commencement of the activity.

8. Double counting

8.1 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream C_{org} sources that are already being captured in inventory reporting (e.g. C_{org} that enters the blue carbon ecosystem through river system or catchment area).

Seagrass meadows are located in the interface between terrestrial and coastal ecosystems and, therefore, are likely to sequester C_{org} originating off-site (inland and/or offshore). Previous studies suggested that around 50% of soil C_{org} sequestered in seagrass meadows is seagrass-derived, while the other 50% is derived from algae, seston or terrestrial (mangrove, tidal marsh and riverine run-off) organic matter. However, spatial variability within the same meadow can be up to 3-fold (Serrano et al. 2016b) and the differentiation among autochthonous C_{org} (seagrass, benthic algae and epiphytic algae) and allochthonous C_{org} pools in seagrass soils can be difficult because the methods commonly used (i.e. stable C and N isotopes and mixing models) to determine their origin often lack sufficient discriminatory power (overlap of isotopic signatures of potential sources) and because of diagenetic effects (i.e. fractionation of isotopes) during accumulation and ageing, both of which could introduce large uncertainties when estimating the origin of C_{org} in seagrass soils.

If not exported and stored in seagrass soils, the fate of C_{org} originating from offsite sources (inland and/or offshore) is uncertain. On one hand, the C_{org} originated offshore and stored in seagrass soils is not accounted for elsewhere (no ERF schemes available to date). A plausible fate of C_{org} originating offshore is remineralisation (GHG emissions). Therefore, the likelihood of double accounting is nil. On the other hand, C_{org} originating inland and stored in seagrass soils may already have been accounted for elsewhere (ERF for terrestrial C_{org} and/or inclusion of mangrove and tidal marshes in ERF schemes). Indeed, if not sequestered by seagrasses, the plausible fate of C_{org} originating in terrestrial, mangrove and tidal marsh ecosystems is remineralisation (GHG emissions), and/or exported and buried in the coastal and/or deep ocean, and/or exported as dissolved C_{org} in oceanic waters (Krause-Jensen and Duarte 2016). However, the risk of double accounting is limited because offsite C_{org} stored in seagrass soils would originate from losses from mangroves, tidal marshes and seagrasses rather than gains (enhanced sequestration) already accounted for.

In summary, double accounting of C_{org} originating from inland (terrestrial systems, mangroves and tidal marshes) could be a remote possibility (i.e. resulting in addition rather than genuine sequestration). In order to avoid double accounting there are different options, ranging from conservative to non-conservative:

1. Estimate the proportion of autochthonous vs allochthonous C_{org} in seagrass soils based on direct measurements (e.g. C and N isotopic signatures of the C_{org}, genetic studies) or literature values. This method entails uncertainties related to Tier 1 or 2 estimates (described above);

2. Assume that all seagrass soil C_{org} is genuine sequestration (i.e. assuming that the inland-derived C_{org} would otherwise be remineralised and/or has not been accounted for in ERF schemes); or

3. Decide whether to follow approach 1 or 2 (above) based on existing projects in the catchment area affecting GHG assessment boundaries (depending on each case).

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the C_{org} stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of C_{org} stored and GHG fluxes:

- Natural disturbances such as cyclones or severe storms may cause damage and/or loss of seagrass biomass, exposing soils to erosion and subsequent C_{org} remineralisation.

- Dieback of seagrass biomass related to extreme temperature events may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Overgrazing related to natural or human induced factors such as climate change may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Extreme flooding events could impact seagrass ecosystems, either causing damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation, or siltation (i.e. over-sedimentation and accumulation of seagrass meadows) which could result in enhanced sequestration.

- Fishing activities (trawling, bait collection) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Some seagrass meadows are ephemeral and their distribution can vary seasonally or inter-annually. In particular, sub-tropical and tropical seagrass of the genera e.g. *Halophila*, *Zostera*, *Halodule* and *Thalassodendrum* form more dynamic and less stable meadows than temperate and sub-tropical seagrass of the genera e.g. *Posidonia* and *Amphibolis* and tropical species of the genus *Enhalus*. The GHG assessment boundaries of ephemeral meadows should be extended to include all potential area extent, and differences in seagrass ecosystem extent could be used to estimate enhanced sequestration and/or avoided emissions.

- Other activities (as listed in Part A of this report) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:
- Changes in soil C_{org} stocks over 1 m-thick deposits.
- Change in CO_2, CH_4 and N_2O fluxes.
- Gain in seagrass extent.

In general, monitoring at frequencies greater than or equal to once every 5 years are recommended.

The following monitoring standards should be considered:
- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).
- The number of sites and replication required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b) in each stratum. Based upon evidence for tidal marshes and mangroves (Chmura et al. 2003), approximately 10-20 samples per stratum will likely be required. For measurement of CH_4 and N_2O fluxes, about 40 samples (chambers) per stratum may be required (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to C_{org}

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

Land or ocean access may be restricted in some areas, owing to marine protected areas, mining sites and/or aboriginal rights. Land occupied by intertidal meadows may be subjected to additional restriction, but the water occupied by sub-tidal meadows is Government property except in the Northern Territory.

All seagrass meadows are found below the mean high water mark (MHWM), and therefore the legal right to C_{org} may belong to the Government or authorities managing coastal areas occupied by seagrasses. Land ownership and legal right of C_{org} for abatement activities influencing seagrass C_{org} storage would need to be explored in greater detail for an ERF method.

7.4.2 Re-establishment of seagrass ecosystem (seagrass)

Category: Avoided emission and/or enhanced sequestration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous C_{org} from autochthonous C_{org}.

Active or passive revegetation of seagrass ecosystem can result in re-establishing sequestration, and avoided emissions as a result of avoided erosion and remineralisation of C_{org} stocks in bare but previously vegetated soils. Restoration of seagrass ecosystems by i) direct revegetation (transplanting, seedling) and ii) passive revegetation (*in situ* and/or offsite activities) by alteration of hydrodynamics (use of or removal of artificial structures; alteration of tidal connectivity, water flow, salinity and other processes) and/or alteration of water quality (suspended sediments, nutrient loads, pollutant loads or salinity) can result in the re-establishment of seagrass ecosystem (enhanced sequestration) and avoided GHG emissions from bare but previously vegetated areas. Activities aimed to restore seagrass ecosystems can enhance C_{org} sequestration and/or avoid GHG to the atmosphere, by enhanced sequestration as a result of increased plant productivity and sedimentation. The seagrass canopy reduces resuspension and enhances sedimentation, fixing the soil avoiding erosion and the subsequent exposure of soil C_{org} to oxic conditions conducive to GHG emissions (avoided emissions).

Abatement activities linked to the revegetation of impacted seagrass beds can enhance C_{org} sequestration and/or avoid emissions of GHG to the atmosphere, by re-establishing the canopy and thereby, their C_{org} sequestration capacity, and by precluding the exposure of soil C_{org} from previously vegetated areas to oxic conditions conducive to GHG emissions. Scientific studies support the hypotheses that this abatement activity can enhance C_{org} sequestration and/or avoid emissions of GHG (i.e. CO_2) to the atmosphere, but little information is available on CH_4 and/or N_2O fluxes in natural or disturbed seagrass ecosystems. Given the presence of sulphate in seagrass soils, CH_4 production is likely low. The production of N_2O is limited to oxic soil horizons, typically found within the top 10 cm of seagrass soils and around seagrass rooting systems. Therefore, N_2O baseline production in seagrass ecosystems is probably low, and certainly revegetation of bare but previously vegetated areas will enhance trapping of fine sediments resulting in soil anoxia, which could reduce N_2O emissions as a result of reduced nitrification and denitrification.

1.2 List the circumstances or conditions under which the activity is to be implemented.
If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Active or passive revegetation of previously impacted seagrass ecosystems can be carried out in any area previously vegetated by seagrasses and where the cause of the previous seagrass loss is not, or will not, be operating. The activities can be implemented in all coastal habitats previously occupied by seagrass ecosystems. However, ecosystem characteristics (including geomorphology and seagrass species chosen for restoration) may influence abatement potential. Coastal geomorphology and environmental ecosystem features may influence the extent of area suitable for revegetation activities (i.e. assessment boundary). The abatement potential for emissions avoidance (i.e. prevention of soil

C_{org} erosion in bare but previously vegetated areas by revegetating) may also be different within and between areas, as a result of pre-existing seagrass soil C_{org} stocks and the hydrodynamic energy within the GHG assessment boundaries.

Some examples of activities are listed below:
- Active revegetation in areas where seagrasses has been lost (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).
- The re-establishment of seagrass ecosystems by managing the coastal environment, either at the intended revegetation site or offsite (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}), such as:
  - Alteration of hydrology and/or hydrodynamic energy to facilitate seagrass revegetation (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).
  - Alteration of water quality (suspended sediment, nutrient and pollutant loads) to promote seagrass revegetation (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

There is peer-reviewed evidence showing that abatement activities dealing with the effect of revegetation and ecosystem restoration can enhance C_{org} sequestration and avoid GHG emissions:

- Marbà et al. (2015) demonstrated erosion of soil C_{org} stocks after loss of living biomass (deforestation) due to chemical disturbance, triggering the erosion of historic C_{org} deposits, estimated at 15 Mg C_{org} ha^{-1}, which is equivalent to 60 years of C_{org} deposition, and the lack of C_{org} sequestration over 35 years of seagrass loss was estimated in 8.5 Mg C_{org} ha^{-1}. Marba et al. (2015) also demonstrated that revegetation projects effectively restore seagrass C_{org} sequestration capacity, by combining C_{org} chronosequences with ^{210}Pb dating of seagrass soils in a meadow that experienced losses until the end of 1980´s and subsequent serial revegetation efforts. Seagrass revegetation enhanced autochthonous and allochthonous C_{org} deposition and accumulation. C_{org} accumulation rates increased with the age of the restored sites, and 18 years after planting they were similar to that in continuously vegetated meadows (0.26 ± 0.008 Mg C_{org} ha^{-1} yr^{-1}). The results presented by Marba et al. (2015) demonstrate that loss of seagrass triggers the erosion of historic C_{org} deposits and that revegetation effectively restores seagrass C_{org} sequestration capacity. Thus, conservation and restoration of seagrass meadows are effective strategies for climate change mitigation.

- Greiner et al. (2013) demonstrated that seagrass restoration enhances C_{org} sequestration in coastal waters. Using a large-scale restoration (>1700 ha) in the Virginia coastal bays as a model system, they evaluated the role of seagrass (*Zostera marina*) restoration in soil C_{org} storage of shallow coastal ecosystems. Soils of replicate seagrass meadows representing different age treatments (as time since seeding: 0, 4, and 10 years), were analysed and showed that soil nutrient and organic content, and C_{org} accumulation rates were higher in 10-year seagrass meadows relative to 4-year old meadow and bare sediment. These differences were consistent with higher shoot density in the older meadow. C_{org} accumulation rates determined for the 10-year restored seagrass meadows were 36.68 g C_{org} m^{-2} yr^{-1}. Within 12 years of seeding, the restored seagrass meadows are expected to accumulate C_{org} at a rate that is comparable to natural seagrass meadows. This was the first study to provide evidence of the potential of seagrass ecosystem restoration to enhance C_{org} sequestration in the coastal zone.

- Reynolds (2016) demonstrated that ecosystems services returned following seagrass restoration. They used a case study—reseeding seagrass to a coastal lagoon—to demonstrate the value of enhanced ecosystem services as a result of restoration. They modelled the recovery of areal plant coverage in a system where seagrasses were lost due to disease and disturbance, and estimated the value of the returned functions of nitrogen removal and C_{org} sequestration. They estimated, as of 2010, that this restoration sequesters C_{org} at a rate of 630 Mg C_{org} y^{-1} in the soil. Further, they estimated that natural recovery would take more than 100 years to reach the areal coverage achieved by restoration using seeds in just 10 years. Restoration enhanced this recovery, and the earlier establishment of plants resulted in a net gain of at least 15,000 Mg of C_{org} sequestered in the soil.

2. Opportunity for uptake and genuine abatement

2.2 Identify potential participant groups for the blue carbon enhancement activity.

State, Council, Commonwealth and Indigenous landholders, companies and Australians that are prepared to restore seagrasses through either passive regeneration techniques or actively restoration or establishment of seagrass.

2.2. Estimate the potential intensity of abatement for the blue carbon enhancement activity.

The following estimates of potential intensity of abatement are based upon mean data of national C_{org} stocks and accumulation rates for seagrasses compiled by the CSIRO Coastal Carbon Cluster, and assuming 25-75% avoidance of soil C_{org} stock remineralisation (in 1 m soil deposits) after revegetation of bare but previously vegetated areas. For the range of estimates and 95% Confidence Intervals (CI) see Appendix 1. The loss and fate of C_{org} stores after disturbance remains poorly understood (e.g. it can range from 0 to 100% loss and the fate is assumed to be 100% remineralisation despite part of the C_{org} could be preserved elsewhere). Indeed, the avoidance of soil C_{org} remineralisation after revegetation is poorly known. Therefore, the estimates of avoided emissions presented in this table are subjected to large uncertainties. Indeed, the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates (e.g. as a function of species composition and geomorphology) entails large uncertainties around the potential intensity of abatement. Estimates of the potential intensity of abatement for non-CO_2 GHG emissions (i.e. CH_4 and N_2O) are not provided because their fluxes in seagrass ecosystems remain poorly understood.

Change in soil C_{org} storage:

- Estimated increase in soil C_{org} sequestration (enhanced sequestration by revegetating):
  - average 0.36 Mg C_{org} ha^{-1} yr^{-1}
  - average 1.32 Mg CO_2 ha^{-1} yr^{-1} (conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Avoided emission rates:

- Estimated soil C_{org} avoided emissions (avoided emissions by revegetating to avoid remineralisation of soil C_{org} stocks from previously vegetated areas):
  - ranging from 28 to 84 Mg C_{org} ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised unless revegetation occurs).
- Estimated CO_2 avoided emissions from soil C_{org} (avoided CO_2 emissions by revegetating to avoid remineralisation of soil C_{org} stocks from previously vegetated areas):

- ranging from 103 to 308 Mg CO_2 ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised unless revegetation occurs). (Conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Area estimates of potential abatement & Total potential abatement volume:

The potential abatement (both areal and by volume) are high, however seagrass revegetation efforts in Australia have not had great success. With a few notable exceptions (e.g. Marba et al. 2015) the areas recovered have been small (few ha). This is largely due to the difficulties in achieving revegetation of the target species, such as *Posidonia* spp. and *Amphibolis* spp., and contrasts the success reported for other species in the USA which are successfully revegetated from seed (Marion & Orth, 2010). Thus, while the potential abatement volume is large, current success rates indicate that only a small portion of this potential could be realised.

Estimates of the area over which this activity could potentially occur are limited and geographically restricted. In some cases multiple factors (physical and chemical) led to the loss of seagrasses.

- Larkum and West (1990) reported 260 ha loss in Botany Bay, NSW

- Kirkman (1997) and references therein reported 7,000 ha loss in Gulf St. Vincent

- Kirkman (1997) and references therein reported 17,800 ha loss in Western Port Bay

- Kirkman (1997) and references therein reported 400 ha loss in Birch Point

- Kirkman (1997) and references therein reported 430 ha loss in Ralphs Bar

- Kirkman (1997) and references therein reported 1,200 ha loss in Pittwater

- Kirkman (1997) and references therein reported 210 ha loss in Norfolk Bar

- Kirkman (1997) and references therein reported 700 ha loss in Lake Macquarie

- Kirkman (1997) and references therein reported 450 ha loss in Clarence River

- Kirkman (1997) and references therein reported >10,000 ha loss in Torres Strait

- Kirkman (1997) and references therein reported 18,300 ha loss in West Island – Limmen Bight

- (Serrano et al. 2016a) reported at least 2 ha of seagrass loss due to mooring at Rottnest Island, WA and report the associated C_{org} loss.

Total potential abatement volume:
The following potential abatement volumes have been calculated based upon the above abatement intensity calculations and reported area estimates:

26,718 – 80,153 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Botany Bay, NSW (Larkum and West 1990)

719,320 - 2,157,960 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Gulf St Vincent (Kirkman 1997) and references therein.

1,829,128 - 5,487,384 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Western Port Bay (Kirkman 1997) and references therein.

41,104 - 123,312 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Birch Point (Kirkman 1997) and references therein.

44,187 - 132,560 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Ralphs Bar (Kirkman 1997) and references therein.

123,312 - 369,936 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Pittwater (Kirkman 1997) and references therein.

21,580 - 64,739 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Norfolk Bar (Kirkman 1997) and references therein.

71,932 - 215,796 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Lake Macquarie (Kirkman 1997) and references therein.

46,242 - 138,726 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) loss in Clarence River (Kirkman 1997) and references therein.

1,027,600 - 3,082,800 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Torres Strait (Kirkman 1997) and references therein.

1,880,508 - 5,641,524 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in West Island – Limmen Bight (Kirkman 1997) and references therein.

206 – 617 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) (Serrano et al. 2016d)

2.3. Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Social impacts through exclusion or restriction of recreational use of seagrass ecosystems.
- Economic cost of restoring seagrass ecosystems through revegetation and/or re-establishment of ecosystem condition by alteration of hydrology, hydrodynamics or water quality.
- Economic cost through exclusion or restriction of coastal development activities.
- Economic cost through exclusion or restriction of offsite activities (agriculture, livestock, coastal development and catchment development).

2.4. Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Conservation of seagrass ecosystems is currently being promoted through legislation. However, loss and degradation of seagrass ecosystems is ongoing (e.g. eutrophication, sediment deposition, erosion). There is the potential for an economic incentive from ERF to help conserving and enhancing C_{org} sequestration by promoting the revegetation of coastal areas.

3. Additionality

3.2 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

It is unlikely that the areas previously vegetated by seagrasses would revegetate autonomously. Management to promote seagrass revegetation could result in additionality issues. Despite other environmental schemes and legislation directly or indirectly protect seagrass ecosystems, it is unlikely that current rates of seagrass ecosystem loss will diminish and also that revegetation without human intervention would occur. There is the potential for an economic incentive from emissions reduction to help fund revegetation activities and communication strategies leading to enhanced C_{org} sequestration and avoided GHG emissions.

Table 35. Abatement integrity assessment for "Re-establishment of seagrass ecosystem". Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in C_{org} abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not result in re-growth, neither in the lack of erosion of soil C_{org} after canopy loss.
4.2. Estimating the activity's C_{org} removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine C_{org} removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Peer-reviewed literature support measurable change in soil C_{org} stock as a result of seagrass restoration and avoided emissions linked to the loss of canopy and subsequent erosion of soil C_{org} stocks.
4.3. C_{org} abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible C_{org} abatement in accordance with the approach outlined in footnote 2.	0- C_{org} abatement from the activity is not eligible C_{org} abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if C_{org} abatement from the activity is eligible C_{org} abatement. It is uncertain whether the C_{org} can be counted towards Australia's national greenhouse gas inventory. 2 - C_{org} abatement from the activity is eligible C_{org} abatement and can be counted towards Australia's national greenhouse gas inventory.	1	If we can track and count it now there is potential for it to be credited.
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	Peer-reviewed literature support change in soil C_{org} stock as a result of ecosystem restoration, and avoided emissions linked to the loss of canopy and subsequent erosion of soil C_{org} stocks.

Integrity requirement	Scoring criteria	Score	Score Justification
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	Combination of other GHG that might be emitted in running/operating/monitoring the project.
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative. 2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.	1	Based on a probability of exceedance >50% rather than mean values. The range of abatements are large, and thus illustrate that the C_{org} sequestration capacity of seagrasses largely differ between ecosystems, and thereby their potential for abatement.
	Total score	10	

Footnote 2: *To be eligible C_{org} abatement, the abatement needs to be able to be captured* in *Australia's nationally reported GHG emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands).*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline prior to activity: Baseline soil C_{org} stocks and sequestration rates in bare but previously vegetated areas can be measured through field soil coring and C_{org} analyses in the laboratory (i.e. to estimate C_{org} stocks) and through the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) throughout the area over which the activity will be applied. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. Radioisotopes could provide estimates of sediment accumulation rates or and/or erosion using a retrospective approach (i.e. reconstruction), and despite they encompass longer periods of time (i.e. decades), it could be obtained right before developing the activity (i.e. being available before SETs or MHs estimates). Emissions of non-CO_2 GHG fluxes may be measured using instruments deployed at the site prior to the activity. These data can be used as a baseline to characterise C_{org} sequestration and stocks before the activity. The duration over which assessments of GHG fluxes are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event.

- Estimation of baseline from literature values: It may be possible to use peer-reviewed literature values to estimate average/median C_{org} stocks and accumulation rates at the study site (bare but previously vegetated areas). Modelling approaches may also be capable of estimating C_{org} sequestration rates and stocks at a study site, using a range of covariates from other locations to construct models capable of predicting baseline stocks and C_{org} storage at the study site. Suitable emissions factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013). However, all of these approaches involve substantial uncertainties and, given the relative ease of undertaking direct measurements, are not the recommended approach.

5.2. List and justify the assumptions and uncertainties on which the baseline is based.

Field sampling of soil C_{org} stocks and accumulation rates, and fluxes of GHG requires sufficient effort and replication to understand spatial and temporal variability. Statistical approaches to sampling design and data analyses exist to allow quantification of the uncertainty associated with measured values (Tier 3).

Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites (Tier 1 or 2). Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013) may underestimate or overestimate baseline values, depending on the specific conditions of the project site. In some instances there may not be suitable reference/control sites to use because of the large uncertainties involved.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

Undertaking the abatement activity will involve estimating the area affected by the activity, determining baseline C_{org} sequestration rates and stock and estimating the enhanced sequestration (i.e. by recovering C_{org} accumulation) and avoided GHG emissions from soils (i.e. by preserving soil C_{org}

stocks). Existing literature can be used to estimate average/median loss of C_{org} stocks and lack of C_{org} sequestration following revegetation to estimate avoided emissions.

The GHG assessment boundaries may be relatively difficult to define and predict for activities resulting in passive revegetation following offsite activities (e.g. alteration of hydrology or water quality). Passive revegetation (enhanced sequestration and/or avoided emissions) linked to the re-establishment of seagrass ecosystem may occur outside the GHG assessment boundaries initially considered. There exist the possibilities to i) define large GHG assessment boundaries to ensure that the whole area with potential for rehabilitation is included; and/or ii) re-assess the boundaries following the activity to include revegetated areas not initially considered.

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Source		Greenhouse gas/ C_{org} pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	
Project activity sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area potentially suitable for seagrass habitat. This could be mapped and through use of aerial imagery, and/or use hydrological models to determine change in ecosystem extent and C_{org} storage gains and/or avoided emissions after the activity.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

<u>Measurement of baseline prior to activity</u>:

- Tier 3: Baseline soil C_{org} stocks can be measured through coring and laboratory analyses of samples prior to the activity. Soil samples (e.g. 1 m long) would need to be collected throughout the coastal area (e.g. within bare soils previously vegetated or unvegetated, including physical and biogeochemical variability) within the GHG assessment boundary. The samples will be processed to estimate soil C_{org} content. Soil accumulation rates combined with C_{org} analyses of surface soils (e.g. top

5 cm) could be used to monitor and measure baseline C_{org} sequestration rates in coastal bare sediments (previously vegetated or not). Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1 cm and could be applied in bare sediments. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. These data can be used as baselines to determine C_{org} stock and sequestration rates prior to the activity (i.e. estimates of the business as normal scenario). GHG fluxes may be measured using instruments deployed at the site prior to the activity (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) to determine baseline GHG fluxes. Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates within the study site, probably reducing the replication needs.

- Tier 1 or 2: Existing literature can be used to estimate average/median C_{org} stocks and sequestration rates prior to the activity (i.e. baseline). Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates at the study site, using a range of covariates from other locations to construct models capable of predicting baseline C_{org} stocks and sequestration rates at the study sites. Emission factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013) or those available in peer-reviewed literature.

<u>Measurement of avoided emissions</u> (i.e. by preserving soil C_{org} stocks) and enhanced sequestration (i.e. by preserving or enhancing C_{org} accumulation):

Estimating avoided emissions can rely on limited peer-reviewed literature or IPCC factors. Enhanced sequestration can be based on baseline data (Tier 3) or literature estimates of C_{org} sequestration in seagrass ecosystems (Tier 1 or 2).

<u>Uncertainties</u>:

A. The inter- and intra-ecosystem variability in C_{org} stocks and sequestration within seagrass ecosystems (i.e. GHG assessment boundaries) can be large (up to 18-fold; Lavery et al. 2013; Serrano et al. 2014). Therefore, the sampling design would need to include physical and biogeochemical ecosystem variability and enough replication to ensure that baseline estimates of C_{org} stock and sequestration rates are representative of the GHG assessment boundary. The use of a probability of exceedance (e.g. >50%) instead of mean or median values is recommended to avoid bias by large/small C_{org} stock and sequestration rates values measured within the GHG assessment boundary, as currently used in the “Sequestering carbon in soils in grazing systems” ERF method.

B. The use of peer-reviewed literature values to determine baseline C_{org} stocks and accumulation rates within the GHG assessment boundary (i.e. instead of direct measurements) would entail larger uncertainties. However, considering the amount of peer-reviewed data available, statistical approaches could be used to quantify uncertainties and develop approaches that are conservative and meet the requirements of ERF methods.

C. The duration over which assessments of GHG fluxes are completed would require further consideration to ensure that measured values are indicative of the true baseline situation and not impacted by any particular temporal event. GHG fluxes may vary substantially across landscapes (e.g. intertidal versus subtidal seagrass meadows, and water depth) and climatic gradients. It would therefore be beneficial to develop emissions factors at local and regional scales (e.g. site or estuary scales). Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties. The quantity and type of GHG fluxes (CO_2, CH_4, N_2O) could by temporally variable. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation.

D. Modelling approaches are also capable of estimating C_{org} stocks and sequestration rates, and avoided emissions over spatial scales. A range of covariates could be used to construct models capable of predicting measured baseline stocks and sequestration rates and then models could be applied, with some validation, to other locations.

E. SETs and MHs techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement to define an accurate baseline. Marker Horizon techniques may prove unreliable due to loss of the marker layer through bioturbation or disturbance to the soil profile.

F. Despite the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates, it is possible to use peer-reviewed literature values to determine average/median C_{org} stocks and accumulation rates at the study site combined with emissions factors (e.g. IPCC Wetlands Supplement, 2013) to estimate emissions' avoidance. However, the use of literature-derived stocks and accumulation rates and global or regional emissions factors may introduce substantial uncertainty as C_{org} stocks and GHG emissions can vary substantially across landscapes, seagrass ecosystems, and climatic gradients. Use of locally derived stocks, accumulation rates and emission factors (Tier 3) may help to overcome some of this uncertainty.

G. Defining the extent of the GHG assessment boundary would be complex for activities linked to the modification of hydrodynamic energy or water flow to habilitate seagrass revegetation. The ad-hoc (i.e. prior to activity) and post-hoc (i.e. after the activity) assessment of seagrass ecosystem extent would reduce uncertainties linked to estimates of GHG assessment boundaries prior to the activity.

H. Moderate alteration of water quality (e.g. increase in sediment run-off and nutrient load) could result in enhanced C_{org} sequestration, while excessive reduction of sediment and nutrient load could result in reduced C_{org} sequestration.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Howard et al. (2014) and IPCC (2013) provide guidelines on how to estimate gains and/or avoided emissions in blue carbon ecosystems. The uncertainties involved in each of the approaches are listed, and are the same as described in Section 7.1. Modelling could be used in all approaches described below to improve the accuracy (i.e. reduce uncertainties) of estimates.

Approaches to calculate avoided emissions and re-established sequestration are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method or radioisotopes can be used to determine the depth at which project measurements should be taken to assess gains (CO_2-C) or losses (CO_2-e) after the activity. For example, if SET measurements show that the surface elevation has grown 5 cm under the project, then the soil C_{org} stock would be measured from 5 to 105 cm soil depth. The top 5 cm of soil accumulated will constitute additional sequestration of soil C_{org} (gain in C_{org} sequestration). Similarly, if the SET or radioisotope measurements show a decrease in surface elevation (i.e. erosion) under the project (e.g. elevation loss of 3 cm) then the soil C_{org} stock estimates will be reduced by the top 97 cm of soil as a result of soil erosion and lack of C_{org} accumulation.

The steps required for estimating project activity emissions and removals are described below:

Approach 1 *(Tier 3, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Collection of 1 m long soil cores throughout the study area and analyses of C_{org} concentration throughout the cores (e.g. at 0-5, 5-20, 20-50, 50-100 cm; in homogenised samples) prior to activity.

c. Deployment of SETs and MHs throughout the study area prior to activity.

d. Measurement of GHG fluxes prior to activity.

e. Estimate enhanced soil GHC sequestration (i.e. by preserving or enhancing C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, based on GHG sequestration rates measured at the study site (i.e. baseline estimates of soil accumulation and C_{org} accumulation and N_2O and CH_4 fluxes in top 5 cm of soil, and measurement of soil surface elevation (i.e. based on the SETs and MHs deployed throughout the study area) (e.g. after 5, 10, 15 and 20 years) and estimate avoided GHG emissions (i.e. by preserving pre-existing seagrass soil C_{org} stocks) based on existing peer-reviewed evidence linking GHG fluxes as a result of the activity at the study site (possible in a few number of cases only).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

Approach 2 *(Tier 1 or 2, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Estimate soil C_{org} stocks (e.g. at 0-5, 5-20, 20-50, 50-100 cm), C_{org} sequestration rates (e.g. surface soils) and GHG fluxes within the GHG assessment boundary based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

c. Estimate enhanced soil GHCs sequestration (i.e. by preserving C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, and estimate avoided GHG emissions (i.e. by preserving pre-existing seagrass soil C_{org} stocks) based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

The approaches to calculate net GHG abatement have been specified in section 7.2. In applying these methods, there is a need to propagate uncertainties and specify the levels of confidence in the estimated abatement. It is suggested that estimates of emission avoidance and sequestration be accompanied by a defined probability of exceedance.

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

The data collection methods have been briefly described in sections 7.1 and 7.2. Below there is a more comprehensive description of methods:

– Mapping of bare but previously vegetated soils can be performed by analysis of existing imagery, or based on existing peer-reviewed literature.

– Soil cores could be collected by means of manual percussion using corers, 75 mm internal diameter. Soil compression (i.e. 'shortening') should be measured in the field to allow normalisation of soil C_{org} stocks and sequestration rates to a certain soil depth. In the laboratory, the core samples should be cut lengthwise, and the soil contained in the cores sliced at desired intervals. The soil samples should be homogenised and processed to estimate C_{org} concentrations. There are several methods to estimate C_{org} concentration in costal sediments, including loss on ignition (and subsequent assumptions of the organic matter:C_{org} ratio), elemental analyser, mass spectrometer, infra-red spectroscopy, etc. (see Howard et al. 2014) for further details. Estimates of C_{org} content can differ between methods, and it is important to establish standard methods for ERF eligibility. Scaling of C_{org} estimates to a certain soil depth should be consistent too.

– Methods for the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) are well known.

– Many of the methods outlined require consideration of temporal and spatial variability expected in C_{org} storage, accumulation and GHG emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be estimated over a certain soil depth (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radioisotope dating is likely to provide long-term records of soil accumulation rates, and may also be used to develop a baseline value of C_{org} stocks and longer-term accumulation rates (e.g. annual to millennial scales) using soil cores collected prior or after the commencement of the activity.

8. Double counting

8.2 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream *C_{org}* sources that are already being captured in inventory reporting (e.g. *C_{org}* that enters the blue carbon ecosystem through river system or catchment area).

Seagrass meadows are located at the interface of terrestrial and coastal ecosystems and, therefore, are likely to sequester C_{org} originating off-site (inland and/or offshore). Previous studies suggested that around 50% of soil C_{org} sequestered in seagrass meadows is seagrass-derived, while the other 50% is derived from algae, seston or terrestrial (mangrove, tidal marsh and riverine run-off) organic matter. However, spatial variability within the same meadow can be up to 3-fold (Serrano et al. 2016b) and differencing autochthonous C_{org} (seagrass, benthic algae and epiphytic algae) and allochthonous C_{org} pools in seagrass soils can be difficult, because the methods commonly used to determine their origin (i.e. stable C and N isotopes and mixing models) often lack sufficient discriminatory power (due to the overlap of isotopic signatures of potential sources) and because of diagenetic effects (i.e. fractionation of isotopes) during accumulation and ageing, both of which could introduce large uncertainties when estimating the origin of C_{org} in seagrass soils.

If not exported and stored in seagrass soils, the fate of C_{org} originating from offsite sources (inland and/or offshore) is uncertain. On one hand, the C_{org} originated offshore and stored in seagrass soils is not accounted for elsewhere (no ERF schemes available to date). A plausible fate of C_{org} originating offshore is remineralisation (GHG emissions). Therefore, there is no likelihood of double accounting. On the other hand, C_{org} originating inland and stored in seagrass soils may already have been accounted for elsewhere (ERF for terrestrial C_{org} and/or inclusion of mangrove and tidal marshes in ERF schemes). Indeed, if not sequestered by seagrasses, the plausible fate of C_{org} originating in terrestrial, mangrove and tidal marsh ecosystems is remineralisation (GHG emissions), and/or exported and buried in the coastal and/or deep ocean, and/or exported as dissolved C_{org} in oceanic waters (Duarte and Dorte-Kausen, 2016). However, the risk of double accounting is limited because offsite C_{org} stored in seagrass soils would originate from losses from forests, tidal marsh and mangroves rather than gains (enhanced sequestration) already accounted for.

In summary, double accounting of C_{org} originated inland (terrestrial, mangrove and tidal marsh ecosystems) could be a remote possibility (i.e. resulting in addition rather than genuine sequestration). In order to avoid double accounting there are different options, ranging from conservative to non-conservative:

1. Estimate the proportion of autochthonous vs allochthonous C_{org} in seagrass soils based on direct measurements (e.g. C and N isotopic signatures of the C_{org}, molecular studies) or literature values. This method entails uncertainties related to Tier 1 or 2 estimates (described above);

2. Assume that all seagrass soil C_{org} is genuine sequestration (i.e. assuming that the inland-derived C_{org} would otherwise be remineralised and/or has not been accounted for in ERF schemes); or

3. Decide whether to follow approach 1 or 2 (above) based on existing projects in the catchment area affecting GHG assessment boundaries (depending on each case).

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the C_{org} stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of C_{org} stored and GHG fluxes:

- Natural disturbances such as cyclone or severe storms may cause damage and/or loss of seagrass biomass, exposing soil C_{org} to erosion and subsequent remineralisation.

- Dieback of seagrass biomass related to extreme temperature events may cause damage and/or loss of seagrass meadows, exposing soil C_{org} to erosion and subsequent remineralisation.

- Overgrazing related to natural or human induced factors such as climate change may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Extreme flooding events could impact seagrass ecosystems, either causing damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation, or siltation (i.e. over-sedimentation and accumulation of seagrass meadows) which could result in enhanced sequestration.

- Fishing activities (trawling, bait collection) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Some seagrass meadows are ephemeral and their distribution can vary seasonally or inter-annually. In particular, sub-tropical and tropical seagrass of the genera e.g. *Halophila*, *Zostera*, *Halodule* and *Thalassodendrum* form more dynamic and less stable meadows than temperate and sub-tropical seagrass of the genera e.g. *Posidonia* and *Amphibolis* and tropical species of the genus *Enhalus*. The GHG assessment boundaries of ephemeral meadows should be extended to include all potential area extent, and differences in seagrass ecosystem extent could be used to estimate enhanced sequestration and/or avoided emissions.

- Other activities (as listed in Part A of this report) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in soil C_{org} stocks over 1 m-thick deposits.

- Change in CO_2, CH_4 and N_2O fluxes.

- Gain in seagrass extent.

In general, monitoring every 5 years may be required. The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The number of sites and replication required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b) in each stratum. Based upon evidence for tidal marshes and mangroves (Chmura et al. 2003), approximately 10-20 samples per stratum will likely be required. For measurement of CH_4 and N_2O fluxes, about 40 samples (chambers) per stratum may be required (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to C_{org}

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

Land or ocean access may be restricted in some areas, owing to marine protected areas, mining sites and/or aboriginal rights. Land occupied by intertidal meadows may be subjected to additional restriction, but the water occupied by sub-tidal meadows is Government property except in the Northern Territory.

All seagrass meadows are found below the mean high water mark (MHWM), and therefore the legal right to C_{org} may belong to the Government or Authorities managing coastal areas occupied by seagrasses. Land ownership and legal right of C_{org} for abatement activities influencing seagrass C_{org} storage would need to be explored in greater detail for an ERF method.

7.4.3 Creation of new seagrass ecosystem (seagrass)

Category: Enhanced sequestration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous C_{org} from autochthonous C_{org}.

Creation of seagrass ecosystems differs to the re-establishment or re-vegetation of former seagrass habitat. Creation implies that the site has not previously supported seagrass and, therefore, presumably has environmental conditions unsuitable for seagrass. Re-vegetation sites may also have unsuitable conditions but these are presumably due to either natural or anthropogenic disturbance to a previously suitable condition. In creating a new seagrass ecosystem, any intrinsic barriers to seagrass establishment will need to be addressed as well as any additional anthropogenic factors. For example, a site may have all the conditions necessary to support seagrass but is too deep and therefore lacks the light required to sustain seagrass. In this case, habitat engineering may be required to create a shallower habitat. Following that, the approaches used for re-vegetation (Section 7.4.2) would be applied. Thus seagrass habitat creation will typically involve some or all of the following: i) habitat engineering (if necessary); followed by ii) direct revegetation (transplanting, seedling); and/or iii) passive revegetation.

The creation of seagrass ecosystem can result in enhanced sequestration in previously bare soils. This is achieved initially through increased plant productivity (autochthonous) and then supplemented through enhanced sedimentation and accumulation of allochthonous and autochthonous C_{org} due to the action of the seagrass canopy in promoting particle trapping and reducing resuspension of the accumulating soils.

Scientific studies support the hypothesis that this abatement activity can enhance C_{org} sequestration, on the assumption that they would behave like restored seagrass ecosystems, which have been shown to regain this function. Little information is available on CH_4 and/or N_2O fluxes in natural or disturbed seagrass ecosystems. Given the presence of sulphate in seagrass soils, CH_4 production is likely low in baseline conditions and it is unlikely that this activity would enhance CH_4 production. The production of N_2O is limited to oxic soil horizons, typically found within the top 10 cm of seagrass soils and around seagrass rooting systems. Therefore, N_2O baseline production in seagrass ecosystems is probably low, and certainly the creation of vegetated areas will enhance trapping of fine sediments resulting in soil anoxia, which could reduce N_2O emissions as a result of reduced nitrification and denitrification.

1.2 List the circumstances or conditions under which the activity is to be implemented.
If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Active or passive creation of seagrass ecosystems can be carried out in any area that has the fundamental conditions (physical, chemical and biological) required to support seagrass. Coastal geomorphology and environmental conditions will influence the extent of area suitable for creation activities (i.e. assessment boundary). The sequestration potential may also be different within and between areas, as a result of pre-existing soil C_{org} stocks and the hydrodynamic energy within the GHG assessment boundaries.

This activity could occur in circumstances where it was possible to modify conditions previously precluding seagrass so that meadows could be established, either actively or passively. This may involve physical works to create suitable conditions (e.g. works to reduce hydrodynamic energy or to reduce the water column depth). Some examples are:

- Creation of a hydrodynamically suitable seagrass lagoon through the formation of off-shore barrier islands or bars using suitable quality dredge spoil and subsequent revegetation techniques;
- Creation of seagrass habitat through the dumping of suitable quality dredge spoil in an area that is too deep to support seagrass but has otherwise suitable hydrodynamic, water quality and biological conditions.

In all cases, the creation of seagrass habitat will involve the loss of some pre-existing habitat. Therefore, this activity could only occur where the change in habit was considered to be environmentally acceptable.

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

There is peer-reviewed evidence showing that revegetation and ecosystem restoration can enhance C_{org} sequestration and avoid GHG emissions. Here, we make the assumption that if seagrass habitat could be successfully created, then it would function much the same as restored seagrass habitat and, therefore, the evidence for the success of seagrass restoration can be transferred to seagrass creation. Some examples of the success of seagrass restoration in enhancing sequestration are:

- Marba et al. (2015) combined C_{org} chronosequences with ^{210}Pb dating of seagrass soils to demonstrate that revegetation efforts effectively restore seagrass C_{org} sequestration capacity in a meadow that experienced losses until the end of 1980´s Seagrass revegetation enhanced autochthonous and allochthonous C_{org} deposition and accumulation. C_{org} accumulation rates increased with the age of the restored sites, and 18 years after planting they were similar to that in continuously vegetated meadows (0.26 ± 0.008 Mg C_{org} ha^{-1} yr^{-1}).

- Greiner et al. (2013) demonstrated that seagrass restoration enhances C_{org} sequestration in coastal waters. Using a large-scale restoration (>1700 ha) in the Virginia coastal bays as a model system, they evaluated the role of seagrass, *Zostera marina*, restoration in C_{org} storage in soils of shallow coastal ecosystems. They showed that soil nutrient and organic content, and C_{org} accumulation rates were higher in 10-year-old restored seagrass meadows relative to 4-year-old restored meadow and bare sediment. C_{org} accumulation rates in the 10-year restored meadows were 36.68 g C_{org} m^{-2} yr^{-1} and were expected to have a rate comparable to that of natural seagrass meadows within a further two years.

- Reynolds et al. (2016) modelled the recovery of plant coverage in a system where seagrasses were lost due to disease and disturbance, and estimated the value of the returned functions of nitrogen removal and C_{org} sequestration. They estimated, as of 2010, that this restoration sequesters C_{org} at a rate of 630 Mg C_{org} yr^{-1} in the soil. Further, they estimated that natural recovery would take more than 100 years to reach the areal coverage achieved by restoration using seeds in just 10 years. Restoration enhanced this recovery, and the earlier establishment of plants results in a net gain of at least 15,000 Mg of C_{org} sequestered in the soil.

2. Opportunity for uptake and genuine abatement

2.3 Identify potential participant groups for the blue carbon enhancement activity.

State, Council, Commonwealth and Indigenous landholders or Australians with right to cause physical disturbance to seagrass meadows.

2.2. Estimate the potential intensity of abatement for the blue carbon enhancement activity.

The following estimates of potential intensity of abatement are based upon mean data of national C_{org} stocks and accumulation rates for seagrasses compiled by the CSIRO Coastal Carbon Cluster. Creation of new habitat is unlikely to deliver any avoidance of emissions. The large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates (e.g. as a function of species composition and geomorphology) entails large uncertainties around the potential intensity of abatement. Estimates of the potential intensity of abatement for non-CO_2 GHG emissions (i.e. CH_4 and N_2O) are not provided because their fluxes in seagrass ecosystems remain poorly understood.

<u>Change in soil C_{org} storage:</u>

Estimated increase in soil C_{org} sequestration (enhanced sequestration by creation of seagrass habitat):

- average 0.36 Mg C_{org} ha^{-1} yr^{-1}
- average 1.32 Mg CO_2 ha^{-1} yr^{-1} (conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Area estimates of potential abatement & Total potential abatement volume:

The potential abatement (both areal and by volume) are high, however seagrass revegetation efforts in Australia have not had great success. With a few notable exceptions (e.g. Marba et al. 2015) the areas recovered have been small (few ha) and therefore. This is largely due to the difficulties in achieving revegetation of the target species, such as *Posidonia* spp. and *Amphibolis* spp., and contrasts the success reported for other species in the USA which are successfully revegetated from seed (Marion and Orth 2010). Thus, while the potential abatement volume is large, current success rates indicate that only a small portion of this potential could be realised at present.

2.3. Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Social impacts through exclusion or restriction of recreational use of the created seagrass ecosystems.
- Economic cost of creating new seagrass ecosystems (physical works to create appropriate physical environment, revegetation, creation of suitable of water quality).
- Economic cost through exclusion or restriction of alternative coastal development activities in the GHG abatement area.

2.4. Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Creation of seagrass ecosystems is not currently being promoted through other schemes, though re-creation of disturbed habitat that previously did support seagrass is supported through legislative legislation. However, loss and degradation of seagrass ecosystems is current (e.g. eutrophication, siltation, erosion). There is the potential for an economic incentive from ERF to help enhance C_{org} sequestration by promoting the creation of new seagrass habitat in coastal areas.

3. Additionality

3.3 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

Without the activity, it is unlikely that the areas previously not vegetated would develop into seagrass habitat and since unvegetated sediments typically sequester less C_{org} than seagrass soils, management to promote seagrass habitat creation could result in additionality. Despite other environmental schemes and legislation directly or indirectly protect seagrass ecosystems, it is unlikely that current rates of seagrass ecosystem loss will diminish and also that creation or revegetation without human intervention would occur. There is the potential for an economic incentive from emissions reduction to help fund creation activities and communication strategies leading to enhanced C_{org} sequestration.

Table 36. Abatement integrity assessment for "Creation of new seagrass ecosystem". Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in C_{org} abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not result in the colonization of bare sediments by seagrasses (otherwise the area would already support seagrass).
4.2. Estimating the activity's C_{org} removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine C_{org} removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Peer-reviewed literature support measurable change in soil C_{org} stock as a result of seagrass restoration, linked to the increased primary productivity, creation of canopy and subsequent stability of soil C_{org} stocks.
4.3. C_{org} abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible C_{org} abatement in accordance with the approach outlined in footnote 2.	0- C_{org} abatement from the activity is not eligible C_{org} abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if C_{org} abatement from the activity is eligible C_{org} abatement. It is uncertain whether the C_{org} can be counted towards Australia's national greenhouse gas inventory. 2 - C_{org} abatement from the activity is eligible C_{org} abatement and can be counted towards Australia's national greenhouse gas inventory.	1	If we can track and count it now there is potential for it to be credited.
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	Peer-reviewed literature support change in soil C_{org} stock as a result of ecosystem restoration.

Integrity requirement	Scoring criteria	Score	Score Justification
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	Combination of other GHG that might be emitted in running/operating/monitoring the project
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative. 2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.	1	Based on a probability of exceedance >50% rather than mean values. The range of abatements are large, and thus illustrate that the Corg sequestration capacity of seagrasses largely differ between ecosystems, and thereby their potential for abatement.
	Total score	10	

Footnote 2: *To be eligible C_{org} abatement, the abatement needs to be able to be captured* in *Australia's nationally reported GHG emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 - *AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline prior to activity: Baseline soil C_{org} sequestration rates in bare sediments can be measured through field soil coring and C_{org} analyses in the laboratory (i.e. to estimate C_{org} stocks) and through the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) throughout the area over which the activity will be applied. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. Radioisotopes could provide with estimates of sediment accumulation rates and/or erosion using a retrospective approach (i.e. reconstruction), and despite they encompass longer periods of time (i.e. decades), it could be obtained right before developing the activity (i.e. being available before SETs or MHs estimates). Emissions of non-CO_2 GHG fluxes may be measured using instruments deployed at the site prior to the activity. These data can be used as a baseline to characterise C_{org} sequestration before the activity. The duration over which assessments of GHG fluxes are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event.

- Estimation of baseline from literature values: It may be possible to use peer-reviewed literature values to estimate average/median C_{org} accumulation rates at the study site (bare sediments). Modelling approaches may also be capable of estimating C_{org} accumulation rates at a study site, using a range of covariates from other locations to construct models capable of predicting baseline stocks and C_{org} storage at the study site. However, all of these approaches involve substantial uncertainties and, given the relative ease of undertaking direct measurements, are not the recommended approach.

5.2. List and justify the assumptions and uncertainties on which the baseline is based.

Field sampling of soil C_{org} accumulation rates, and fluxes of GHG requires sufficient effort and replication to understand spatial and temporal variability. Statistical approaches to sampling design and data analyses exist to allow quantification of the uncertainty associated with measured values.

Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites (Tier 1 or 2). Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013) may underestimate or overestimate baseline values, depending on the specific conditions of the project site. In some instances there may not be suitable reference/control sites to use because of the large uncertainties involved.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

Undertaking the abatement activity will involve estimating the area extent affected by the activity, determining baseline C_{org} sequestration rates and estimating the enhanced sequestration (i.e. by seagrass C_{org} accumulation).

The GHG assessment boundaries can be defined spatially and fixed for the duration of the project.

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Source		Greenhouse gas/ C_{org} pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	
Project activity sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area potentially suitable for seagrass colonization. This could be mapped ad-hoc and post-hoc through use of aerial imagery, and/or use hydrological models to determine change in ecosystem extent and C_{org} storage gains after the activity.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Measurement of baseline prior to activity:

- Tier 3: Baseline soil C_{org} accumulation rates can be measured through coring and laboratory analyses of samples prior to the activity. Soil samples (e.g. 20 cm long) would need to be collected across diverse coastal areas (e.g. within bare sediments, including physical and biogeochemical variability) within the GHG assessment boundary. In the laboratory, the samples will be processed to estimate soil C_{org} content. Soil accumulation rates combined with C_{org} analyses of surface soils (e.g. top 5 cm) could be used to monitor and measure baseline C_{org} sequestration rates in coastal bare sediments (previously vegetated or not). Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1cm and could be applied in bare sediments. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. These data can be used as a control to determine gain in C_{org} sequestration after the activity. GHG fluxes may be measured using instruments deployed at the site prior to the activity (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) to determine baseline GHG fluxes. Modelling approaches are also capable of quantifying C_{org} sequestration rates within the study site, probably reducing the replication needs.

- Tier 1 or 2: Existing literature can be used to estimate average/median C_{org} sequestration rates prior to the activity (i.e. baseline). Modelling approaches are also capable of quantifying C_{org} sequestration rates at the study site, using a range of covariates from other locations to construct models capable of predicting baseline C_{org} sequestration rates at the study sites.

Measurement of enhanced sequestration (i.e. by the creation of new seagrass ecosystems):

Enhanced sequestration can be based on baseline data (Tier 3) or literature estimates of C_{org} sequestration in seagrass ecosystems (Tier 1 or 2).

Uncertainties:

A. The inter- and intra-ecosystem variability in C_{org} sequestration within seagrass ecosystems (i.e. GHG assessment boundaries) can be large (Serrano et al. 2014). Therefore, the sampling design would need to include physical and biogeochemical ecosystem variability and enough replication to ensure that baseline estimates of C_{org} sequestration rates are representative of the GHG assessment boundary. The use of a probability of exceedance (e.g. >50%) instead of mean or median values is recommended to avoid bias by large/small C_{org} stock and sequestration rates values measured within the GHG assessment boundary, as currently used in the "Sequestering carbon in soils in grazing systems" ERF method.

B. The use of peer-reviewed literature values to determine baseline C_{org} accumulation rates within the GHG assessment boundary (i.e. instead of direct measurements) would entail larger uncertainties. However, considering the amount of peer-reviewed data available, statistical approaches could be used to quantify uncertainties and develop approaches that are conservative and meet the requirements of ERF methods.

C. The duration over which assessments of GHG fluxes are completed would require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event. GHG fluxes may vary substantially across landscapes (e.g. intertidal versus subtidal seagrass meadows, and water depth) and climatic gradients. It would therefore be beneficial to develop emissions factors at local and regional scales (e.g. site or estuary scales). Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties. The quantity and type of GHG fluxes (CO_2, CH_4, N_2O) could by temporally variable. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation.

D. Modelling approaches are also capable of estimating C_{org} sequestration rates over spatial scales. A range of covariates could be used to construct models capable of predicting measured baseline sequestration rates and then models could be applied, with some validation, to other locations.

E. SETs and MHs techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement to define an accurate baseline. Marker Horizon techniques may prove unreliable due to loss of the marker layer through bioturbation or disturbance to the soil profile.

F. Despite the large inter- and intra-ecosystem variability in seagrass C_{org} sequestration rates, it is possible to use peer-reviewed literature values to determine average/median C_{org} accumulation rates at the study site to estimate emissions' avoidance. However, the use of literature-derived accumulation rates may introduce substantial uncertainty as C_{org} stocks and GHG emissions can vary substantially across landscapes, seagrass ecosystems, and climatic gradients. Use of locally derived accumulation rates and emission factors (Tier 3) may help to overcome some of this uncertainty.

G. Defining the extent of the GHG assessment boundary would be complex for activities linked to the modification of hydrodynamic energy or water flow to habilitate seagrass colonization. The ad-hoc (i.e. prior to activity) and post-hoc (i.e. after the activity) assessment of seagrass ecosystem extent would reduce uncertainties linked to estimates of GHG assessment boundaries prior to the activity.

H. Moderate alteration of water quality (e.g. increase in sediment run-off and nutrient load) could result in enhanced C_{org} sequestration, while excessive reduction of sediment and nutrient load could result in reduced C_{org} sequestration.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Howard et al. (2014) and IPCC (2013) provide guidelines on how to estimate gains in blue carbon ecosystems. The uncertainties involved in each of the approaches are listed, and are the same as described in Section 7.1. Modelling could be used in all approaches described below to improve the accuracy (i.e. reduce uncertainties) of estimates.

Approaches to calculate avoided emissions and enhanced sequestration are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method or radioisotopes can be used to determine the depth at which project measurements should be taken to assess gains (CO_2-C) or losses (CO_2-e) after the activity. For example, if SET measurements show that the surface elevation has grown 5 cm under the project, then the soil C_{org} stock would be measured from 5 to 105 cm soil depth. The top 5 cm of soil accumulated will constitute additional sequestration of soil C_{org} (gain in C_{org} sequestration). Similarly, if the SET or radioisotope measurements show a decrease in surface elevation (i.e. erosion) under the project (e.g. elevation loss of 3 cm) then the soil C_{org} stock estimates will be reduced by the top 97 cm of soil as a result of soil erosion and lack of C_{org} accumulation.

The steps required for estimating project activity emissions and removals are described below:

Approach 1 *(Tier 3, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Collection of 20 cm long soil cores throughout the study area and analyses of C_{org} concentration throughout the cores (e.g. at 0-5, 5-10, 10-15, 15-20 cm; in homogenised samples) prior to activity.

c. Deployment of SETs and MHs throughout the study area prior to activity.

d. Measurement of GHG fluxes prior to activity.

e. Estimate enhanced soil GHC sequestration (i.e. by enhancing C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, based on GHG sequestration rates measured at the study site (i.e. baseline estimates of soil accumulation and C_{org} accumulation and N_2O and CH_4 fluxes in top 5 cm of soil, and measurement of soil surface elevation (i.e. based on the SETs and MHs deployed throughout the study area) (e.g. after 5, 10, 15 and 20 years).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

Approach 2 *(Tier 1 or 2, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Estimate soil C_{org} sequestration rates (e.g. surface soils) and GHG fluxes within the GHG assessment boundary based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

c. Estimate enhanced soil GHCs sequestration (i.e. by preserving C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

The approaches to calculate net GHG abatement have been specified in section 7.2. There is a need to propagate uncertainties and specify a confidence required. It is suggested that emission avoidance and sequestration results be expressed as the magnitude associated with a defined probability of exceedance.

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

The data collection methods have been briefly described in sections 7.1 and 7.2. Below there is a more comprehensive description of methods:

- Mapping of bare but previously vegetated soils can be performed by analyses of existing imagery, or based on existing peer-reviewed literature.
- Soil cores could be collected by means of manual percussion. The corers could consist of PVC pipes, 75 mm internal diameter. Soil compression (i.e. 'shortening') should be measured in the field to allow normalisation of soil C_{org} stocks and sequestration rates to a certain soil depth. In the laboratory, the core samples should be cut lengthwise, and the soil contained in the cores sliced at desired intervals. The soil samples should be homogenised and processed to estimate C_{org} concentrations. There are several methods to estimate C_{org} concentration in costal sediments, including loss on ignition, elemental analyser, mass spectrometer, infra-red spectroscopy, etc. (see Howard et al. 2014) for further details. Estimates of C_{org} content can differ between methods, and it is important to establish standard methods for ERF eligibility. Scaling of C_{org} estimates to a certain soil depth should be consistent too.
- Methods for the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) are well known.
- Many of the methods outlined require consideration of temporal and spatial variability expected in C_{org} storage, accumulation and GHG emissions. SET and MH techniques provide

high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be estimated over a certain soil depth (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radioisotope dating is likely to provide long-term records of soil accumulation rates, and may also be used to develop a baseline value of C_{org} stocks and longer-term accumulation rates (e.g. annual to millennial scales) using soil cores collected prior or after the commencement of the activity.

8. Double counting

8.3 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream C_{org} sources that are already being captured in inventory reporting (e.g. C_{org} that enters the blue carbon ecosystem through river system or catchment area).

Seagrass meadows are located in the interface between terrestrial and coastal ecosystems and, therefore, are likely to sequester C_{org} originating off-site (inland and/or offshore). Previous studies suggested that around 50% of soil C_{org} sequestered in seagrass meadows is seagrass-derived, while the other 50% is derived from algae, seston or terrestrial (mangrove, tidal marsh and riverine run-off) organic matter. However, spatial variability within the same meadow can be up to 3-fold (Serrano et al. 2016b) and the differentiation among autochthonous C_{org} (seagrass, benthic algae and epiphytic algae) and allochthonous C_{org} pools in seagrass soils can be difficult because the methods commonly used (i.e. stable C and N isotopes and mixing models) to determine their origin often lack sufficient discriminatory power (overlap of isotopic signatures of potential sources) and because of diagenetic effects (i.e. fractionation of isotopes) during accumulation and ageing, both of which could introduce large uncertainties when estimating the origin of C_{org} in seagrass soils.

If not exported and stored in seagrass soils, the fate of C_{org} originating from offsite sources (inland and/or offshore) is uncertain. On one hand, the C_{org} originated offshore and stored in seagrass soils is not accounted for elsewhere (no ERF schemes available to date). A plausible fate of C_{org} originating offshore is remineralisation (GHG emissions). Therefore, the likelihood of double accounting is nil. On the other hand, C_{org} originating inland and stored in seagrass soils may already have been accounted for elsewhere (ERF for terrestrial C_{org} and/or inclusion of mangrove and tidal marshes in ERF schemes). Indeed, if not sequestered by seagrasses, the plausible fate of C_{org} originating in terrestrial, mangrove and tidal marsh ecosystems is remineralisation (GHG emissions), and/or exported and buried in the coastal and/or deep ocean, and/or exported as dissolved C_{org} in oceanic waters (Duarte and Dorte-Kausen, 2016). However, the risk of double accounting is limited because offsite C_{org} stored in seagrass soils would originate from losses from forests, tidal marsh and mangroves rather than gains (enhanced sequestration) already accounted for.

In summary, double accounting of C_{org} originated inland (terrestrial, mangrove and tidal marsh ecosystems) it could be a remote possibility (i.e. resulting in addition rather than genuine sequestration). In order to avoid double accounting there are different options, ranging from conservative to non-conservative:

1. Estimate the proportion of autochthonous vs allochthonous C_{org} in seagrass soils based on direct measurements (e.g. C and N isotopic signatures of the C_{org}, genetic studies) or literature values. This method entails uncertainties related to Tier 1 or 2 estimates (described above);

2. Assume that all seagrass soil C_{org} is genuine sequestration (i.e. assuming that the inland-derived C_{org} would otherwise be remineralised and/or has not been accounted for in ERF schemes); or

3. Decide whether to follow approach 1 or 2 (above) based on existing projects in the catchment area affecting GHG assessment boundaries (depending on each case).

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the C_{org} stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of C_{org} stored and GHG fluxes:

- Natural disturbances such as cyclone or severe storms may cause damage and/or loss of seagrass biomass, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Dieback of seagrass biomass related to extreme temperature events may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Overgrazing related to natural or human induced factors such as climate change may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Extreme flooding events could impact seagrass ecosystems, either causing damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation, or siltation (i.e. over-sedimentation and accumulation of seagrass meadows) which could result in enhanced sequestration.

- Fishing activities (trawling, bait collection) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Some seagrass meadows are ephemeral and their distribution can vary seasonally or inter-annually. In particular, sub-tropical and tropical seagrass of the genera e.g. *Halophila*, *Zostera*, *Halodule* and *Thalassodendrum* form more dynamic and less stable meadows than temperate and sub-tropical seagrass of the genera e.g. *Posidonia* and *Amphibolis* and tropical species of the genus *Enhalus*. The GHG assessment boundaries of ephemeral meadows should be extended to include all potential area extent, and differences in seagrass ecosystem extent could be used to estimate enhanced sequestration and/or avoided emissions.

- Other activities (as listed in Part A of this report) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in soil C_{org} stocks over 1 m-thick deposits.

- Change in CO_2, CH_4 and N_2O fluxes.

- Gain in seagrass extent.

In general, monitoring every 5 years may be required. The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The number of sites and replication required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b) in each stratum. Based upon evidence for tidal marshes and mangroves (Chmura et al. 2003), approximately 10-20 samples per stratum will likely be required. For measurement of CH4 and N2O) fluxes, about 40 samples (chambers) per stratum may be required (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to C_{org}

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

Land or ocean access may be restricted in some areas, owing to marine protected areas, mining sites and/or aboriginal rights. Coastal land may be subjected to additional restriction, but the sub-tidal land is Government property except in the Northern Territory.

All seagrass meadows are found below the mean high water mark (MHWM), and therefore the legal right to C_{org} may belong to the Government or Authorities managing coastal areas below MHWM. Land ownership and legal right of C_{org} for abatement activities influencing seagrass C_{org} storage would need to be explored in greater detail for an ERF method.

7.4.4 Avoidance of seagrass ecosystem loss through water quality changes (seagrass)

Category: Avoided emission and/or enhanced sequestration.

1. Blue carbon enhancement activity scope

1.1 Describe the specific blue carbon ecosystem activity that could enhance abatement.

- This may be a specific set of activities or a management practice in the blue carbon ecosystem, or for upstream sources that are impacting on the ecosystem.
- Explain how the abatement activity will sequester and/or avoid greenhouse gases (GHG) from the atmosphere, discerning allochthonous C_{org} from autochthonous C_{org}.

Conservation and restoration of seagrass ecosystem can result in enhanced sequestration, and avoided emissions as a result of avoided erosion and remineralisation of C_{org} stocks as a consequence of meadow loss. Restoration of seagrass ecosystems by managing the catchment to improve water quality (sediment, nutrient and pollutant loading) can result in the conservation of seagrass ecosystem (enhanced sequestration). Activities aimed to restore seagrass ecosystems can enhance C_{org} sequestration and/or avoid GHG to the atmosphere, by enhanced sequestration as a result of increased plant productivity and sedimentation and avoided GHG emissions by preserving seagrass ecosystems. The seagrass canopy reduces resuspension and enhances sedimentation, fixing the soil avoiding erosion and the subsequent exposure of soil C_{org} to oxic conditions conducive to GHG emissions (avoided emissions).

Scientific studies support the hypotheses that this abatement activity can enhance C_{org} sequestration and/or avoid emissions of GHG (i.e. CO_2) to the atmosphere, but little information is available on CH_4 and/or N_2O fluxes in natural or disturbed seagrass ecosystems. Given the presence of sulphate in seagrass soils, CH_4 production is likely low in baseline conditions but it is unknown whether this activity would enhance CH_4 production. The production of N_2O is limited to oxic soil horizons, typically found within the top 10 cm of seagrass soils and around seagrass rooting systems. Therefore, N_2O baseline production in seagrass ecosystems is probably low, and certainly conservation of seagrass ecosystems will keep soils anoxic, which could reduce N_2O emissions as a result of reduced nitrification and denitrification.

1.2 List the circumstances or conditions under which the activity is to be implemented.
If the activity can be implemented under different circumstances or conditions (for example, climatic conditions, soil types and other regionally specific conditions), specify any differences in implementation for each of the different circumstances or conditions.

Avoidance of seagrass ecosystem loss through water quality changes can be carried out in any area vegetated by seagrasses. The activities can be implemented in all coastal habitats occupied by seagrass ecosystems. However, ecosystem characteristics (including geomorphology and seagrass species chosen for restoration) may influence abatement potential. Coastal geomorphology and environmental ecosystem features may influence the extent of area suitable for revegetation activities (i.e. assessment boundary). The abatement potential for emissions avoidance (i.e. prevention of soil C_{org} erosion in bare but previously vegetated areas by revegetating) may also be different within and between areas, as a result of pre-existing seagrass soil C_{org} stocks and the hydrodynamic energy within the GHG assessment boundaries.

Some examples below:

- Conservation of seagrass ecosystems in areas where seagrasses are being lost or are suitable to be lost (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).

- The conservation of seagrass ecosystem by managing the coastal environment (in situ and/or offsite) (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}), such as:

- Alteration of hydrology and/or hydrodynamic energy can result in seagrass conservation (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).
- Alteration of water quality (suspended sediment, nutrient and pollutant loads) can result in seagrass conservation (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).
- Change point to diffuse source effects (e.g. stormwater, sewage, brine and industrial discharge) can result in seagrass conservation (enhanced C_{org} sequestration and avoided emission of autochthonous and allochthonous C_{org}).

1.3 Where available, provide background information about the abatement activity. This could include case studies that demonstrate the successful implementation of the abatement activity.

There is peer-reviewed evidence showing that abatement activities dealing with the effect of revegetation and ecosystem restoration can enhance C_{org} sequestration and avoid GHG emissions:

- Marba et al. (2015) demonstrated erosion of soil C_{org} stocks after loss of living biomass (deforestation) due to chemical disturbance, triggering the erosion of historic C_{org} deposits, estimated at 15 Mg C_{org} ha-1, which is equivalent to 60 years of C_{org} deposition, and the lack of C_{org} sequestration over 35 years of seagrass loss was estimated in 8.5 Mg C_{org} ha-1. The results presented by Marba et al. (2015) demonstrate that loss of seagrass triggers the erosion of historic C_{org} deposits and that revegetation effectively restores seagrass C_{org} sequestration capacity. Thus, conservation and restoration of seagrass meadows are effective strategies for climate change mitigation.

Other peer-reviewed literature linking seagrass C_{org} storage and water quality changes: Macreadie et al. 2012; Dahl et al. 2016; Liu et al. 2016; Reynolds et al. 2016; Ribaudo et al. 2016; Watanabe and Kuwae, 2015; Kuwae et al. 2016; Armitage and Fourqurean 2016; and Howard et al. 2016.

2. Opportunity for uptake and genuine abatement

2.1 Identify potential participant groups for the blue carbon enhancement activity.

State, Council, Commonwealth and Indigenous landholders or Australians with the right to cause physical disturbance to seagrass meadows.

2.2. Estimate the potential intensity of abatement for the blue carbon enhancement activity.

The following estimates of potential intensity of abatement are based upon mean data of national C_{org} stocks and accumulation rates for seagrasses compiled by the CSIRO Coastal Carbon Cluster, and assuming 25-75% avoidance of soil C_{org} stock remineralisation (in 1 m soil deposits) after conservation of seagrass ecosystems. For the range of estimates and 95% Confidence Intervals (CI) see Appendix 1. The loss and fate of C_{org} stores after disturbance remains poorly understood (e.g. it can range from 0 to 100% loss and the fate is assumed to be 100% remineralisation despite part of the C_{org} could be preserved elsewhere). Therefore, the estimates of avoided emissions presented in this table are subjected to large uncertainties. Indeed, the large inter- and intra-ecosystem variability in seagrass

C_{org} stocks and sequestration rates (e.g. as a function of species composition and geomorphology) entails large uncertainties around the potential intensity of abatement. Estimates of the potential intensity of abatement for non-CO_2 GHG emissions (i.e. CH_4 and N_2O) are not provided because their fluxes in seagrass ecosystems remain poorly understood.

Change in soil C_{org} storage:

- Estimated conservation of soil C_{org} sequestration (enhanced sequestration by avoidance of seagrass ecosystem loss):
    - average 0.36 Mg C_{org} ha^{-1} yr^{-1}
    - average 1.32 Mg CO_2 ha^{-1} yr^{-1} (conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Avoided emission rates:

- Estimated soil C_{org} avoided emissions (avoided emissions by avoidance of seagrass ecosystem loss and avoided remineralisation of existing soil C_{org} stocks):
    - ranging from 28 to 84 Mg C_{org} ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised unless revegetation occurs).
- Estimated CO_2 avoided emissions from soil C_{org} (avoided emissions by avoidance of seagrass ecosystem loss and avoided remineralisation of existing soil C_{org} stocks):
    - ranging from 103 to 308 Mg CO_2 ha^{-1} (assuming that 25 to 75% soil C_{org} stocks in 1 m soil deposits are remineralised unless revegetation occurs) (conversion factor: 1 C_{org} remineralised equals 3.67 CO_2 emitted).

Area estimates of potential abatement:

Estimates of the area over which this activity could potentially occur are limited and geographically restricted. In some cases multiple factors (physical and chemical) led to the loss of seagrasses.

- King and Hodgson (1986) reported 700 ha loss in Lake Macquarie NSW.

- King and Hodgson (1986) reported 1300 ha loss in Tuggerah Lakes.

- Cambridge and McComb (1984), Cambridge et al. (1986) and Silberstein et al. (1986) reported 3300 ha loss in Cockburn Sound, WA.

- Bastyan (1986) reported 1530 ha loss in Princess Royal Harbour and Oyster Harbour in WA.

- Neverauskas (1985a, b) reported 5,280 ha loss in Holdfast Bay and off Bolivar, SA.

- Larkum and West (1990) reported 260 ha loss in Botany Bay, NSW.

- Kirkman (1997) reported 810 ha loss in Princess Royal Harbour.

- Kirkman (1997) reported 720 ha loss in Oyster Harbour.

- Kirkman (1997) reported 7,000 ha loss in Gulf St. Vincent.

- Kirkman (1997) reported 400 ha loss in Birch Point.

- Kirkman (1997) reported 430 ha loss in Ralphs Bar.

- Kirkman (1997) reported 1,200 ha loss in Pittwater.

- Kirkman (1997) reported 2,150 ha loss in Norfolk Bar.

- Kirkman (1997) reported 700 ha loss in Lake Macquarie.

- Kirkman (1997) reported 450 ha loss in Clarence River.

- Kirkman (1997) reported 100,000 ha loss in Hervey Bay.

- Kirkman (1997) reported >10,000 ha loss in Torres Strait.

- Kirkman (1997) reported 11,300 ha loss of seagrass loss in Port Macquarie.

- Cambridge et al. (1986) and Kendrick et al. (2002) reported 230 ha loss in Cockburn Sound.

Total potential abatement volume:

The following potential abatement volumes have been calculated based upon the above abatement intensity calculations and reported area estimates:

71,932 – 215,796 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Lake Macquarie NSW (King and Hodgson 1986)

133,588 - 400,764 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Tuggerah Lakes (King and Hodgson 1986)

339,108 - 1,017,324 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Cockburn Sound, WA (Cambridge and McComb, 1984; Cambridge et al. 1986; Silberstein et al. 1986)

157,223 – 471,668 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Princess Royal Harbour and Oyster Harbour in WA (Bastyan, 1986)

542,573 – 1,627,718 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Holdfast Bay and off Bolivar, SA (Neverauskas, 1985a, b)

26,718 – 80,153 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Botany Bay, NSW (Larkum and West 1990)

83,236 – 249,707 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Princess Royal Harbour (Kirkman 1997) and references therein.

73,987 – 221,962 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Oyster Harbour (Kirkman 1997) and references therein.

719,320 - 2,157,960 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Gulf St. Vincent (Kirkman 1997) and references therein.

41,104 – 123,312 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Birch Point (Kirkman 1997) and references therein.

44,187 – 132,560 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Ralphs Bar (Kirkman 1997) and references therein.

123,312 – 369,936 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Pittwater (Kirkman 1997) and references therein.

220,934 – 662,802 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Norfolk Bar (Kirkman 1997) and references therein.

71,932 – 215,796 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Lake Macquarie (Kirkman 1997) and references therein.

46,242 – 138,726 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Clarence River (Kirkman 1997) and references therein.

10,276,000 – 30,828,000 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Hervey Bay (Kirkman 1997) and references therein.

1,027,600 – 3,082,800 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Torres Strait (Kirkman 1997) and references therein.

1,161,188 – 3,483,564 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Port Macquarie (Kirkman 1997) and references therein.

23,635 – 70,904 Mg CO_2 ha^{-1} (from avoided soil C_{org} emissions) + 1.32 Mg CO_2 ha^{-1} yr^{-1} (enhanced sequestration) in Cockburn Sound (Cambridge et al. 1986; Kendrick et al. 2002)

2.3. Consider the extent to which the enhancement activity could have adverse social, environmental or economic impacts.

Adverse impacts may include:

- Social impacts through exclusion or restriction of recreational use of seagrass ecosystems.
- Economic cost of conserving seagrass ecosystems (management of hydrology, water quality or change point to diffuse source effects).
- Economic cost through exclusion or restriction of coastal development activities.
- Economic cost through exclusion or restriction of offsite activities (agriculture, livestock, coastal development and catchment development).

2.4. Determine alternative measures (existing schemes, legislation etc.) that the enhancement activity could be (or already is) promoted through.

Conservation of seagrass ecosystems is currently being promoted through legislation. However, loss and degradation of seagrass ecosystems is current (e.g. eutrophication, siltation, erosion). There is the potential for an economic incentive from ERF to help conserving and enhancing C_{org} sequestration by promoting the revegetated of coastal areas.

3. Additionality

3.4 Demonstrate how emission reductions achieved through the blue carbon enhancement activity are unlikely to occur in the ordinary course of events.

Management to promote seagrass conservation to avoid loss through water quality change could result in additionality. Despite other environmental schemes and legislation directly or indirectly protect seagrass ecosystems, it is unlikely that current rates of seagrass ecosystem loss will diminish. There is the potential for an economic incentive from emissions reduction to help fund conservation activities and communication strategies leading to enhanced C_{org} sequestration and avoided GHG emissions.

Table 37. Abatement integrity assessment for "Avoidance of seagrass ecosystem loss through water quality changes". Scores for each integrity requirement item are to be entered as 0, 1, or 2 according to the criteria provided.

Integrity requirement	Scoring criteria	Score	Score Justification
4.1. Undertaking the blue carbon enhancement activity must result in C_{org} abatement that is unlikely to occur in the ordinary course of events.	0 - The enhancement activity is likely to occur regardless of ERF participation. 1 - Based on available course of events information it is not possible to ascertain the likelihood of the activity occurring in the ordinary course of events. 2 - Based on available information, including current practice and existing regulations, it is considered likely that undertaking the activity would be additional to what is likely to occur in the ordinary course of events.	2	In most circumstances the ordinary course of events would not result in seagrass conservation, neither in the lack of erosion of soil C_{org} after canopy loss.
4.2. Estimating the activity's C_{org} removals, reductions or emissions must be achieved using an approach that is measurable and capable of being verified.	0 - There are currently no recognised measurable or verifiable approaches available to determine C_{org} removals, reductions or emissions relating to the activity. 1 - There are measurement approaches but they are not currently backed by substantiated evidence. 2 - There are recognised measurable or verifiable approaches backed by peer reviewed literature and validated case studies	2	Peer-reviewed literature support measurable change in soil C_{org} stock as a result of seagrass restoration and conservation, and avoided emissions linked to the loss of canopy and subsequent erosion of soil C_{org} stocks.
4.3. C_{org} abatement using in ascertaining the carbon dioxide net abatement amount for the activity must be eligible C_{org} abatement in accordance with the approach outlined in footnote 2.	0- C_{org} abatement from the activity is not eligible C_{org} abatement. It cannot be counted towards Australia's national greenhouse gas inventory 1 - It cannot be determined if C_{org} abatement from the activity is eligible C_{org} abatement. It is uncertain whether the C_{org} can be counted towards Australia's national greenhouse gas inventory. 2 - C_{org} abatement from the activity is eligible C_{org} abatement and can be counted towards Australia's national greenhouse gas inventory.	1	If we can track and count it now there is potential for it to be credited.
4.4. The approaches used for the activity must be supported by clear and convincing evidence	0 - There is currently limited or nil clear and convincing evidence to support the blue carbon enhancement activity. 1 -There is supporting evidence but it is not considered to be clear and convincing evidence. 2 - The proposed blue carbon enhancement activity and associated measurement approaches are supported by clear and convincing evidence backed by peer reviewed literature and validated case studies.	2	Peer-reviewed literature support change in soil C_{org} stock as a result of ecosystem restoration and conservation, and avoided emissions linked to the loss of canopy and subsequent erosion of soil C_{org} stocks.

Integrity requirement	Scoring criteria	Score	Score Justification
4.5. Material amounts of greenhouse gases that are emitted as a direct consequence of the activity must be considered.	0 – any material amounts of greenhouse gases emitted through the activity would be unable to be unaccounted for. 1 - It cannot be determined whether there will be material amounts of greenhouse gases emitted as part of the activity 2 - There are demonstrable approaches for ensuring material amounts of greenhouse gases will be able to be accounted for and deducted from net abatement amounts in carrying out the activity.	2	Combination of other GHG that might be emitted in running/operating/monitoring the project
4.6. Estimates, projections or assumptions regarding activity abatement are conservative	0- Estimates, projections or assumptions used to work out the net abatement amount are not conservative. 1 - It cannot be determined whether estimates, projections or assumptions are conservative but the approaches are anecdotally considered conservative. 2 - Estimates, projections or assumptions used to work out the net abatement are supported by peer reviewed literature that demonstrates conservativeness.	1	Based on a probability of exceedance >50% rather than mean values. The range of abatements are large, and thus illustrate that the C_{org} sequestration capacity of seagrasses largely differ between ecosystems, and thereby their potential for abatement.
	Total score	10	

Footnote 2: *To be eligible C_{org} abatement, the abatement needs to be able to be captured* in *Australia's nationally reported GHG emissions. In the absence of current national reporting on blue carbon capture and storage, consideration should be given to the IPCC 2006 Guidelines (Volume* 4 *- AFOLU), and the 20 J* 3 *Supplementary guidelines on wetlands (Chapter* 4 *Coastal Wetlands)*

Note: Where a total score of eight (8) or greater is provided above to a blue carbon enhancement activity being assessed, Part 2 of this document should also be completed for the activity. A score less than eight (8) will only require Part 1 to be completed.

5. Identifying the baseline

5.1 Specify a process for identifying the blue carbon enhancement activity baseline.

- Direct measurement of baseline prior to activity: Baseline soil C_{org} stocks and sequestration rates in bare but previously vegetated areas can be measured through field soil coring and C_{org} analyses in the laboratory (i.e. to estimate C_{org} stocks) and through the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) throughout the area over which the activity will be applied. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. Radioisotopes could provide with estimates of sediment accumulation rates or and/or erosion using a retrospective approach (i.e. reconstruction), and despite they encompass longer periods of time (i.e. decades), it could be obtained right before developing the activity (i.e. being available before SETs or MHs estimates). Emissions of non-CO_2 GHG fluxes may be measured using instruments deployed at the site prior to the activity. These data can be used as a baseline to characterise C_{org} sequestration and stocks before the activity. The duration over which assessments of GHG fluxes are completed will require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event.

- Estimation of baseline from literature values: It may be possible to use peer-reviewed literature values to estimate average/median C_{org} stocks and accumulation rates at the study site (bare but previously vegetated areas). Modelling approaches may also be capable of estimating C_{org} sequestration rates and stocks at a study site, using a range of covariates from other locations to construct models capable of predicting baseline stocks and C_{org} storage at the study site. Suitable emissions factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013). However, all of these approaches involve substantial uncertainties and, given the relative ease of undertaking direct measurements, are not the recommended approach.

5.2. List and justify the assumptions and uncertainties on which the baseline is based.

Field sampling of soil C_{org} stocks and accumulation rates, and fluxes of GHG requires sufficient effort and replication to understand spatial and temporal variability. Statistical approaches to sampling design and data analyses exist to allow quantification of the uncertainty associated with measured values (Tier 3).

Where baseline measurements are not possible within the project area, reference sites may offer an alternative; however, this approach will assume that baseline conditions throughout the project area are similar to the reference sites (Tier 1 or 2). Global or regionally-derived emissions factors (including IPCC Wetlands Supplement 2013) may underestimate or overestimate baseline values, depending on the specific conditions of the project site. In some instances there may not be suitable reference/control sites to use because of the large uncertainties involved.

5.3 Describe the steps and/or processes involved in undertaking the abatement activity.

- Identify any emissions sources or sinks affected by the activity that will be excluded from the GHG assessment boundary.
- Flowcharts may be used to illustrate typical GHG assessment boundaries.

Undertaking the abatement activity will involve estimate the area extent affected by the activity, determine baseline C_{org} sequestration rates and stock and estimate the enhanced sequestration (i.e. by maintaining seagrass ecosystems and associated C_{org} accumulation) and avoided GHG emissions from soils (i.e. by preserving soil C_{org} stocks). Existing literature can be used to estimate average/median loss of C_{org} stocks and lack of C_{org} sequestration following seagrass loss to estimate avoided emissions and enhanced sequestration.

The GHG assessment boundaries may be relatively difficult to define and predict for activities resulting in passive revegetation after offsite activities (e.g. alteration of hydrology or water quality). Passive revegetation (enhanced sequestration and/or avoided emissions) linked to the re-establishment of seagrass ecosystem may occur outside the GHG assessment boundaries initially considered. There exist the possibilities to i) define large GHG boundaries to ensure that the whole are with potential for rehabilitation is included; and/or ii) re-asses boundaries post-hoc to include revegetated areas not initially considered.

5.4 List all emissions sources and sinks affected by the activity in the table below. Indicate whether the source or sink is to be included or excluded from the baseline or GHG assessment boundary and provide justification for any exclusions. Expand the table to include additional sources and sinks, as necessary.

Source		Greenhouse gas/ C_{org} pools	Included or excluded	Justification for exclusion
Baseline emissions sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	
Project activity sources/sinks	CO_2 emission	Seagrass soil C_{org}	Included	
	CH_4 emission	Seagrass soil C_{org}	Included	
	N_2O emission	Seagrass soil C_{org}	Included	

6. Activity Area

6.1 Specify how the blue carbon ecosystem enhancement activity area and boundaries would be determined.

Activity area boundaries would be defined by the extent of area potentially suitable for seagrass conservation activities (i.e. impacted by water quality changes). This could be mapped ad-hoc and post-hoc through use of aerial imagery, and/or use hydrological models to determine change in ecosystem extent and C_{org} storage gains and/or avoided emissions after the activity.

7. Estimating abatement

7.1 Provide a summary of approaches on how to calculate baseline emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Measurement of baseline prior to activity:

- Tier 3: Baseline soil C_{org} stocks can be measured through coring and laboratory analyses of samples prior to the activity. Soil samples (e.g. 1 m long) would need to be collected across divers coastal areas (e.g. within bare soils previously vegetated or not, including physical and biogeochemical variability) within the GHG assessment boundary. In the laboratory, the samples will be processed to estimate soil C_{org} content. Soil accumulation rates combined with C_{org} analyses of surface soils (e.g. top 5 cm) could be used to monitor and measure baseline C_{org} sequestration rates in coastal bare sediments (previously vegetated or not). Methods commonly used in mangrove and tidal marsh ecosystems include the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989), which provide accuracy to <1cm and could be applied in bare sediments. Alternatively, radioisotopes (e.g. ^{210}Pb and ^{137}Cs) could be used to determine short-term (i.e. decadal) C_{org} sequestration rates. These data can be used as a control to determine gain in C_{org} stock and sequestration prior to the activity. GHG fluxes may be measured using instruments deployed at the site prior to the activity (e.g. eddy covariance flux measurement towers; chamber-based gas collection measurements) to determine baseline GHG fluxes. Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates within the study site, probably reducing the replication needs.

- Tier 1 or 2: Existing literature can be used to estimate average/median C_{org} stocks and sequestration rates prior to the activity (i.e. baseline). Modelling approaches are also capable of quantifying C_{org} stocks and sequestration rates at the study site, using a range of covariates from other locations to construct models capable of predicting baseline C_{org} stocks and sequestration rates at the study sites. Emission factors may also be used, such as those outlined in the IPCC Wetlands Supplement (2013) or those available in peer-reviewed literature.

Measurement of avoided emissions (i.e. by preserving soil C_{org} stocks) and enhanced sequestration (i.e. by preserving or enhancing C_{org} accumulation):

Estimating avoided emissions can rely on limited peer-reviewed literature or IPCC factors. Enhanced sequestration can be based on baseline data (Tier 3) or literature estimates of C_{org} sequestration in seagrass ecosystems (Tier 1 or 2).

Uncertainties:

A. The inter- and intra-ecosystem variability in C_{org} stocks and sequestration within seagrass ecosystems (i.e. GHG assessment boundaries) can be large (up to 18-fold; Lavery et al. 2013; Serrano et al. 2014). Therefore, the sampling design would need to include physical and biogeochemical ecosystem variability and enough replication to ensure that baseline estimates of C_{org} stock and sequestration rates are representative of the GHG assessment boundary. The use of a probability of exceedance (e.g. >50%) instead of mean or median values is recommended to avoid bias by large/small C_{org} stock and sequestration rates values measured within the GHG assessment boundary, as currently used in the "Sequestering carbon in soils in grazing systems" ERF method.

B. The use of peer-reviewed literature values to determine baseline C_{org} stocks and accumulation rates within the GHG assessment boundary (i.e. instead of direct measurements) would entail larger uncertainties. However, considering the amount of peer-reviewed data available, statistical approaches could be used to quantify uncertainties and develop approaches that are conservative and meet the requirements of ERF methods.

C. The duration over which assessments of GHG fluxes are completed would require further consideration to ensure that measured values are indeed indicative of the true baseline situation and not impacted by any particular temporal event. GHG fluxes may vary substantially across landscapes (e.g. intertidal versus subtidal seagrass meadows, and water depth) and climatic gradients. It would therefore be beneficial to develop emissions factors at local and regional scales (e.g. site or estuary scales). Chamber-based measurements require sufficient effort and replication to understand spatial and temporal variability in atmospheric flux. Insufficient sampling effort may lead to substantial inaccuracies or uncertainties. The quantity and type of GHG fluxes (CO_2, CH_4, N_2O) could by temporally variable. Therefore, a sufficient baseline measurement period is required, including measurement across seasons – both in regards to precipitation/inundations regimes (wet season versus dry season), temperature, day length and light intensity, as well as diel variation.

D. Modelling approaches are also capable of estimating C_{org} stocks and sequestration rates, and avoided emissions over spatial scales. A range of covariates could be used to construct models capable of predicting measured baseline stocks and sequestration rates and then models could be applied, with some validation, to other locations.

E. SETs and MHs techniques only provide information beginning at the date of installation. These techniques may require multiple years of measurement to define an accurate baseline. Marker Horizon techniques may prove unreliable due to loss of the marker layer through bioturbation or disturbance to the soil profile.

F. Despite the large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates, it is possible to use peer-reviewed literature values to determine average/median C_{org} stocks and accumulation rates at the study site combined with emissions factors (e.g. IPCC Wetlands Supplement, 2013) to estimate emissions' avoidance. However, the use of literature-derived stocks and accumulation rates and global or regional emissions factors may introduce substantial uncertainty as C_{org} stocks and GHG emissions can vary substantially across landscapes, seagrass ecosystems, and climatic gradients. Use of locally derived stocks, accumulation rates and emission factors (Tier 3) may help to overcome some of this uncertainty.

G. Defining the extent of the GHG assessment boundary would be complex for activities linked to the modification of hydrodynamic energy or water flow to habilitate seagrass revegetation. The ad-hoc (i.e. prior to activity) and post-hoc (i.e. after the activity) assessment of seagrass ecosystem extent would reduce uncertainties linked to estimates of GHG assessment boundaries prior to the activity.

H. Moderate alteration of water quality (e.g. increase in sediment run-off and nutrient load) could result in enhanced C_{org} sequestration, while excessive reduction of sediment and nutrient load could result in reduced C_{org} sequestration.

7.2 Provide a summary of approaches to calculate project activity emissions and removals. For any uncertainties around these approaches, outline what the uncertainties are, whether they are material and how could they be addressed.

Howard et al. (2014) and IPCC (2013) provide guidelines on how to estimate gains and/or avoided emissions in blue carbon ecosystems. The uncertainties involved in each of the approaches are listed, and are the same as described in Section 7.1. Modelling could be used in all approaches described below to improve the accuracy (i.e. reduce uncertainties) of estimates.

Approaches to calculate avoided emissions and enhanced sequestration are the same as for calculating baseline values (7.1). An exception to this is the depth of soil measurement to be undertaken in the project activity scenario. While the baseline soil C_{org} stock will be measured using a set depth of measurement (e.g. 1 m of soil profile), the SET method or radioisotopes can be used to determine the depth at which project measurements should be taken to assess gains (CO_2-C) or losses (CO_2-e) after the activity. For example, if SET measurements show that the surface elevation has grown

5 cm under the project, and then the soil C_{org} stock would be measured from 5 to 105 cm soil depth. The top 5 cm of soil accumulated will constitute additional sequestration of soil C_{org} (gain in C_{org} sequestration). Similarly, if the SET or radioisotope measurements show a decrease in surface elevation (i.e. erosion) under the project (e.g. elevation loss of 3 cm) then the soil C_{org} stock estimates will be reduced by the top 97 cm of soil as a result of soil erosion and lack of C_{org} accumulation.

The steps required for estimating project activity emissions and removals are described below:

Approach 1 *(Tier 3, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Collection of 1 m long soil cores throughout the study area and analyses of C_{org} concentration throughout the cores (e.g. at 0-5, 5-20, 20-50, 50-100 cm; in homogenised samples) prior to activity.

c. Deployment of SETs and MHs throughout the study area prior to activity.

d. Measurement of GHG fluxes prior to activity.

e. Estimate enhanced soil GHC sequestration (i.e. by preserving or enhancing C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, based on GHG sequestration rates measured at the study site (i.e. baseline estimates of soil accumulation and C_{org} accumulation and N_2O and CH_4 fluxes in top 5 cm of soil, and measurement of soil surface elevation (i.e. based on the SETs and MHs deployed throughout the study area) (e.g. after 5, 10, 15 and 20 years) and estimate avoided GHG emissions (i.e. by preserving pre-existing seagrass soil C_{org} stocks) based on existing peer-reviewed evidence linking GHG fluxes as a result of the activity at the study site (possible in a few number of cases only).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

Approach 2 *(Tier 1 or 2, accounting for CO_2, CH_4 and N_2O fluxes):*

a. Definition of GHG assessment boundaries and mapping of seagrass meadows prior to activity.

b. Estimate soil C_{org} stocks (e.g. at 0-5, 5-20, 20-50, 50-100 cm), C_{org} sequestration rates (e.g. surface soils) and GHG fluxes within the GHG assessment boundary based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

c. Estimate enhanced soil GHCs sequestration (i.e. by preserving C_{org} accumulation) after e.g. 5, 10, 15 and 20 years of conducting the activity, and estimate avoided GHG emissions (i.e. by preserving pre-existing seagrass soil C_{org} stocks) based on existing peer-reviewed literature for similar ecosystems (Tier 2) or global values (Tier 1).

Uncertainties: **A**, **C**, **D**, **E**, **F**, **G** and **H** listed in Section 7.1.

7.3 Provide a summary of approaches to calculate net GHG abatement. This should be the difference between the baseline and project activity emissions and removals.

The approaches to calculate net GHG abatement have been specified in section 7.2. There is a need to propagate uncertainties and specify a confidence required. It is suggested that emission avoidance and sequestration results be expressed as the magnitude associated with a defined probability of exceedance.

7.4 Provide a summary of approaches on data collection methods for the baseline emissions and removals and project activity emissions and removals.

The data collection methods have been briefly described in sections 7.1 and 7.2. Below there is a more comprehensive description of methods:

- Mapping of seagrass ecosystems can be performed by analyses of existing imagery, or based on existing peer-reviewed literature.
- Soil cores could be collected by means of manual percussion. The corers could consist of PVC pipes, 75 mm internal diameter. Soil compression (i.e. 'shortening') should be measured in the field to allow normalisation of soil C_{org} stocks and sequestration rates to a certain soil depth. In the laboratory, the core samples should be cut lengthwise, and the soil contained in the cores sliced at desired intervals. The soil samples should be homogenised and processed to estimate C_{org} concentrations. There are several methods to estimate C_{org} concentration in costal sediments, including loss on ignition, elemental analyser, mass spectrometer, infra-red spectroscopy, etc. (see Howard et al. 2014) for further details. Estimates of C_{org} content can differ between methods, and it is important to establish standard methods for ERF eligibility. Scaling of C_{org} estimates to a certain soil depth should be consistent too.
- Methods for the installation and monitoring of Surface Elevation Tables (SETs) (Webb et al. 2013) and installation and monitoring of Marker Horizons (MHs) (Cahoon and Turner 1989) are well known.
- Many of the methods outlined require consideration of temporal and spatial variability expected in C_{org} storage, accumulation and GHG emissions. SET and MH techniques provide high precision information on contemporary surface soil dynamics. While the baseline soil C_{org} stock will be estimated over a certain soil depth (e.g. 1 m of soil profile), the SET method can be used to determine the depth at which project measurements should be taken (see example in response 7.2). Radioisotope dating is likely to provide long-term records of soil accumulation rates, and may also be used to develop a baseline value of C_{org} stocks and longer-term accumulation rates (e.g. annual to millennial scales) using soil cores collected prior or after the commencement of the activity.

8. Double counting

8.4 Provide a summary of approaches on how to avoid the double counting of up-stream and down-stream C_{org} sources that are already being captured in inventory reporting (e.g. C_{org} that enters the blue carbon ecosystem through river system or catchment area).

Seagrass meadows are located in the interface between terrestrial and coastal ecosystems and, therefore, are likely to sequester C_{org} originating off-site (inland and/or offshore). Previous studies suggested that around 50% of soil C_{org} sequestered in seagrass meadows is seagrass-derived, while the other 50% is derived from algae, seston or terrestrial (mangrove, tidal marsh and riverine run-off) organic matter. However, spatial variability within the same meadow can be up to 3-fold (Serrano et al. 2016b) and the differentiation among autochthonous C_{org} (seagrass, benthic algae and epiphytic algae) and allochthonous C_{org} pools in seagrass soils can be difficult because the methods commonly used (i.e. stable C and N isotopes and mixing models) to determine their origin often lack sufficient discriminatory power (overlap of isotopic signatures of potential sources) and because of diagenetic effects (i.e. fractionation of isotopes) during accumulation and ageing, both of which could introduce large uncertainties when estimating the origin of C_{org} in seagrass soils.

If not exported and stored in seagrass soils, the fate of C_{org} originating from offsite sources (inland and/or offshore) is uncertain. On one hand, the C_{org} originated offshore and stored in seagrass soils is not accounted for elsewhere (no ERF schemes available to date). A plausible fate of C_{org} originating offshore is remineralisation (GHG emissions). Therefore, the likelihood of double accounting is nil. On the other hand, C_{org} originating inland and stored in seagrass soils may already have been accounted for elsewhere (ERF for terrestrial C_{org} and/or inclusion of mangrove and tidal marshes in ERF schemes). Indeed, if not sequestered by seagrasses, the plausible fate of C_{org} originating in terrestrial, mangrove and tidal marsh ecosystems is remineralisation (GHG emissions), and/or exported and buried in the coastal and/or deep ocean, and/or exported as dissolved C_{org} in oceanic waters (Duarte and Dorte-Kausen, 2016). However, the risk of double accounting is limited because offsite C_{org} stored in seagrass soils would originate from losses from forests, tidal marsh and mangroves rather than gains (enhanced sequestration) already accounted for.

In summary, double accounting of C_{org} originated inland (terrestrial, mangrove and tidal marsh ecosystems) it could be a remote possibility (i.e. resulting in addition rather than genuine sequestration). In order to avoid double accounting there are different options, ranging from conservative to non-conservative:

1. Estimate the proportion of autochthonous vs allochthonous C_{org} in seagrass soils based on direct measurements (e.g. C and N isotopic signatures of the C_{org}, genetic studies) or literature values. This method entails uncertainties related to Tier 1 or 2 estimates (described above);

2. Assume that all seagrass soil C_{org} is genuine sequestration (i.e. assuming that the inland-derived C_{org} would otherwise be remineralised and/or has not been accounted for in ERF schemes); or

3. Decide whether to follow approach 1 or 2 (above) based on existing projects in the catchment area affecting GHG assessment boundaries (depending on each case).

9. Permanence and Leakage

9.1 Provide an assessment of factors likely to influence permanence (over both 25 and 100 year periods) of the C_{org} stored as a result of the blue carbon ecosystem enhancement project activity. Outline likely leakages that may eventuate through long term events, environmental or otherwise.

The following factors may influence permanence of C_{org} stored and GHG fluxes:

- Natural disturbances such as cyclone or severe storms may cause damage and/or loss of seagrass biomass, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Dieback of seagrass biomass related to extreme temperature events may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Overgrazing related to natural or human induced factors such as climate change may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Extreme flooding events could impact seagrass ecosystems, either causing damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation, or siltation (i.e. over-sedimentation and accumulation of seagrass meadows) which could result in enhanced sequestration.

- Fishing activities (trawling, bait collection) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

- Some seagrass meadows are ephemeral and their distribution can vary seasonally or inter-annually. In particular, sub-tropical and tropical seagrass of the genera e.g. *Halophila*, *Zostera*, *Halodule* and *Thalassodendrum* form more dynamic and less stable meadows than temperate and sub-tropical seagrass of the genera e.g. *Posidonia* and *Amphibolis* and tropical species of the genus *Enhalus*. The GHG assessment boundaries of ephemeral meadows should be extended to include all potential area extent, and differences in seagrass ecosystem extent could be used to estimate enhanced sequestration and/or avoided emissions.

- Other activities (as listed in Part A of this report) may cause damage and/or loss of seagrass meadows, exposing soil C_{org} soils to erosion and subsequent remineralisation.

10. Monitoring and reporting

10.1 Outline the elements of the activity that will be monitored and reported and describe how monitoring and reporting approaches will be undertaken, including frequency of monitoring and standards of monitoring.

The following elements might be measured and reported in relation to this activity:

- Changes in soil C_{org} stocks over 1 m-thick deposits.

- Change in CO_2, CH_4 and N_2O fluxes.

- Gain in seagrass extent.

In general, monitoring every 5 years may be required. The following monitoring standards should be considered:

- Stratification is normally used to divide large heterogeneous sites (which require many samples to account for variation) into smaller more homogeneous areas (where fewer samples are needed) (Howard et al. 2014b).

- The number of sites and replication required for monitoring can be derived as a function of a coefficient of variation of the quantity being estimated (as is used in the Verified Carbon Standard) (Restore America's Estuaries and Silvestrum 2015b) in each stratum. Based upon evidence for tidal marshes and mangroves (Chmura et al. 2003), approximately 10-20 samples per stratum will likely be required. For measurement of CH_4 and N_2O) fluxes, about 40 samples (chambers) per stratum may be required (Restore America's Estuaries and Silvestrum 2015a).

11. Land ownership and legal right to C_{org}

11.1 Outline land access and ownership rights issues that may affect the person who intends to carry out the activity through the ERF.

Land or ocean access may be restricted in some areas, owing to marine protected areas, mining sites and/or aboriginal rights. Land occupied by intertidal meadows may be subjected to additional restriction, but the water occupied by sub-tidal meadows is Government property except in the Northern Territory.

All seagrass meadows are found below the mean high water mark (MHWM), and therefore the legal right to C_{org} may belong to the Government or Authorities managing coastal areas occupied by seagrasses. Land ownership and legal right of C_{org} for abatement activities influencing seagrass C_{org} storage would need to be explored in greater detail for an ERF method.

8 PART 3: RECOMMENDATIONS FOR POTENTIAL METHOD DEVELOPMENT

In the final section of the report recommendations on activities that could be included in the development of a blue carbon ERF method are provided and potential barriers and/or constraints are identified for each activity. The ordering of these recommendations reflects the organisational approach taken in the report and does not imply any prioritisation or assessment of readiness for ERF method development. It is important to recognise that the work included in this report and the recommendations have been developed considering the policy context as at 2016/17. Policy shifts at Federal or State level may influence the appropriateness of the recommendations for development of a potential ERF Method. In addition to using research outcomes to underpin potential method development, ERF method development must also consider social, economic and environmental impacts.

8.1 Recommended activities for Mangroves

On the basis of the assessments undertaken in this report it is recommended that the following activities be considered high priorities for method development relating to mangroves. These recommendations (and the data presented therein) are based upon the assumptions and caveats which are discussed in the main body of this report.

8.1.1 Introduction of tidal flow

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity - Introduction of tidal flow has the potential to sequester carbon through new growth of mangrove biomass and accumulation of addition soil carbon, plus reductions in greenhouse gas fluxes from sites which are currently drained or ponded with freshwater. On the basis of national mangrove carbon stock data and IPCC Wetland Supplement emissions factors the potential abatement intensity has been estimated at 15.4 Mg C ha^{-1} (range = 1.7-63.7 Mg C ha^{-1}) for introduction of tides to drained, treeless areas resulting in mangrove development, and 12.9 Mg C ha^{-1} (range = 0.8-170.7 Mg C ha^{-1}) for introduction of saline water to ponded freshwaters resulting in the development of a mangroves.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. The Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration is a globally applicable method which can be used to guide the development of a methodology for this activity along with ERF Vegetation management and Soil carbon methods.

3. Potential for uptake – This activity may encompass a broad range of settings and scenarios, including tidal restoration to areas that have previously been degraded and/or works that have created new habitat through tidal connection. Although data on the potential area suitable for this activity are limited at the national level, there are sufficient state-based data and case studies to suggest that this area is likely to be extensive. In some cases, a small amount of effort (e.g. minor earthworks to open

an artificial floodplain levee) may be sufficient to achieve a large sequestration of carbon and avoided emission.

4. Multiple co-benefits – This activity may complement efforts to initiate tidal restoration works for other purposes, such as fisheries habitat and biodiversity enhancements, agricultural and acid sulphate soil management. These co-benefits may result in a higher level of uptake of than would be possible based solely on carbon based activities.

Application to other ecosystems

This activity may also be applicable to tidal marshes and seagrasses. However, aboveground biomass carbon pools of tidal marsh and seagrass should be excluded due to their smaller size, variable annual production and rapid turnover relative to the woody biomass of mangroves.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. Limited information on atmospheric fluxes that may occur under baseline and activity conditions for Australian mangroves. This is particularly the case for N_2O emissions and CH_4 emissions from the baseline condition and which may result from rewetting of mangroves through reconnection to tidal flow.

Legislative constraints:

2. In some circumstances there may be legislative controls which constrain implementation. These may include controls regarding water management structures and water sharing, vegetation and habitat protection (e.g. for threatened species which inhabit freshwater or brackish water ecosystems).

Practical constraints:

3. Potential for third-party impacts, particularly in terms of flooding and salinity intrusion to neighbouring or nearby properties

4. Community resistance to restoration projects due to real or perceived threat of mosquito (and other nuisance fauna) colonisation.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Development of a specific methodology as this activity is not aligned with any existing methodologies

B. Review whether to include tidal marsh and seagrass ecosystems within a methodology or whether separate methodologies may be required for each type of blue carbon ecosystem.

8.1.2 Avoided clearing and avoided soil disturbance

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity – Avoided clearing of mangrove biomass and avoided disturbance to mangrove soils may result in substantial avoided emissions. On the basis of national mangrove carbon stock data it is estimated that a one-off emission avoidance of 124.83 Mg C ha^{-1} may be achieved where clearing of mangrove aboveground biomass is avoided. Where both aboveground biomass plus soil disturbance is avoided, then this one-off avoided emission estimate increases to 250.57 Mg C ha^{-1} (assuming 50% of soil C to 1 m depth returns to the atmosphere as a result of disturbance). In addition, avoided biomass clearing and avoided soil disturbance will allow the mangrove ecosystem to continue to accumulate soil carbon (sequestration), estimated at 1.26 Mg C ha^{-1} yr^{-1} on the basis of national data.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or to make use of IPCC Wetland Supplement (Tier 1) emission factors. While not specifically applicable to this activity, the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration may be used for guidance in the development of a methodology for this activity. While not specific to coastal ecosystems, the VCS VM0009 Methodology for Avoided Ecosystem Conversion and the ERF vegetation management methods may also be used to guide development of portions of a methodology developed for this activity.

3. Multiple co-benefits – This activity may complement other climate change mitigation efforts and/or habitat and biodiversity protection initiatives.

Application to other ecosystems

Avoided soil disturbance may also be applicable to tidal marshes and seagrasses. Avoided biomass removal might be excluded due to their smaller size, variable annual production and rapid turnover relative to the woody biomass of mangroves.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. Limited information on atmospheric flux that may occur under baseline conditions (mangrove clearing) for Australian mangrove ecosystems.

Practical constraints:

2. Potential for uptake may be limited. There are legislative controls in place in all jurisdictions which regulate the removal of mangrove biomass and disturbance to mangrove soils. The likelihood of there being historic clearing consents which have not been acted upon may therefore be quite low.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Review potential for uptake – i.e. determine whether approvals have been granted to clear sufficient areas of mangroves to warrant method development.

B. Assess the potential for expanding the existing *Avoided deforestation* ERF methodology to include mangrove ecosystems. For soil disturbance a separate methodology may be required.

C. Dependant on (A and B), development a methodology which combines avoided biomass removal and avoided soil disturbance.

D. Review whether to include tidal marshes and seagrasses within a methodology or whether separate methodologies may be required for each ecosystem. Avoided biomass removal may not be relevant to tidal marsh and seagrass ecosystems.

8.1.3 Land-use planning for sea level rise

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity – Altering land-use for the purpose of allowing mangrove forest to migrate under sea level rise has the potential to enable substantial carbon removals through new growth of mangrove biomass carbon pools and mangrove soil carbon pools. Depending on existing land-use, reductions in greenhouse gas fluxes may also occur. On the basis of national mangrove carbon stock data, the potential abatement intensity has been estimated at 7.5 Mg C ha^{-1} (range = 0.5-19.7 Mg C ha^{-1}). No estimate has been made for atmospheric fluxes as these are likely to vary according to current land-uses.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. While not specifically applicable to this activity, the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration may be used for guidance in the development of a methodology for this activity.

3. Potential for uptake – This activity may encompass a broad geographic area and existing land-use types. An upper limit estimate based upon supratidal acid sulphate soil distributions suggests future areas of intertidal habitat (inclusive of mangrove and tidal marsh) may include up to 16,348 km^2. Although this may be an overestimate, it points to the extensive area that may be available for mangrove migration under this activity.

4. Multiple co-benefits – This activity may complement other climate change mitigation efforts and/or habitat creation works for other purposes, such as fisheries habitat and biodiversity enhancements. These co-benefits may result in a higher level of uptake of these activities.

Application to other ecosystems

This activity may also be applicable to tidal marshes and seagrasses. Aboveground biomass carbon pools of tidal marsh and seagrass might be excluded due to their smaller size, variable annual production and rapid turnover relative to the woody biomass of mangroves.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. This activity requires an ability to predict future sea level rise and ecosystem response. The adequacy and spatial coverage of such information may present a significant constraint to this activity, although modelling is available for some sites.

2. Limited information on atmospheric flux that may occur under baseline and activity conditions for Australian mangrove ecosystems, particularly for N_2O and CH_4.

Legislative constraints:

3. There may be legislative controls which constrain implementation. These may include requirement to change multiple planning instruments (such as local environmental plans, regional environmental plans, etc.).

4. Social and/or political opposition to legislating changes to existing land-use planning instruments.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Review current capacity and adequacy to predict future sea level rise and carbon storage response of mangrove and tidal marshes

B. Development of specific methodology as this activity is not aligned with any existing methodologies

C. Review whether to include tidal marsh and seagrass ecosystems within a methodology or whether separate methodologies may be required for each ecosystem type.

8.2 Recommended activities for Tidal Marshes

On the basis of the assessments undertaken in this report it is recommended that the following activities be considered high priorities for method development relating to tidal marshes.

8.2.1 Introduction of tidal flow

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity - Introduction of tidal flow has the potential to enable substantial carbon sequestration in tidal marsh soils, plus reductions in greenhouse gas fluxes from sites which are currently drained or ponded with freshwater. On the basis of national tidal marsh carbon stock data and IPCC Wetland Supplement emissions factors the potential abatement intensity has been estimated at 8.3 Mg C ha^{-1} (range = 1.2-46.1 Mg C ha^{-1}) for introduction of tides to drained, treeless areas resulting in tidal marsh development, and 5.8 Mg C ha^{-1} (range = 0.3-153.2 Mg C ha^{-1}) for introduction of saline water to ponded freshwaters which results in the development of a tidal marsh.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. The Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass

Restoration is a globally applicable method which can be used to guide the development of a methodology for this activity.

3. Potential for uptake – This activity may encompass a broad range of settings and scenarios, including tidal restoration to areas which have previously been degraded and/or works which create new habitat through tidal connection. Although data on the potential area suitable for this activity are limited at the national level, there is sufficient information from state-based data and case studies to suggest that this area is likely to be extensive. In some cases, a small amount of effort (e.g. minor earthworks to open an artificial floodplain levee) may be sufficient to achieve large carbon removals or avoided emissions.

4. Multiple co-benefits – This activity may complement efforts to initiate tidal restoration works for other purposes, such as fisheries habitat and biodiversity enhancements, agricultural and acid sulphate soil management. These co-benefits may result in a higher level of uptake of these activities.

Application to other ecosystems

This activity may also be applicable to mangrove and seagrass ecosystems. However, aboveground biomass carbon pools of mangroves might be included due to their large size and longer-term storage potential of woody biomass. At present there are no IPCC Tier 1 estimates of carbon losses from drained soils applicable to seagrass meadows.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. Limited information on atmospheric flux that may occur under baseline and activity conditions for Australian tidal marsh ecosystems. This is particularly the case for N_2O emissions and CH_4 emissions that occur under the baseline and which may result from rewetting of tidal marshes through reconnection of hydrology.

Legislative constraints:

2. In some circumstances there may be legislative controls which constrain implementation. These may include controls regarding water management structures and water sharing, vegetation and habitat protection (e.g. for threatened species which inhabit freshwater or brackish water ecosystems).

Practical constraints:

3. Potential for third-party impacts, particularly in terms of flooding and salinity intrusion to neighbouring or nearby properties

Steps to implementation

In order to implement this activity, the following steps are required:

A. Development of a specific methodology as this activity is not aligned with any existing methodologies
B. Review whether to include mangrove and seagrass ecosystems within a methodology or whether separate methodologies may be required for each.

8.2.2 Avoided soil disturbance

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity – Avoided disturbance of tidal marsh soils may result in substantial avoided emissions. On the basis of national tidal marsh carbon stock data it is estimated that a one-off emission avoidance of 83.95 Mg C ha^{-1} may be achieved where soil disturbance is avoided (assuming 50% of soil C to 1 m depth returns to the atmosphere as a result of disturbance). In addition, avoided soil disturbance will allow the tidal marsh ecosystem to continue to accumulate soil carbon (sequestration), estimated at 0.39 Mg C ha^{-1} yr^{-1} on the basis of national data.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. While not specifically applicable to this activity, the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration may be used for guidance in the development of a methodology for this activity. While not specific to coastal ecosystems, the VCS VM0009 Methodology for Avoided Ecosystem Conversion and the ERF soil carbon methods may also be used to guide development of methodology for this activity.

3. Multiple co-benefits – This activity may complement other climate change mitigation efforts and/or habitat and biodiversity protection initiatives.

Application to other ecosystems

Avoided soil disturbance may also be applicable to mangrove and seagrass ecosystems. For mangroves avoided biomass removal might be included due to the larger size and slow turnover of woody biomass of mangroves.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. Limited information on atmospheric flux that may occur under baseline conditions (soil disturbance) for Australian tidal marsh ecosystems.

Practical constraints:

2. Potential for uptake may be limited. There are legislative controls in place in all jurisdictions which regulate the disturbance of tidal marsh soils. The likelihood of there being historic clearing consents which have not been acted upon may therefore be quite low.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Review potential for uptake – i.e. determine whether sufficient avoided disturbance has been already approved to warrant method development.

B. Development of specific methodology as this activity is not aligned with any existing methodologies

C. Review whether to include mangrove and seagrass ecosystems within a methodology or whether separate methodologies may be required for each ecosystem. Avoided biomass removal may only be relevant to mangrove ecosystems.

8.2.3 Land-use planning for sea level rise

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. Moderate carbon abatement intensity – Altering land-use for the purpose of allowing tidal marsh to migrate under sea level rise has the potential to enable substantial carbon removals through new growth of tidal marsh soil carbon pools. Depending on existing land-use, reductions in greenhouse gas fluxes may also occur. On the basis of national tidal marsh carbon stock data the potential abatement intensity has been estimated at 0.39 Mg C ha^{-1} (range = 0.03-2.21 Mg C ha^{-1}). No estimate has been made for atmospheric fluxes as these are likely to vary according to current land-uses. These may be additional to the estimate of abatement intensity above.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be directly measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. While not specifically applicable to this activity, the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration and the ERF soil carbon methods may be used for guidance in the development of a methodology for this activity.

3. Potential for uptake – This activity may encompass a broad geographic area and existing land-use types. An upper limit estimate based upon supratidal acid sulphate soil distributions suggests future areas of intertidal habitat (inclusive of mangrove and tidal marsh) may include up to 16,348 km^2. Although this may be an overestimate, it points to the extensive area that may be available for mangrove migration under this activity.

4. Multiple co-benefits – This activity may complement other climate change mitigation efforts and/or habitat creation works for other purposes, such as fisheries habitat and biodiversity enhancements. These co-benefits may result in a higher level of uptake of these activities.

Application to other ecosystems

This activity may also be applicable to mangrove and seagrass ecosystems. Aboveground biomass carbon pools of seagrass might also be excluded. For mangroves, aboveground biomass carbon pools could be included due to their larger size and slow turnover of woody biomass.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints:

1. This activity requires an ability to predict future sea level rise and ecosystem response. The adequacy and spatial coverage of such information may present a significant constraint to this activity, although models are available for some sites.

2. Limited information on atmospheric flux that may occur under baseline and activity conditions for Australian tidal marsh ecosystems, particularly for N_2O and CH_4.

Legislative constraints:

3. There may be legislative controls which constrain implementation. These may include requirement to change multiple planning instruments (such as local environmental plans, regional environmental plans, etc.).

4. Social and/or political opposition to legislating changes to existing land-use planning instruments.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Review current capacity and adequacy to predict future sea level rise and ecosystem response.

B. Development of specific methodology as this activity is not aligned with any existing methodologies

C. Review whether to include mangrove and seagrass ecosystems within a methodology or whether separate methodologies may be required for each ecosystem type.

8.3 Recommended activities for Seagrasses

On the basis of the assessments undertaken in this report it is recommended that the following activities be considered high priorities for method development relating to seagrasses.

8.3.1 Avoidance of seagrass ecosystem loss, re-establishment and/or creation of seagrass ecosystem through water quality management and revegetation

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity – management activities to promote avoidance of seagrass ecosystem loss, re-establishment of seagrass ecosystem or creation of new seagrass ecosystem through the management to improve water quality (i.e. reducing sediment, nutrient and pollutant loading), direct revegetation (transplanting, seedling) and/or passive revegetation (in situ and/or offsite activities such as modification of tidal flow or hydrodynamic energy) have the potential to avoid substantial GHG emissions through the preservation of soil C_{org} stocks and sequestration rates. Poor management of catchment area and *in situ* activities, such as dredging, result in the deterioration of water quality, constituting the main threat to seagrass ecosystems in Australia and causing the loss of large areas of seagrass ecosystems. For avoidance of seagrass loss and on the basis of national seagrass carbon stock data, a one-off emission avoidance of 28-84 Mg C ha^{-1} may be achieved where soil disturbance is avoided (assuming 25-75% of soil C to 1 m depth returns to the atmosphere as a result of disturbance). In addition, avoided soil disturbance will allow the seagrass ecosystem to continue to accumulate soil carbon (sequestration), estimated at 0.36 Mg C ha^{-1} yr^{-1} on the basis of national data. For seagrass creation there is unlikely to be an avoided emission, but new seagrass ecosystem will accumulate soil carbon (sequestration), estimated at 0.36 Mg C ha^{-1} yr^{-1}.

2. Existing information base - There exist measurement techniques by which baseline and avoided emissions could be measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. The Verified Carbon

Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration is globally applicable method, which can be used to guide the development of a methodology for this activity.

3. Potential for uptake – this activity may encompass a broad range of settings and scenarios, including catchment restoration to areas which have previously been degraded or have the potential to be colonised by seagrasses, and/or management activities to improve water quality to promote seagrass growth. Although data on the potential area suitable for this activity are limited at the national level, there are sufficient state-based data and case studies to suggest that this area is likely to be extensive.

4. Multiple co-benefits – this activity may complement efforts to initiate seagrass restoration works and promote seagrass conservation for other purposes, such as fisheries habitat and biodiversity enhancements. These co-benefits may result in a higher level of uptake of these activities.

Application to other ecosystems

This activity may also be applicable to tidal marsh and mangrove forest ecosystems. However, tidal marshes and mangroves are less impacted by poor water quality. Therefore, direct revegetation (transplanting, seedling) and/or passive revegetation (in situ and/or offsite activities such as modification of tidal flow or hydrodynamic energy) have higher potential to enhance and/or avoid GHG emissions in tidal marsh and mangrove forest ecosystems.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints: limited information on GHG fluxes that may occur under baseline and activity conditions for Australian seagrass ecosystems. This is particularly the case for N_2O emissions and CH_4 emissions that may result from re-establishment of seagrass ecosystem or creation of new seagrass ecosystem.

Legislative constraints: land ownership and legal right of C_{org} for abatement activities influencing will need to be considered.

Practical constraints: difficulty to link offsite activities to direct effect on GHG emissions (i.e. enhanced sequestration and/or avoided emissions); difficulty to determine the extent of area affected by the activity.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Development of a specific methodology as this activity is not aligned with any existing methodologies.

B. Review whether to include tidal marsh and mangrove forest ecosystems within a methodology or whether separate methodologies may be required for each ecosystem type.

8.3.2 Avoidance of seagrass ecosystem loss through direct physical disturbance

Rationale for recommendation

This activity is recommended on the basis of the following factors:

1. High carbon abatement intensity – Avoided clearing of seagrass biomass and associated avoided disturbance to seagrass soils can result in substantial avoided GHG emissions. Poor management of

e.g. dredging, construction of coastal infrastructure and boating activities constitutes one of the main threats to seagrass ecosystems in Australia, causing the loss of large areas of seagrass ecosystems. On the basis of national seagrass carbon stock data a one-off emission avoidance of 28-84 Mg C ha^{-1} may be achieved where soil disturbance is avoided (assuming 25-75% of soil C to 1 m depth returns to the atmosphere as a result of disturbance). In addition, avoided soil disturbance will allow the seagrass ecosystem to continue to accumulate soil carbon (sequestration), estimated at 0.36 Mg C ha^{-1} yr^{-1} on the basis of national data.

2. Existing information base - There are existing measurement techniques by which baseline and abatement removals and emissions could be measured. Further there is potential for baseline and abatement values to be modelled and/or make use of IPCC Wetland Supplement (Tier 1) emission factors. While not specifically applicable to this activity, the Verified Carbon Standard VM0033 Methodology for Tidal Wetland and Seagrass Restoration may be used for guidance in the development of a methodology for this activity. While not specific to coastal ecosystems, the VCS VM0009 Methodology for Avoided Ecosystem Conversion may also be used to guide development of methodology for this activity.

3. Potential for uptake – this activity may encompass a broad range of settings and scenarios, including large areas in WA, NT and QLD. Although data on the potential area suitable for this activity are limited at the national level, there is sufficient information from state-based data and case studies to suggest that this area is likely to be extensive.

4. Multiple co-benefits – This activity may complement other climate change mitigation efforts and/or habitat and biodiversity protection initiatives.

Application to other ecosystems

Avoided soil disturbance may also be applicable to tidal marsh and mangrove forest ecosystems. Avoided biomass removal may be relevant to mangroves.

Barriers to implementation

Barriers and constraints to implementation of this activity may include:

Information constraints: limited information on GHG fluxes that may occur under baseline and activity conditions for Australian seagrass ecosystems. This is particularly the case for N_2O emissions and CH_4 emissions that may result from disturbance of seagrass soils.

Legislative constraints: land ownership and legal right of C_{org} for abatement activities will need to be considered.

Practical constraints: Estimating sediment and carbon accumulation using SET or MH techniques.

Steps to implementation

In order to implement this activity, the following steps are required:

A. Review potential for uptake – i.e. determine whether sufficient avoided disturbance has been already approved to warrant method development.

B. Development of specific methodology as this activity is not aligned with any existing methodologies

C. Review whether to include tidal marsh and mangrove forest ecosystems within a methodology or whether separate methodologies may be required for each ecosystem type.

8.4 Allochthonous v autochthonous

8.4.1 Autochthonous and allochthonous sources of carbon and consistency with national accounting

The organic carbon (C_{org}) accumulated in mangroves, tidal marshes and seagrasses can exist in vegetative biomass and soils. Sequestration of carbon in vegetation is considered for mangroves due to the presence of significant measureable quantities of long lived woody biomass. For the soils of these ecosystems, the accumulation of C_{org} can be derived from autochthonous sources (C_{org} derived from CO_2 captured within the ecosystem) or allochthonous sources (C_{org} derived from CO_2 captured outside the ecosystem and transported into the ecosystem). Quantification of genuine rates of sequestration (trapping and retention of atmospheric CO_2-C as C_{org}) offered by these ecosystems requires exclusion of C_{org} derived from allochthonous sources. Thus in addition to measuring temporal changes in soil C_{org} stocks, an ability to differentiate the source of the C_{org} present in the soils is required to quantify the magnitude of sequestration of carbon derived from the defined ecosystem.

Attempts to differentiate the origin of C_{org} within the soils of blue carbon ecosystems have used differences in the $\delta^{13}C$ signature of C_3 and C_4 plants and other potential sources of C_{org} (e.g. algae, seston). For nine NSW estuaries, Kelleway et al. (2016b) obtained data suggesting that allochthonous inputs of C_{org} were more significant in tidal marshes where succulent and grass vegetation dominated compared to those dominated by rush vegetation. For the mangrove and tidal marsh systems examined by Saintilan et al. (2013), $\delta^{13}C$ values and other data were interpreted to indicate that allochthonous inputs of C_{org} were not stable and that autochthonous inputs from mangrove roots was the form of C_{org} that accumulated over time. Using $\delta^{13}C$ values acquired for a range of mangrove soils, Kristensen et al. (2008) suggested that mangrove litter was an important contributor to soil C_{org} in 58% of the soils. Contributions of allochthonous sources of C_{org} to seagrass soils acquired for a range of seagrass soils have been estimated at a mean of 49% (25th and 75th percentiles of 38% and 67%, respectively) (Kennedy et al. 2010), and ranging from 40 to 90% across a range of Australian locations showing variable seagrass canopy complexity (Samper-Villarreal et al. 2016).

A range of factors can make it difficult to obtain accurate quantitative estimates of the relative contributions of autochthonous and allochthonous sources of carbon including:

- temporal and spatial variability in the range of $\delta^{13}C$ values associated with different potential sources of carbon input,
- overlap in the range of $\delta^{13}C$ values associated with different potential sources of C_{org}, thereby lacking sufficient discriminatory power,
- variability in habitat and the ability to capture allochthonous sources of carbon,
- relative rates of input and degradability of allochthonous and autochthonous material, and
- potential changes may that can occur during diagenesis

However, through a review of published $\delta^{13}C$ data and the inclusion of other data sources (e.g. biomarkers, mid-infrared spectroscopy, nuclear magnetic resonance spectroscopy, etc.), values of autochthonous carbon sequestration rates within an ecosystem may be derived which could provide conservative estimates of autochthonous carbon sequestration rates within an ecosystem (as recommended in the VCS VM0033 methodology). It is recommended that a review complimented by new data collection and modelling be undertaken to derive appropriate Australian values as a component associated with the development of any potential ERF method for C_{org} sequestration in coastal blue carbon ecosystems. Focal points of new data collection should be settings that are currently under-represented in national datasets, including tidal marshes (including saltflats) outside of SE Australia and temperate seagrasses other than *Posidonia australis* meadows. Further support for taking such an approach to estimate the autochthonous component of C_{org} stock change would be the reduction in measurement costs that ERF projects would incur relative to a situation where they were required to derive project specific estimates by measurement.

An additional item for consideration is related to the requirement that carbon sequestration and emission avoidance methods developed within the ERF are consistent with approaches within the Australian National Invenrtory Report (NIR). Currently the modelling framework used within the NIR assumes that all C_{org} exiting the soil component of terrestrial systems is lost to the atmosphere as CO_2.

Undoubtedly, some soil C_{org} is lost via erosion of soil particles and leaching of dissolved components into water ways and potentially to coastal ecosystems and open oceans. As a result, the current NIR approach used to account for soil C_{org} is conservative in that it potentially over estimates net carbon emissions to the atmosphere. Any terrestrially derived soil C_{org} captured and retained within blue carbon coastal ecosystems (i.e. terrestrially derived allochthonous C_{org}) could be viewed as an avoided emission, but doing so would reduce the conservative nature of current terrestrial soil C_{org} stock change estimates.

Allochthonous C_{org} entering blue carbon coastal ecosystems can also be derived from the marine environment. For example, carbon derived from phytoplankton production can be trapped and incorporated into seagrass, mangrove and tidal marsh sediments. Seagrass meadows also trap large amounts of macroalgae dislodged from adjacent reef ecosystems (Wernberg et al. 2006).

The important question to answer in considering allochthonous C_{org} is "Would the allochthonous C_{org} have been remineralised if it was not captured and retained within the blue carbon ecosystem in response to an applied activity (i.e. against the business as usual case)". Where the answer is yes, then capturing and retaining allochthonous C_{org} could be viewed as an avoided emission. It is recommended that further consideration and development of these concepts is required for each activity included in apotential ERF blue carbon method.

Irrespective of whether an ERF blue carbon method would require differentiation between autochthonous and allochthonous C_{org}, an ability to differentiate the relative contributions would be useful. Understanding the magnitude of allochthonous C_{org} capture and retention will provide:

- improved data to advance our understanding of carbon processing in blue carbon environments
- an indication of how conservative NIR accounting is through definition of the fraction of terrestrial C thought to be emitted to atmosphere but in reality retained in blue carbon environments.

8.4.2 Review greenhouse gas emissions from land-uses that could be restored to blue carbon ecosystems

It was not possible to derive full estimates of potential abatement intensity for many of the activities assessed in Section B. Consequently, a number of activities were not recommended as being of 'high priority' on the basis of insufficient information availability. A common cause of this was a lack of data on greenhouse gas emissions from existing land-uses (Appendix A; Appendix B). For natural ecosystem conditions and some altered land-uses (such as wetlands that have been drained) it was possible to use IPCC Wetland Supplement emission factors, though these data may not be applicable in all circumstances. For some land-uses there may be existing data or an opportunity to collate new data which will 1) improve estimates of carbon abatement intensity; and 2) provide the information necessary to recommend other blue carbon activities for future ERF method development.

8.5 Soil sampling depth

A requirement of the development of ERF methods is that carbon abatement must be able to be used to meet Australia's climate change targets and as such be reflected in the National Inventory Report. The IPCC Wetlands Supplement (2013) recommends that the soils in blue carbon ecosystems be sampled to a depth of 1 m. The planned approach within the Australian inventory for blue carbon ecosystems is to follow this recommendation and it is likely that the inventory will use a constant depth through time, that is, continue to monitor the surface 1 m of soil (De Kluyver pers. comm.). This is consistent with what is done in terrestrial agricultural soils with the exception that the depth of soil used in the inventory for terrestrial agricultural soils is 0.30 m.

8.5.1 Approach used for terrestrial agricultural soils

In carbon accounting projects (e.g. ERF projects), it is critical that methods take into account changes in soil bulk density due to spatial variation, applied management practices and swelling and shrinking due to changes in soil water content present at the time soil samples are collected. In the terrestrial ERF grazing systems soils method, this is handled by calculating the 0-0.3 m equivalent soil mass based on the soil conditions present during the baseline sampling (see the "Sequestering carbon in soils in grazing systems" on https://www.environment.gov.au/climate-change/emissions-reduction-fund/methods for details). Using this equivalent soil mass and the carbon contents determined for the collected samples, an equivalent soil mass organic carbon stock is calculated.

At subsequent temporal soil sampling events throughout the duration of an ERF project, equivalent soil mass carbon stocks are calculated using the equivalent soil mass derived in the baseline sampling round. This is required to compensate for any changes in bulk density that may have occurred as a result of the applied management practices, spatial variations in bulk density and variations in bulk density for soils that swell and shrink in response to changing water content. At this point, if there has been a change in bulk density, the actual depth of soil included in the derivation of soil carbon stock values will no longer be equivalent to 0.30 m. For example, if bulk density has increased, the equivalent mass of soil may correspond to a depth of 0.28 m or if the bulk density has decreased the equivalent soil mass may correspond to a depth of 0.32 m.

The current terrestrial agricultural soil carbon method does not account for neither the loss of existing soil (erosion) nor the gain of new soil (deposition) relative to that present at the baseline sampling. It is possible to calculate these losses and additions using stocks of caesium, lead or plutonium isotopes; however, additional analyses, and therefore expense, would be required.

8.5.2 Approach proposed for blue carbon ecosystems

In blue carbon ecosystems, changes in bulk density through time (induced by applied management activities), spatially (inherent variability) and as a function of soil water content at sampling can all occur just as described for terrestrial agricultural soils. Consideration was given to application of the equivalent mass calculations described in section 8.5.1 for terrestrial soils. It was concluded that the use of the equivalent mass approach was not applicable to blue carbon ecosystems. This lack of applicability results from the potentially very high content of organic matter within the soils of these ecosystems. The concept of equivalent mass works for terrestrial agricultural soils because carbon contents are typically low (<5%), the mass of the soil is dominated by the mass of the minerals, and the mass of the minerals present does not change over time if erosion and deposition are excluded. In blue carbon ecosystems, the mass of soil in a given depth layer can be dominated by the mass of organic materials which can change over time due to decomposition processes. Thus, it is not possible to use the mass of the soil present at the baseline sampling event as a reference point for future sampling rounds.

In addition, the soil of blue carbon ecosystems can be exposed to losses (erosion) and gains (deposition) of soil material carrying organic carbon over time. Indeed, a significant component of the potential carbon sequestration offered by blue carbon ecosystems relates to the temporal accumulation of new soil material and its associated soil carbon. Under such a scenario, neither the equivalent soil mass approach nor the use of stocks of caesium, lead or plutonium isotopes can provide the data required to account for additions or losses.

In this report we have proposed the use of surface elevation tables (SETs) to provide a reference point for sampling the 0-1 m soil layer. This reference point would be set at the time of the baseline sampling round. At subsequent sampling times, the depth of sampling would be defined using the change in surface elevation obtained from SETs. For example, if project specific SET measurements show that the surface elevation has increased by 5cm under the project, then the soil organic carbon stock would be measured to a depth of 1.05 m from the new surface. Similarly, if the SET measurements show a decrease in surface elevation under the project (e.g. elevation loss of 3 cm) then the soil organic carbon stocks would be measured to a depth of 0.97 m from the new surface. This approach will effectively handle variations in bulk density and accumulations (deposition) or losses (erosion) of soil organic carbon associated with temporal fluxes of soil material.

8.5.3 Summary/recommendation

It is recommended that surface elevation tables (SETs) be installed at the time of baseline sampling to provide an elevation reference point for sampling the 0-1 m soil layer. At subsequent sampling times, the depth of sampling should be defined using the change in surface elevation obtained from SETs to account for the temporal loss or addition of soil material.

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APPENDIX 1 – POTENTIAL MANGROVE & TIDAL MARSH ABATEMENT INTENSITY FOR ACTIVITIES ASSESSED

First pass assessment of potential carbon abatement intensity associated with activities in mangroves and tidal marshes. Data are subject to the assumptions, caveats and methods detailed in the main report and should not be quoted or considered in isolation.

CARBON POOL / EMISSION				BASELINE VALUES		POTENTIAL ACTIVITY REMOVALS RATES AND AVOIDED EMISSIONS										
		Habitat		Stock	Accumulation or emission rate	ACTIVITY 1A - Tidal introduction to drained, treeless community	ACTIVITY 1B - Introduction of saline water to ponded freshwater	ACTIVITY 2 - Enhancing sediment supply	ACTIVITY 3A - Land-use change: existing areas	ACTIVITY 3B - Land-use change: planning for SLR	ACTIVITY 4A - Avoided clearing (biomass only)	ACTIVITY 4 - Avoided clearing (biomass + soil)	ACTIVITY 5A - Direct manipulation of mangrove species composition	ACTIVITY 5B - Enabling mangrove encroachment of tidal marsh	ACTIVITY 6A - Offsite management of nutrients	ACTIVITY 6B - Offsite management of salinity
				Mg C ha^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} (one-off)	Mg ha^{-1} yr^{-1} for soil removals; Mg ha^{-1} (one-off) for avoided emissions	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}
REMOVALS (CSIRO Coastal Carbon Cluster data unless otherwise specified)	Biomass[a]	Mangrove	Mean	124.83	6.24	6.24	6.24	N/A	No data available - Likely to vary according to land-use types	6.24	N/A	N/A	No data available	N/A	No data available	No data availabl e
			Min.	7.10	0.36	0.36	0.36			0.36						
			Max.	328.00	16.40	16.40	16.40			16.40						
			95% CI lower	95.77	4.79	4.79	4.79			4.79						
			95% CI upper	153.90	7.70	7.70	7.70			7.70						
		Tidal marsh	Mean	3.22	0.16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	*0.41 [k]*	N/A	N/A
			Min.	0.64	0.03									*0.23*		
			Max.	6.35	0.32									*0.58*		
			95% CI lower	1.46	0.07									*0.23*		
			95% CI upper	4.97	0.25									*0.58*		
	Soil (1m)	Mangrove	Mean	251.47	1.26	1.26	1.26	1.26 f	No data available - Likely to vary according	1.26	N/A	1.26	No data available	N/A	No data available	No data availabl e
			Min.	26.66	0.17	0.17	0.17	0.17		0.17		0.17				
			Max.	997.05	3.36	3.36	3.36	3.36		3.36		3.36				
			95% CI lower	232.66	0.90	0.90	0.90	0.90		0.90		0.90				

		Habitat		Stock	Accumulation or emission rate	ACTIVITY 1A - Tidal introduction to drained, treeless community	ACTIVITY 1B - Introduction of saline water to ponded freshwater	ACTIVITY 2 - Enhancing sediment supply	ACTIVITY 3A - Land-use change: existing areas	ACTIVITY 3B - Land-use change: planning for SLR	ACTIVITY 4A - Avoided clearing (biomass only)	ACTIVITY 4 - Avoided clearing (biomass + soil)	ACTIVITY 5A - Direct manipulation of mangrove species composition	ACTIVITY 5B - Enabling mangrove encroachment of tidal marsh	ACTIVITY 6A - Offsite management of nutrients	ACTIVITY 6B - Offsite management of salinity
			95% CI upper	270.28	1.62	1.62	1.62	1.62	to land-use types	1.62		1.62				
		Tidal marsh	Mean	167.90	0.39	0.39	0.39	0.39 [f]	No data available - Likely to vary according to land-use types	0.39	N/A	0.39	N/A	*2.30* [l]	No data available	No data available
			Min.	13.93	0.03	0.03	0.03	0.03		0.03		0.03		*2.30*		
			Max.	962.68	2.21	2.21	2.21	2.21		2.21		2.21		*2.30*		
			95% CI lower	153.37	0.35	0.35	0.35	0.35		0.35		0.35		*0.83*		
			95% CI upper	182.43	0.42	0.42	0.42	0.42		0.42		0.42		*3.77*		
AVOIDED EMISSIONS (IPCC Wetlands Supplement Emissions Factors unless otherwise specified)	CO_2-C emission	Mangrove	Mean	N/A	1.62	7.90 d		No data available	No data available - Likely to vary according to land-use types	No data available - Likely to vary according to initial land-use	124.83 [h]	250.57 [i]	No data available - change in emissions unlikely	No data available - change in emissions unlikely	No data available	No data available
			Min.		0.10	1.20					7.10	20.43				
			Max.		10.20	43.90					328.00	826.53				
			95% CI lower		1.30	5.20					95.77	212.10				
			95% CI upper		2.00	11.80					153.90	289.04				
		Tidal marsh	Mean	N/A	0.91	7.90 d		No data available	No data available - Likely to vary according to land-use types	No data available - Likely to vary according to initial land-use	N/A	83.95 [j]	N/A	No data available - change in emissions unlikely	No data available	No data available
			Min.		0.05	1.20						6.97				
			Max.		4.65	43.90						481.34				
			95% CI lower		0.70	5.20						76.68				
			95% CI upper		1.10	11.80						91.21				
	CH_4 emission [b]	Mangrove	Mean	N/A	5.42 [c]		5.42	No data available	No data available - Likely to vary according to land-use types	No data available - Likely to vary according to initial land-use	N/A	No data available	No data available - change in emissions unlikely	No data available - change in emissions unlikely	No data available	No data available
			Min.		0.31		0.31									
			Max.		150.98		150.98									
			95% CI lower		2.79		2.79									
			95% CI upper		10.02		10.02									
		Tidal marsh	Mean	N/A	5.42 [c]		5.42	No data available	No data available - Likely to	No data available - Likely to	N/A	No data available	N/A	No data available - change in	No data available	No data available
			Min.		0.31		0.31									

		Habitat		Stock	Accumulation or emission rate	ACTIVITY 1A - Tidal introduction to drained, treeless community	ACTIVITY 1B - Introduction of saline water to ponded freshwater	ACTIVITY 2 - Enhancing sediment supply	ACTIVITY 3A - Land-use change: existing areas	ACTIVITY 3B - Land-use change: planning for SLR	ACTIVITY 4A - Avoided clearing (biomass only)	ACTIVITY 4 - Avoided clearing (biomass + soil)	ACTIVITY 5A - Direct manipulation of mangrove species composition	ACTIVITY 5B - Enabling mangrove encroachment of tidal marsh	ACTIVITY 6A - Offsite management of nutrients	ACTIVITY 6B - Offsite management of salinity
			Max.		150.98		150.98		vary according to land-use types	vary according to initial land-use				emissions unlikely		
			95% CI lower		2.79		2.79									
			95% CI upper		10.02		10.02									
	N_2O emission	Mangrove	Mean	N/A	No data available	No data available	No data available	No data available	No data available - Likely to vary according to land-use types	No data available - Likely to vary according to initial land-use	N/A	No data available	No data available - change in emissions unlikely	No data available - change in emissions unlikely	No data available	No data available
			Min.													
			Max.													
			95% CI lower													
			95% CI upper													
		Tidal marsh	Mean	N/A	No data available	No data available	No data available	No data available	No data available - Likely to vary according to land-use types	No data available - Likely to vary according to initial land-use	N/A	No data available	N/A	No data available - change in emissions unlikely	No data available	No data available
			Min.													
			Max.													
			95% CI lower													
			95% CI upper													
TOTAL REMOVALS + AVOIDED EMISSIONS		Mangrove	Sum of Mean			15.40	12.93	1.26 f	No data available - Likely to vary according to land-use types	7.50	124.83 (one-off)	250.57 (one-off) + 1.26 (annual)	No data available	N/A	No data available	No data available
			Sum of Min.			1.72	0.83	0.17		0.52	7.10 (one-off)	20.43 (one-off) + 0.17 (annual)				
			Sum of Max.			63.66	170.74	3.36		19.76	328.00 (one-off)	826.53 (one-off) + 3.36 (annual)				
			Sum of 95% CI lower			10.89	8.49	0.90		5.69	95.77 (one-off)	212.10 (one-off) + 0.90 (annual)				
			Sum of 95% CI upper			21.11	19.34	1.62		9.31	153.90 (one-off)	289.04 (one-off) + 1.62 (annual)				

Habitat	Stock	Accumulation or emission rate	ACTIVITY 1A - Tidal introduction to drained, treeless community	ACTIVITY 1B - Introduction of saline water to ponded freshwater	ACTIVITY 2 - Enhancing sediment supply	ACTIVITY 3A - Land-use change: existing areas	ACTIVITY 3B - Land-use change: planning for SLR	ACTIVITY 4A - Avoided clearing (biomass only)	ACTIVITY 4 - Avoided clearing (biomass + soil)	ACTIVITY 5A - Direct manipulation of mangrove species composition	ACTIVITY 5B - Enabling mangrove encroachment of tidal marsh	ACTIVITY 6A - Offsite management of nutrients	ACTIVITY 6B - Offsite management of salinity
	POTENTIAL AREA OF ABATEMENT		Limited data available. Area may be extensive (e.g. 62,000 ha of coastal wetlands drained in NSW) [e]	Limited data available. Area may be extensive (e.g. up to 35,000 ha of tidal marsh has been converted to ponded pastures in QLD) [e]	No data available	No data available	No data available specific to land-use change. Area of future potential mangrove and tidal marsh estimated at up to 16,348 km^2 [g]	No data available	No data available	No data available	No data available	No data available	No data available
Tidal marsh	Sum of Mean		8.29	5.81	0.39	No data available - Likely to vary according to land-use types	0.39	N/A	83.95 (one-off) + 0.39 (annual)	N/A	*2.71*	No data available	No data available
	Sum of Min.		1.23	0.34	0.03		0.03		6.97 (one-off) + 0.03 (annual)		*2.53*		
	Sum of Max.		46.11	153.19	2.21		2.21		481.34 (one-off) + 2.21 (annual)		*2.88*		
	Sum of 95% CI lower		5.55	3.15	0.35		0.35		76.68 (one-off) + 0.35 (annual)		*1.06*		
	Sum of 95% CI upper		12.22	10.44	0.42		0.42		91.21 (one-off) + 0.42 (annual)		*4.35*		
	POTENTIAL AREA OF ABATEMENT		Limited data available. Area may be extensive (e.g. 62,000 ha of coastal wetlands drained in NSW) [e]	Limited data available. Area may be extensive (e.g. up to 35,000 ha of tidal marsh has been converted to ponded pastures in QLD) [e]	No data available	No data available	No data available specific to land-use change. Area of future potential mangrove and tidal marsh estimated at up to -	No data available	No data available	No data available	No data available	No data available	No data available

Habitat	Stock	Accumulation or emission rate	ACTIVITY 1A - Tidal introduction to drained, treeless community	ACTIVITY 1B - Introduction of saline water to ponded freshwater	ACTIVITY 2 - Enhancing sediment supply	ACTIVITY 3A - Land-use change: existing areas	ACTIVITY 3B - Land-use change: planning for SLR	ACTIVITY 4A - Avoided clearing (biomass only)	ACTIVITY 4 - Avoided clearing (biomass + soil)	ACTIVITY 5A - Direct manipulation of mangrove species composition	ACTIVITY 5B - Enabling mangrove encroachment of tidal marsh	ACTIVITY 6A - Offsite management of nutrients	ACTIVITY 6B - Offsite management of salinity
							16,348 km^2 [g]						

Values in italics are from sources other than CSIRO Coastal Carbon Cluster data and IPCC Wetland Supplement default values.

[a] Annual biomass C accumulation rates are linear rates for a 20 year period of afforestation/reforestation. These are calculated by dividing the biomass C stock by 20 years (unless otherwise specified).

[b] IPCC values for CH_4 have been multiplied by 28 to convert to C equivalent.

c IPCC emission factors for estimation of rewetted land previously vegetated by tidal marshes and mangroves.

d IPCC emission factors associated with drainage on aggregated organic and mineral soils.

e Estimates provided from state-based assessments in NSW (Rogers et al. 2015) and QLD (Wegscheidl et al. 2015).

f excludes any change associated with C contained within the sediment being deposited

g National mapping of coastal acid sulfate soil extent (Fitzpatrick et al. 2008) was used to estimate the area of supratidal land which may become inundated under higher sea level. The area over which land-use planning changes could occur would form an unknown fraction of this estimate.

h One-off avoided emission of 1x biomass stock. Assumes that 1) all biomass is removed and decomposes under aerobic conditions; and 2) all carbon in this pool is emitted as CO_2 during the year of extraction.

i One-off avoided emission of 1x biomass stock + 0.5x soil (1 m) stock. Assumes that 1) all biomass is removed and decomposes under aerobic conditions; and 2) all carbon in these pools is emitted as CO_2 during the year of extraction.

j One-off avoided emission of 0.5x soil (1 m) stock. Assumes that 1) all soil C is removed and decomposes under aerobic conditions; and 2) all carbon in this pool is emitted as CO_2 during the year of extraction.

k Based upon two temperate sites experiencing change from tidal marsh to mangrove and development of mangrove forest over <70 y (Kelleway et al. 2016). Assumes a biomass %C content of 44.6%.

l Based upon a single temperate site experiencing change from tidal marsh to mangrove and development of mangrove forest over <70 y (Kelleway et al. 2016 GCB). Minimum and maximum values are the same as the mean value as only one study estimate was available. 95%CI values refer to within-site estimate of rate of change.

APPENDIX 2 – FIRST PASS ASSESSMENT OF POTENTIAL CARBON ABATEMENT INTENSITY ASSOCIATED WITH POTENTIAL ACTIVITIES IN SEAGRASS MEADOWS

Table 38: A) Baseline estimates of C_{org} stocks and accumulation rates; B) estimates of enhanced CO_2 sequestration (i.e. by avoiding the loss of seagrass canopy and preserving soil C_{org} accumulation) and avoided CO_2 emissions (i.e. by avoiding disturbance of soil C_{org}). Activities 1 to 4: the estimates of potential intensity of abatement are based upon mean data of national C_{org} stocks and accumulation rates for seagrasses compiled by the CSIRO Coastal Carbon Cluster, and assuming that 25-75% soil C_{org} stocks in 1 m soil deposits are remineralised after disturbance and/or emitted as CO2 over the abatement assessment period. The loss and fate of C_{org} stores after disturbance remains poorly understood (e.g. it can range from 0 to 100% loss and the fate is assumed to be 100% remineralisation despite part of the C_{org} could be preserved elsewhere), thereby the estimates of avoided emissions presented in this table are subjected to large uncertainties. The large inter- and intra-ecosystem variability in seagrass C_{org} stocks and sequestration rates (e.g. as a function of species composition and geomorphology) entails large uncertainties around the potential intensity of abatement. Estimates of the potential intensity of abatement for non-CO2 GHG emissions (i.e. CH_4 and N_2O) are not provided because their fluxes in seagrass ecosystems remain poorly understood. A conversion factor of 3.67 is used to calculate CO2 emission (i.e. 1 C_{org} remineralised equals 3.67 CO_2 emitted).

				ACTIVITY 1 - Avoidance of seagrass ecosystem loss through direct physical disturbance		ACTIVITY 2 - Re-establishment of seagrass ecosystem		ACTIVITY 3 -Creation of new seagrass ecosystem		ACTIVITY 4 - Avoidance of seagrass ecosystem loss through water quality changes	
A)	CARBON POOL	Habitat		Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate
				Mg C_2 ha^{-1}	Mg C ha^{-1} y^{-1}	Mg C ha^{-1}	Mg C ha^{-1} yr^{-1}	Mg C ha^{-1}	Mg Cha^{-1} yr^{-1}	Mg CO_2 ha^{-1}	Mg C ha^{-1} y^{-1}
BASELINE C_{org} STOCK AND ACCUMULATION RATES	Soil (1m) (C_{org} storage)	Seagrass	Mean	112.08	0.36	112.08	0.36	112.08	0.36	112.08	0.36
			Median	84.96	0.25	84.96	0.25	84.96	0.25	84.96	0.25
			SD	88.14	0.33	88.14	0.33	88.14	0.33	88.14	0.33
			Min.	0.92	0.02	0.92	0.02	0.92	0.02	0.92	0.02
			Max.	609.71	1.41	609.71	1.41	609.71	1.41	609.71	1.41
			95% CI lower	104.70	0.25	104.70	0.25	104.70	0.25	104.70	0.25
			95% CI upper	119.45	0.47	119.45	0.47	119.45	0.47	119.45	0.47

B)	CARBON POOL	Habitat		ACTIVITY 1 - Avoidance of seagrass ecosystem loss through direct physical disturbance		ACTIVITY 2 - Re-establishment of seagrass ecosystem		ACTIVITY 3 -Creation of new seagrass ecosystem		ACTIVITY 4 - Avoidance of seagrass ecosystem loss through water quality changes	
				Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate
				Mg C_2 ha^{-1}	Mg C ha^{-1} y^{-1}	Mg C ha^{-1}	Mg C ha^{-1} yr^{-1}	Mg C ha^{-1}	Mg Cha^{-1} yr^{-1}	Mg CO_2 ha^{-1}	Mg C ha^{-1} y^{-1}
ENHANCED CO_2 SEQUESTRATION	Soil (C_{org} accumulation)	Seagrass	Mean	N/A	1.32	N/A	1.32	N/A	1.32	N/A	1.32
			Median		0.94		0.94		0.94		0.94
			SD		1.21		1.21		1.21		1.21
			Min.		0.07		0.07		0.07		0.07
			Max.		5.16		5.16		5.16		5.16
			95% CI lower		0.93		0.93		0.93		0.93
			95% CI upper		1.72		1.72		1.72		1.72

	CARBON POOL	Habitat		Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate	Stock	Accumulation rate
				Mg C_2 ha^{-1}	Mg C ha^{-1} y^{-1}	Mg C ha^{-1}	Mg C ha^{-1} yr^{-1}	Mg C ha^{-1}	Mg Cha^{-1} yr^{-1}	Mg CO_2 ha^{-1}	Mg C ha^{-1} y^{-1}
AVOIDED CO_2 EMISSIONS	Soil (C_{org} stocks)	Seagrass	Mean	103 - 308	N/A	103 - 308	N/A	103 - 308	N/A	103 - 308	N/A
			Median	78 - 234		78 - 234		78 - 234		78 - 234	
			SD	81 - 243		81 - 243		81 - 243		81 - 243	
			Min.	0.84 - 2.53		0.84 - 2.53		0.84 - 2.53		0.84 - 2.53	
			Max.	559 - 1678		559 - 1678		559 - 1678		559 - 1678	
			95% CI lower	96 - 288		96 - 288		96 - 288		96 - 288	
			95% CI upper	110 - 329		110 - 329		110 - 329		110 - 329	

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