Coastal carbon opportunities: carbon storage and accumulation rates at three case study sites

SUMMARY REPORT

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Glossary

Above ground stocks	Carbon stored in above-ground biomass (e.g. trunks, stems, leaves) or other above-ground carbon sinks.
Accumulation rate	The rate at which atmospheric CO_2 is sequestered. Usually reported as a mass per unit area per year.
Activity	An action undertaken to reduce anthropogenic greenhouse gas emissions or an action undertaken to increase anthropogenic greenhouse gas removals by sinks.
Additional/additionality	The effect of a project activity to reduce anthropogenic greenhouse gas emissions below the level that would have occurred in the absence of the project activity; or The effect of a project activity to increase actual net greenhouse gas removals by sinks above the sum of the changes in carbon stocks in the carbon pools within the project boundary that would have occurred in the absence of the project activity.
Approved methodology	A methodology for undertaking a project activity that has been approved by the appropriate authority for projects or activities.
Autochthonous carbon	Carbon (organic or inorganic) formed at a site distant to that where it is found.
Below ground storage	Carbon stored below ground level as biomass (e.g. roots and rhizomes) or sedimentary/soil carbon.
Biomass	The quantity (usually weight) of organisms (here, mainly mangroves, tidal marsh or seagrass) in a given area or volume.
Blue carbon	The carbon stored and sequestered in coastal ecosystems such as mangrove forests, seagrass meadows or tidal marshes.

Carbon pools	Above-ground biomass, below-ground biomass, litter, dead wood and soil/sediment organic carbon.
C_{org}	Organic carbon
CO_2	Carbon dioxide, a gas composed of one carbon and two oxygen atoms. It is a major component of the global carbon cycle and a key greenhouse gas
CO_{2-eq}	a measure of the environmental impact of one tonne of any greenhouse gases in comparison to that of one tonne of CO_2.
Dating methods	The various methods used to age sediments or carbon within sediments, thereby allowing the accumulation rate to be determined. The most common methods involve the use of the radioisotopes Carbon-14 or Lead-210.
Emissions	An amount of a substance (usually a gas) that is released into the environment (usually the atmosphere). Here, the most commonly considered emissions are CO_2, CH_4, N_20.
Greenhouse gas (GHG)	A greenhouse gas listed in Annex A to the Kyoto Protocol, unless otherwise specified in a particular methodology. With respect to blue carbon ecosystems, the most commonly considered greenhouse gas s are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)
Inorganic C (C_{inorg})	Carbon, both particulate and dissolved, not in an organic compound, including gaseous and dissolved carbon dioxide, and dissolved and particulate carbonates
Kyoto Protocol	The protocol to the Convention adopted in Kyoto, Japan on 11 December 1997, which entered into force on 16 February 2005. The Kyoto Protocol, among other things, sets binding targets for the reduction of greenhouse gas emissions by Annex I Parties.
Labile carbon	Forms of carbon relatively easily degraded or remineralised.
Organic carbon	Carbon, both particulate and dissolved, found in an organic compound, including living organisms, detritus, litter, and dissolved compounds
Project	A coordinated action by a private or public entity which coordinates and implements any policy/measure or stated goal (i.e. incentive schemes and voluntary programmes) that leads to greenhouse gas emission reductions or net anthropogenic greenhouse gas removals by sinks that are additional to any that would occur in the absence of the coordinated action.
Project boundary	The physical delineation and/or geographical area of a project activity and the specification of greenhouse gases and sources under the control of the project participants that are significant and reasonably attributable to the project activity, in accordance with the applied methodologies and, where applicable, the applied standardized baselines; or The delineation of a geographical area of the project activity under the control of the project participant as determined in accordance with the applied methodologies and, where applicable, the applied standardized baselines.

Recalcitrant carbon	Carbon that is relatively resistant to degradation (used interchangeably with refractory)
Remineralisation	The process in which organic carbon is transformed into inorganic forms, such as carbon dioxide (CO_2)
SAR	Sediment accumulation rate – the net rate of vertical accumulation of sediment at a site.
Sediment	Naturally occurring material broken down by weathering and erosion, and subsequently transported to a place where it accumulates. In contrast to solids, sediments are relatively unstructured and are not formed by interaction of biological, physical and chemical processes.
Sedimentary carbon	Organic and inorganic carbon stored within sediments
Sequestration	The capture and long-term storage of atmospheric carbon dioxide.
Sink	A reservoir that accumulates and stores carbon-containing chemical compounds. Use of the term sink usually implies that the storage is long-term (or semi-permanent).
Soil	A complex, structured mixture of organic matter, minerals gases, liquids and living organisms formed by the interaction of the parent material, organisms, climate and relief.
Soil carbon	Organic and inorganic carbon stored within soils
Stocks (of carbon)	The total amount of, in this case, carbon stored in an area or volume. Used interchangeably with 'store'.
Verification	The periodic independent evaluation and retrospective (ex post) determination of monitored greenhouse gas emission reductions that have occurred as a result of a project activity; or the periodic independent evaluation and retrospective (ex post) determination of monitored net anthropogenic greenhouse gas removals by sinks achieved by a project activity.

Units used in this report

Mt	Megatonne	10^6 tonnes
Tg	Teragram	10^{12} g = 1 Mt
ha	Hectare	10,000 m^2 = 0.01 km^2
km^2	Square kilometre	10^6 m^2 = 100 ha
Mg ha^{-1}	Megagrams per hectare	10^6 g ha = 0.1 kg m^{-2}

1 Background

Coastal carbon, also known as blue carbon, refers to the atmospheric carbon dioxide (CO_2) captured and stored in coastal vegetated ecosystems. Interest in blue carbon intensified following the release of reports in 2009 (Laffoley & Grimsditch 2009, Nellemann et al. 2009) highlighting the exceptional capacity of blue carbon ecosystems to sequester atmospheric CO_2. This, together with the high rates of loss of blue carbon ecosystems, globally, make them of significant interest for national and regional climate change mitigation strategies. Subsequent research indicated that blue carbon ecosystems could capture and bury one to two orders of magnitude more CO_2 than terrestrial forest ecosystems (McLeod et al. 2011), which are commonly embedded in climate mitigation and carbon crediting schemes.

The exceptional capacity of blue carbon ecosystems to sequester CO_2 results from the combination of biogeochemical factors. They are highly productive, thereby capturing CO_2 from the atmosphere and turning this into organic carbon (C_{org}) as plant biomass. They also tend to have high sediment accumulation rates, a result of the trapping of suspended particles (Gacia & Duarte 2001, Gacia et al. 2003) from the overlying water and the vertical accumulation of the soil as the below-ground plant biomass grows and accumulates. This high sediment accumulation rate results in carbon entering the soils becoming buried, usually in anoxic conditions that helps to preserve the buried carbon, slowing down its rate of remineralisation (Burdige 2007) and return to the atmosphere as CO_2.

Blue carbon ecosystems store C_{org} in two main pools: the above-ground pool, mainly comprising living biomass and litter; and the below-ground pool, comprising roots and rhizomes, dead below-ground plant organs and soil (or sedimentary) C_{org}. The majority of the C_{org} stocks in blue carbon ecosystems are found in this below-ground pool (Duarte et al. 2013), typically around 90% of total C_{org} stocks in tidal marshes and seagrasses and in the order of 75% in mangroves (Nellemann et al. 2009, Alongi 2014). This predominant storage of C_{org} within the below-ground pool (hereafter referred to as soil C_{org}) makes this pool of primary interest in blue carbon initiatives (Sutton-Grier et al. 2014). Global estimates suggested that tidal marshes bury, on average, 1.51 tonnes C ha^{-1} y^{-1} , mangroves bury a similar amount (1.39 tonnes C ha^{-1} y^{-1} and seagrasses bury 0.83 tonnes C ha^{-1} y^{-1} (Table 1).

Table 1. Estimated ranges of global areas, soil C_{org} stocks and accumulation rates of blue carbon ecosystems. Values in parentheses are means.

Ecosystem	Area	Soil C_{org} stock		C_{org} burial rate		Reference
	million km^2	kg C_{org} m^2	Mt C_{org}	g C_{org} m^{-2} yr^{-1}	t C_{org} y^{-1}	
Mangroves	0.08 - 0.3	150 – 15,270	4400	20 – 654 (83)	17 – 23.6	1,2
Tidal marshes	0.4 - 0.8	140-9,630		15 – 2400 (151)	60-70	1,3,4,5,6
Seagrass	0.18 – 1.6	90-8,300	4200-8400	56 – 182 (139)	114 - 131	1,7,8

[1] Atwood et al. 2017; [2] Nellemann et al. 2009; [3] Chmura et al. 2003; [4] Duarte et al. 2005; [5] Ouyang & Lee 2014; [6] Macreadie et al. 2017; [7] Jayathilake & Costello 2018; [8] Fourqurean et al. 2012.

The capacity of different blue carbon ecosystems to trap and store carbon in their soils varies, with up to 18-fold differences among seagrass habitats (Lavery et al. 2013), and up to 4-fold in mangroves and tidal marshes (Pendleton et al. 2012). Geomorphological settings, soil characteristics, and biological features all interact to control the soil C_{org} storage in blue carbon ecosystems (Adame et al. 2013, Ouyang & Lee 2014, Serrano et al. 2016). Understanding this variability and the factors that control the stocks and accumulation rates is key to identifying opportunities to enhance C_{org} stocks or avoid emissions of greenhouse gas, thereby contributing to the mitigation of greenhouse gas emissions and forming the basis for potential inclusion of blue carbon activities within programs such as the Australian Government's Emissions Reduction Fund (Kelleway et al. 2017).

Under the existing frameworks for carbon crediting (e.g. the Verified Carbon Standard - VERRA, 2019), there is a requirement to demonstrate 'additionality', that is there must be a demonstrable increase in either the sequestration of carbon or a reduction in the emissions of greenhouse gas relative to the baseline or 'business as usual' scenario. Most crediting projects attempt to restore or create coastal carbon habitats, to enhance CO_2 sequestration, or conserve these ecosystems to avoid emissions. Implicit in these projects is the assumption that the disturbed state will sequester less carbon than the restored or conserved state, and disturbance will result in a net emission of CO_2. Understanding whether these assumptions are valid is a prerequisite to assessing the potential of any blue carbon project.

The South Australian Government has established policy objectives around a Carbon Neutral Adelaide (2020) and Net Zero Emissions by 2050 targets (DEWNR 2018). Existing information suggest that South Australia's coastal ecosystems have the potential to contribute significantly to achieving those policy objectives, as well as providing financial opportunities in the national Emissions Reduction Fund (ERF). While there is not currently an ERF pathway for coastal carbon – in SA or elsewhere –the Commonwealth Government is currently investigating options for this). However, before that potential can be explored in detail, a number of significant knowledge gaps need to be addressed, in particular:

1. Regionally relevant data on carbon stocks and sequestration rates from different coastal carbon systems, which can then be used to parameterise models for carbon offsets and crediting systems; and
2. Information on the impact of ecosystem health and restoration on carbon sequestration and storage into South Australian coastal carbon systems is also not available.

This lack of data is a barrier to the adoption of a framework in South Australia that allows coastal carbon to contribute to the Emissions Reduction Fund (ERF, now renamed the Climate Solutions Fund, or CSF), other climate change mitigation strategies or greenhouse gas inventory.

There is a clear need for the development and refinement of coastal carbon assessment methods that are representative of South Australian coastal systems, to use in validating default values for carbon storage and sequestration rates that are often based on measurements from northern hemisphere or tropical ecosystems. The 'Coastal Carbon Opportunities' project was funded by the Goyder Institute for Water Research to provide scientific knowledge to support policy objectives by generating data that fill critical knowledge gaps around carbon in coastal ecosystems, thus supporting the development of the *State Carbon Sequestration Strategy* (DEWNR 2018). The project had 3 work packages:

- Work package 1: Estimating below-ground carbon storage at three case study locations (seagrass and Mangrove/tidal marsh)
- Work package 2: Vegetation dynamics and above-ground biomass assessment in mangrove and tidal marsh ecosystems; and
- Work package 3: Review of knowledge around South Australian coastal carbon ecosystems and a meta-analysis of the value of associated co-benefits.

This report is a summary of the findings of Work package 1, which was designed to help in filling identified knowledge gaps relating to issues of carbon accounting and sequestration rates in natural and restored systems. This was achieved through collection of data at case-study sites for seagrass and mangrove/tidal marsh ecosystems. These case studies focused on carbon storage and ecosystem dynamics in both natural and restored systems to demonstrate the potential for carbon gains and achieving carbon offsets through coastal carbon ecosystem rehabilitation, restoration and creation. Full details of the Work package 1 study can be found in the technical report (Lavery et al. 2019). The report also summarises the review of existing knowledge on the organic carbon stocks and accumulation rates of blue carbon ecosystems in South Australia.

2 What we did

To estimate the amount nor organic carbon stored below-ground in South Australian coastal carbon ecosystems, and the rate at which it accumulates, we gathered the existing data available from a blue carbon inventory undertaken by the study team in 2014, and supplemented this with targeted sampling in 2016 and 2017. To fill information gaps on the potential of management actions to enhance CO_2 sequestration or avoiding CO_2 emissions, we undertook 3 case studies, two in seagrass and one in mangrove habitat. The case studies focussed on the potential for restoration or conservation actions to enhance CO_2 sequestration or avoiding CO_2 emissions in relation to physical disturbance or eutrophication-related seagrass loss or where mangroves have been/will be isolated from tidal inundation. In all cases we did this by comparing the C_{org} stocks and accumulation rates in disturbed and undisturbed habitat sites.

Baseline sampling of the soil C_{org} stocks and accumulation rates in South Australian coastal carbon ecosystems.

In 2014, Edith Cowan University, SA Water and the EPA of South Australia, sampled seagrass, mangrove and tidal marsh sites (37 soil cores) in the Adelaide coastal waters, Port Broughton, Port Pirie, Port Augusta and Whyalla (Figure 1). The focus of this project was to obtain initial baseline estimates of the variability in stocks and accumulation rate within and between the different coastal carbon habitats. These sites were classified as 'undisturbed' in that we were unaware of any significant habitat loss at the sites.

A second survey was undertaken in spring 2016 and spring 2017 to quantify and compare the carbon content of surface soils (top 10 cm) in mangrove and tidal marsh ecosystems, primarily to assess whether this varied between the different vegetation types, or whether the two can be considered similar in terms of carbon stocks. A total of 216 soils were collected. We focused on the top 10 cm of soil as this was expected to be the depth of soil most susceptible to the short-term influence of the overlying vegetation (Yando et al. 2016, Kelleway et al. 2017). In addition, we also explored the spatial variability of soil carbon within nine temperate mangrove and tidal marsh sites, to inform the design of future blue carbon ecosystem assessments for greenhouse gas accounting purposes.

Case-studies of the potential for restoration to enhance carbon sequestration or avoid carbon emissions.

Soil cores (23 in total) were collected from the dominant seagrass, mangrove or tidal marsh habitat from nine locations in South Australia (

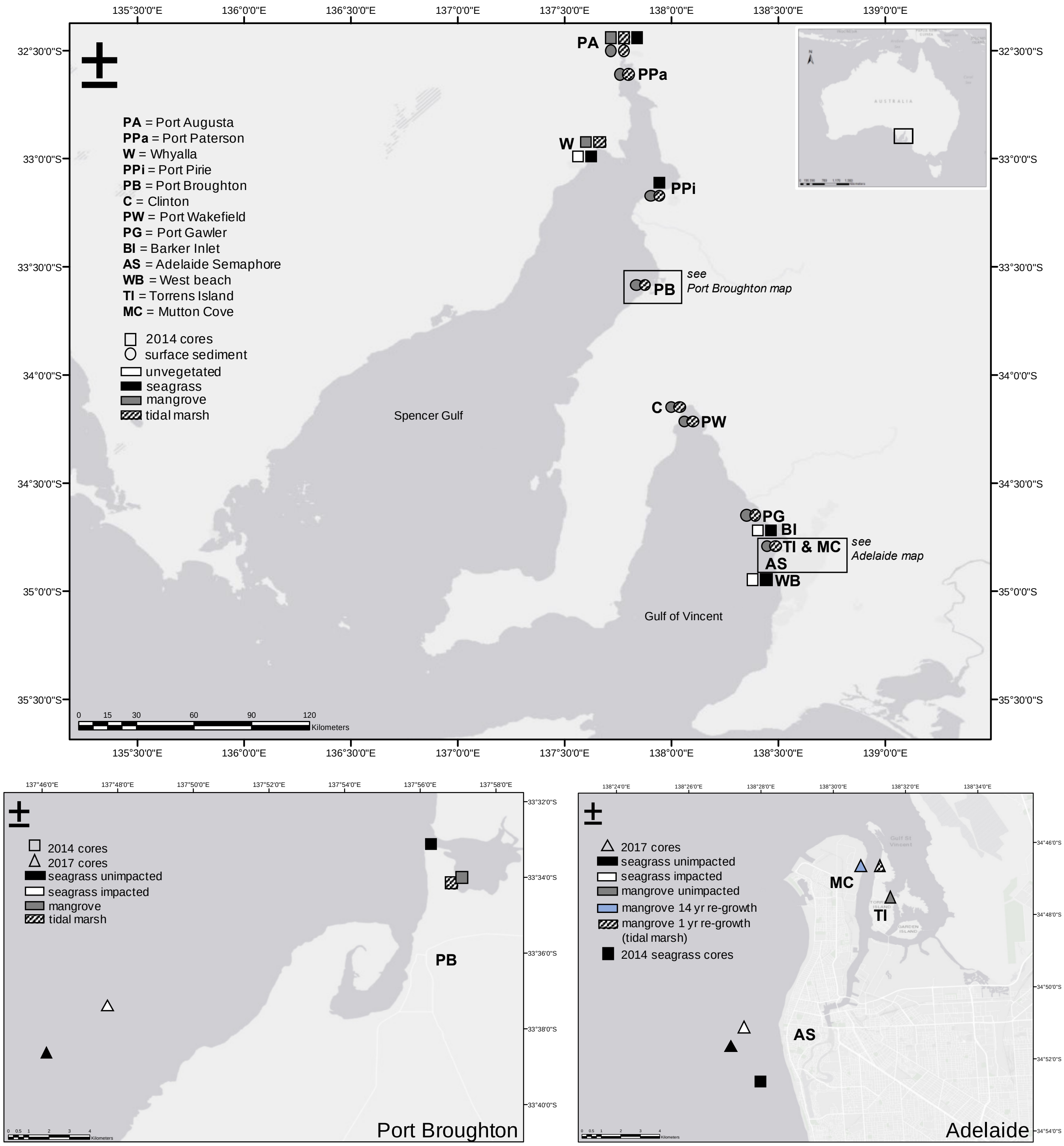


Figure 1. Locations of Blue Carbon study sites sampled in Spencer Gulf and Gulf St Vincent (South Australia) in 2014 and 2017.

Table 2). In 2017, we undertook case studies comparing the soil C_{org} stocks and accumulations rates in disturbed and undisturbed seagrass and mangrove habitats, to assess the opportunity that conservation or restoration may provide for avoided emissions or enhanced sequestration activities. At Port Broughton seagrass (mixed *Posidonia australis*/*P. sinuosa*) had historically been lost due to physical disturbance through dredge-mining. At Semaphore, seagrass (mixed *Posidonia australis*/*P. sinuosa*) had been lost through sewage-related eutrophication. For the mangrove case study, we sampled a disturbed mangrove site at Mutton Cove and compared this with an undisturbed mangrove site at Torrens Island (TI). At Mutton Cove, mangroves had been lost following the construction of a levy which disconnected the site from tidal inundation and led to widespread drying and subsidence. Subsequent restoration attempts involved reconnection to controlled tidal flow through pipes in the levy wall in 2005, resulting in the partial recovery of mangroves in the south-west of the site. We sampled an area of recent (1 year) mangrove regrowth and a second site with about 14 years of mangrove regrowth (see Jones et al. 2019). The comparison of the three sites was intended to provide information on both the differences in below-ground carbon stocks resulting from disturbance as well as the rate of recovery of stocks and sequestration potential following controlled re-inundation of mangrove sites. Three replicate sediment cores were collected from random locations in each of the sites all within 10 m of each other.

Summary details of all 60 baseline and case study cores are provided in Appendix 1.

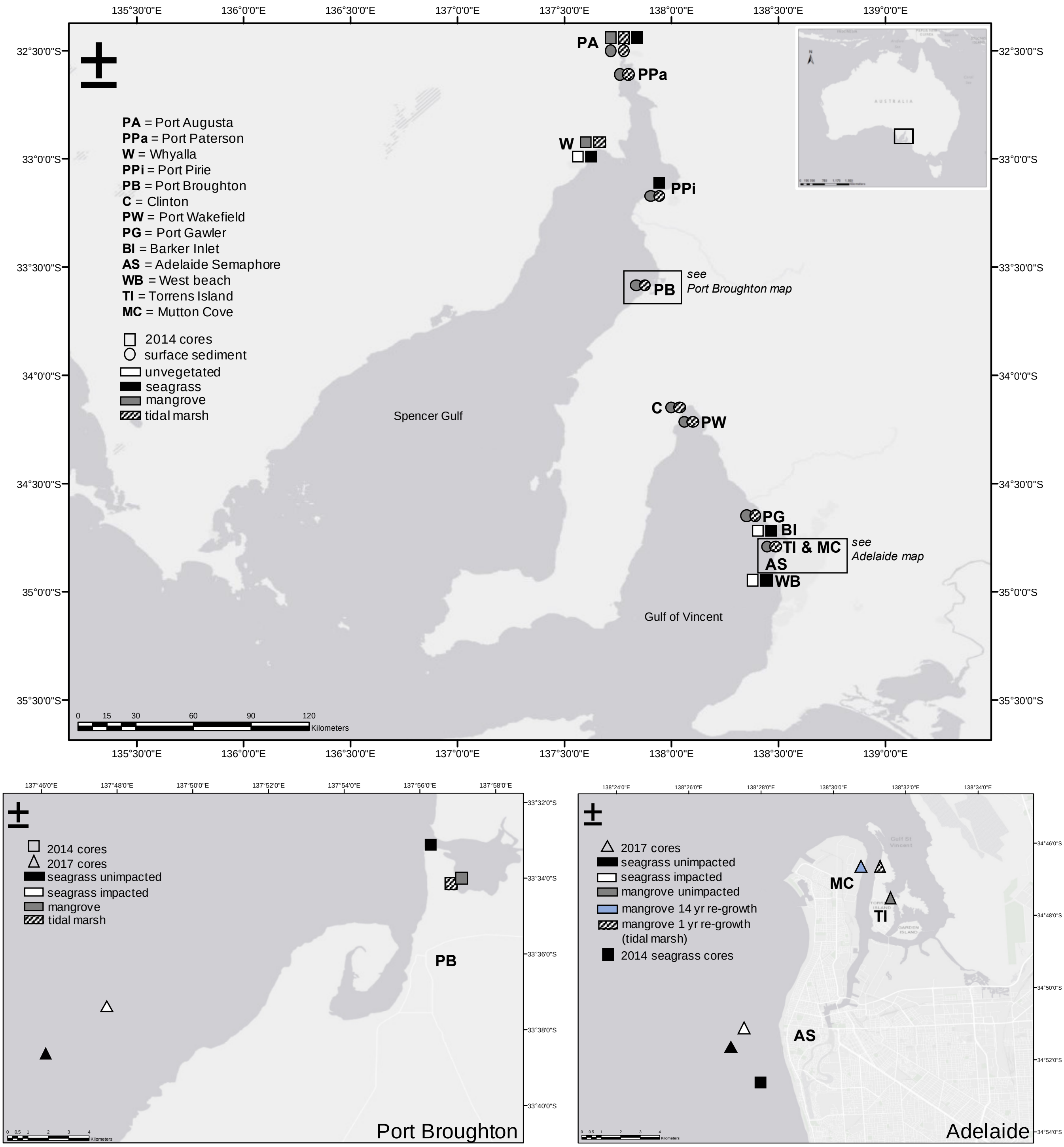


Figure 1. Locations of Blue Carbon study sites sampled in Spencer Gulf and Gulf St Vincent (South Australia) in 2014 and 2017.

Table 2. Sampling locations and dominant habitat type for blue carbon ecosystems sampled in 2014 and 2017

Ecosystem	Core ID	Habitats sampled
Seagrass	Adelaide - Barker Inlet	*Posidonia sinuosa, Zostera nigricaulis*
	Adelaide - West Beach	*Amphibolis antarctica, Posidonia sinuosa, Zostera nigricaulis*
	Adelaide - Semaphore	*Posidonia sinuosa*
	Port Broughton	*Posidonia australis*
	Port Pirie	*Posidonia australis*
	Whyalla	*Posidonia australis, Posidonia sinuosa*
Mangrove	Adelaide - Mutton Cove	*Avicennia marina*
	Adelaide – Torrens Island	*Avicennia marina*
	Port Augusta	*Avicennia marina*
	Port Broughton	*Avicennia marina*
	Whyalla	*Avicennia marina*
Tidal marsh	Port Augusta	*Sarcocornia spp.*
	Port Broughton	*Sarcocornia spp.*
	Whyalla	*Sarcocornia spp.*

2.1 Core collection, processing and analysis

At all study sites the soils were sampled using standard coring methods and analysed to determine the total amount of organic carbon they contained (stocks) and the accumulation rate. Full details of the sampling and analysis procedures for deep cores are available in Lavery et al. (2019) and, for the surface soil assessment (top 10 cm), in Asanopoulos et al. (2019).

3 What we found

3.1 Stocks and accumulation rates in SA coastal carbon ecosystems

Generally, the C_{org} stocks in the top 1 m of undisturbed mangrove and tidal marsh soils were higher than those in undisturbed seagrass soils (

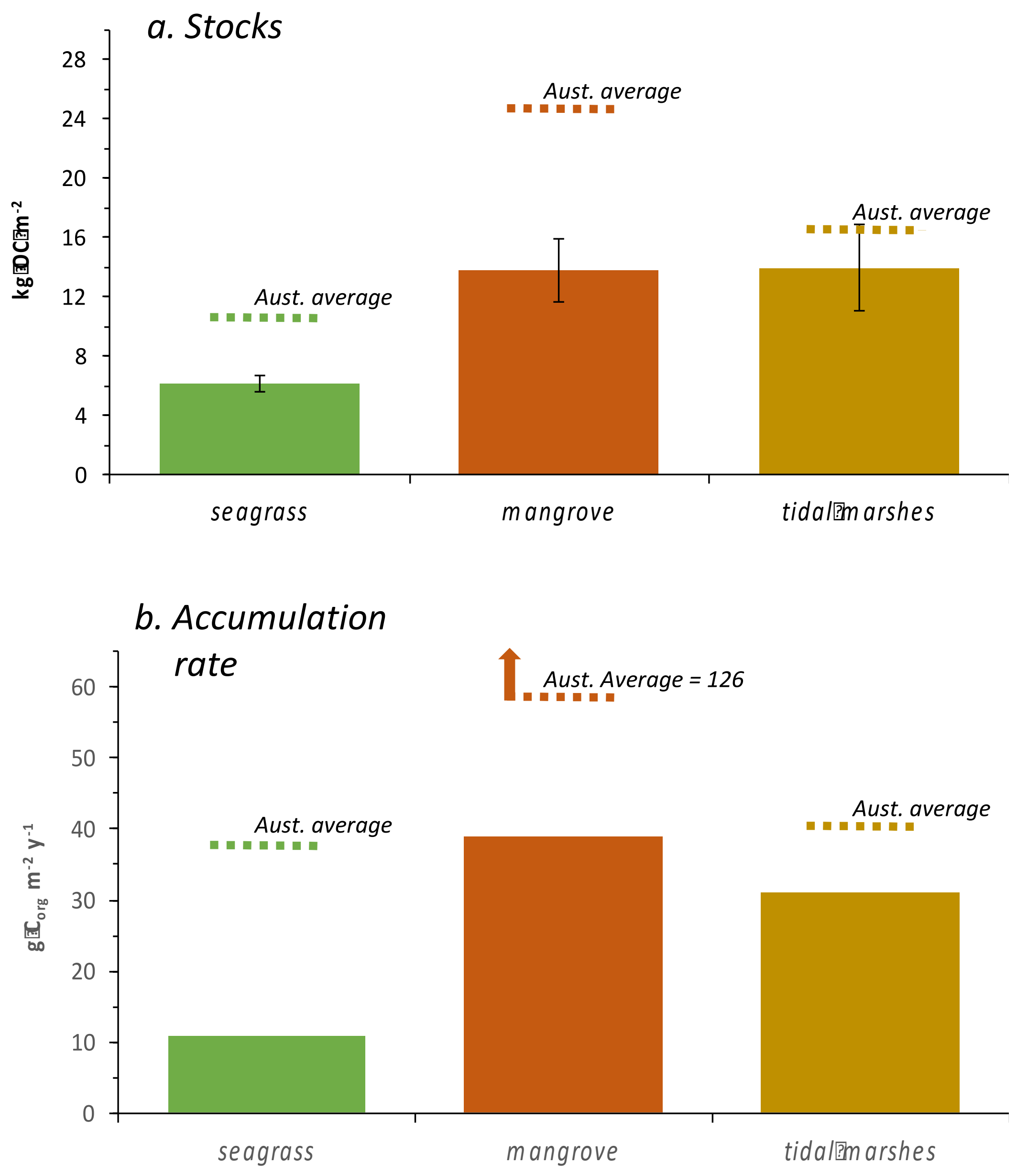
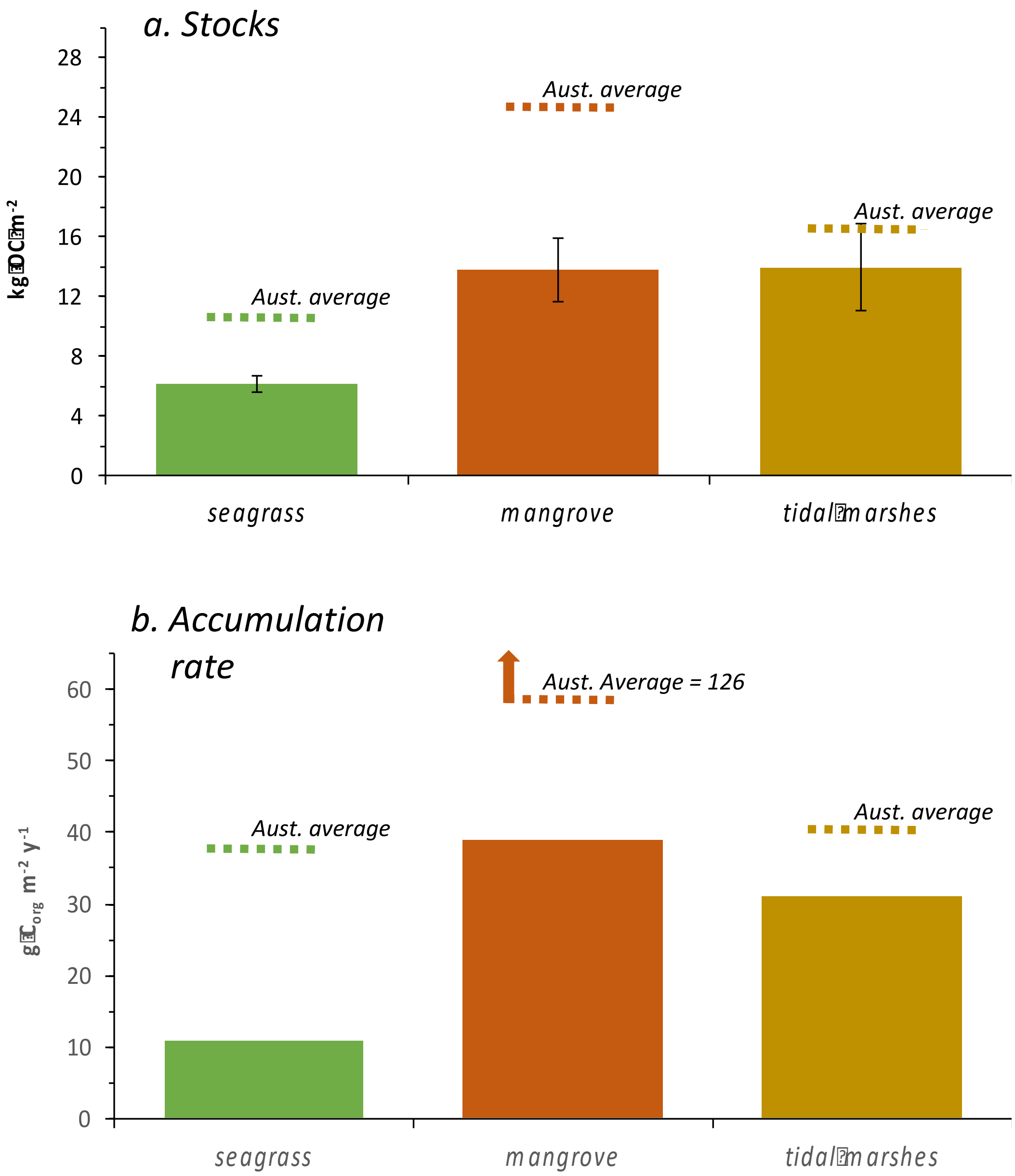


Figure 2. Mean C_{org} stock in the top 100-cm of soil (a) and organic carbon accumulation rates (b) per unit area of coastal carbon habitats in South Australia. For seagrass, only *Posidonia* sites are included. Australian averages are from Kelleway et al. (2017)

). Averaged across all vegetated blue carbon ecosystem sites sampled in the State, the average C_{org} stocks in seagrass, tidal marshes and mangrove ecosystems were 6.1, 14.0 and 14.4 kg C_{org} m^{-2}, respectively, and the mean C_{org} accumulation rates were 10.1, 31.1 and 38.8 g C_{org} m^{-2} y^{-1}, respectively (



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, Table 3).

The similarity in mangrove and tidal marsh C_{org} stocks for the top 1 m was also apparent in the surface soils (top 10 cm) which, averaged across all sites, were 1.8 kg C_{org} m^{-2} for mangroves and 1.7 kg C_{org} m^{-2} for tidal marshes (Figure 3). These values are comparable to those recorded for the deep (1 m) cores described above when corrected for differences in the soil depth being considered. Across the State, no significant difference in surface soil C_{org} stocks between vegetation types was found (p=0.51). However, within some sites there were difference between mangrove and tidal marsh, though the differences were not consistent. For example, mangroves at Clinton and Port Augusta had significantly higher mean surface soil C_{org} stocks than tidal marshes, while at Torrens Island, tidal marsh had a significantly higher stock than the mangroves (Figure 2).

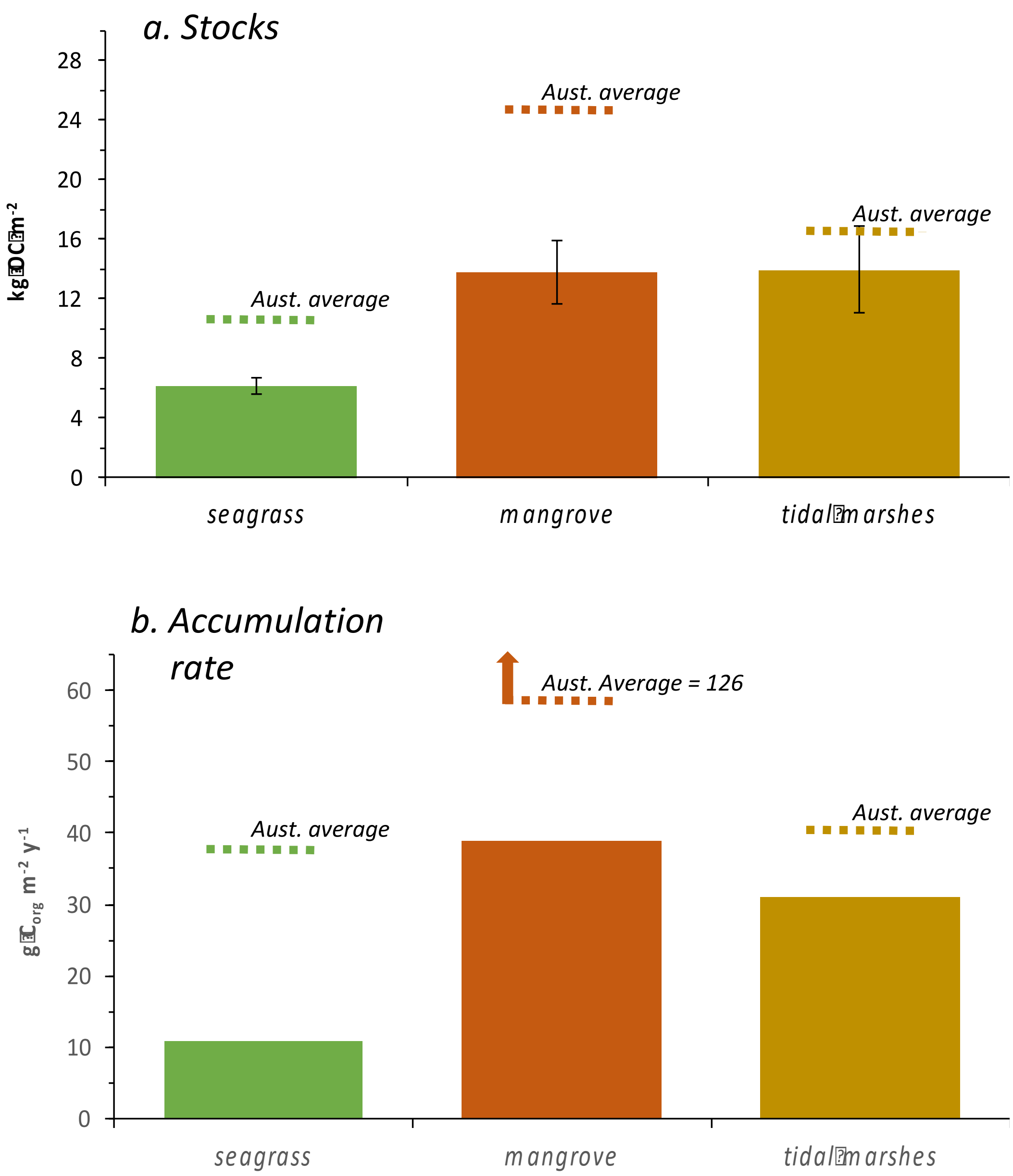
For all three ecosystems (mangrove, tidal marsh and seagrass), the carbon stocks in the soils of South Australian sites were lower than the Australia-wide estimates. It is important to note, however, that the data for South Australia were not collected with the intention of developing a representative assessment of the carbon stock in the State; they were generally collected for other purposes and, in many cases, focussed on sites likely to have relatively low carbon stocks (e.g. exposed ocean sites rather than sheltered embayments and depositional sites). Furthermore, the aridity and low productivity of the adjacent land areas, and the low tidal regime, may all contribute to low mangrove and tidal marsh productivity and capture of external carbon entering from either the land or adjacent marine ecosystems.

Table 3. Estimates of mean soil C_{org} stocks and accumulation rates per unit area (m^2) for South Australian seagrasses, tidal marshes and mangrove

Ecosystem	*n*	Stocks - top 1 m (kg C_{org} m^{-2})		Accumulation rates (g Corg m^{-2} y^{-1})			
				Short-term (since 1950)		Long-term (>700 yr)	
		Mean	Range	Mean	Range	Mean	Range
Seagrass	24	6.1±2.5	0.9-10.9	10.9±8.4	0.9 - 30.7	4.2 ± 0.6	0.26 - 10.6
Tidal marsh	8	13.9±8.4	0.6-25	31.1±11.2	4.3- 94.1	5.1 ± 1.4	0.4 - 10.8
Mangrove	11	14.5±7.03	2.7-22.7	38.8 ± 9.7	9.3 - 97.1	5.8 ± 1.3	1.8 - 15.6

The total soil C_{org} stocks and accumulation rates for South Australia have been estimated by scaling up the average stock in the top meter of soil for each blue carbon ecosystem type to the total area occupied by each ecosystem in the state (Table 4). South Australia is estimated to contain up to 7.6% (0.99 – 1.16 Mha) of the total area of blue carbon ecosystems in Australia (Kelleway et al. 2017, Foster et al. 2019), of which seagrass accounts for about 94%. The blue carbon habitat in SA was estimated to contain between about 5% (up to 76 Mt) of the nation's soil C_{org} stocks, of which about 90% is in seagrass ecosystems. SA blue carbon ecosystems sequester 0.11 – 0.14 Tg C_{org} y^{-1} (Table 4), or about 2-3% of the national sequestration. Seagrasses account for about 85% of the South Australian sequestration, tidal marshes and mangroves about 5 – 10% each.

In attempting to estimate the carbon accumulation rates of South Australian blue carbon ecosystems, 31 sediment cores from vegetated seagrass, mangrove or tidal marsh sites were dated using radioisotopes. Only 13 cores were suitable for determining short-term carbon accumulation rates, which are often required for assessing carbon crediting potential. These cores contained suitable amounts of radioisotope and showed no signs of mixing. The remaining cores either lacked excess radioisotopes, indicating a lack of sediment accumulation at the site, or were mixed due to hydrodynamic action or turnover by biota, making it impossible to estimate accumulation rates. These findings highlight the usefulness of radioisotope techniques in clarifying the processes occurring at individual sites, but also indicate that the inherent sedimentation characteristics at some sites will make them unsuitable for dating using radioisotope techniques. Surface elevation tables (SETs) were also established at all sites and these tended to confirm the findings from the radio-isotope data, that most of the seagrass sites were subject to erosion or a lack of sediment accumulation. While the SETs show promise as a tool for measuring sediment accumulation, the data were extremely variable, indicating that a much longer time period will be required (possibly decadal) to establish reliable estimates.



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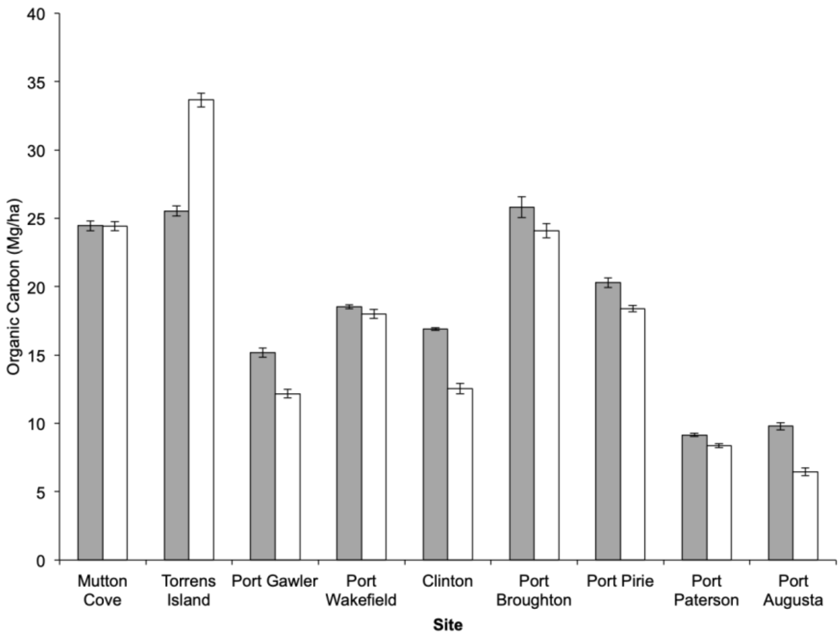

Figure 3. Average organic carbon content (Mg ha^{-1}) in the upper 10 cm of mangrove (grey) and tidal marsh (white) surface soils for each of the nine temperate blue carbon wetland sites sampled in South Australia. Error bars represent standard error. For comparison with other data, 1 Mg ha^{-1} = 0.1 kg m^{-2}.

Table 4. Total area of blue carbon ecosystems in South Australia and their estimated total soil C_{org} stock and soil C_{org} accumulation rates.

Ecosystem	Area (km^2)		Accumul. rate (g C_{org} m^{-2} y^{-1})	Total accumulation (Mt C_{org} y^{-1})		Stock kg C_{org} m^{-2}	Total stock (Mt C_{org})	
	Lower	Upper		Lower	Upper		Lower	Upper
Seagrass	9612*	10809	10.9	0.105	0.118	6.10	58.6	65.9
Tidal marsh	198	481#	31.1	0.006	0.015	13.95	2.8	6.7
Mangrove	164	293#	38.8	0.006	0.011	14.35	2.4	4.2
TOTAL	**9,974**	**11,583**		**0.117**	**0.144**		**63.7**	**76.8**

Area estimates: * Edyvane (1999), #Kelleway et al. 2017 and references therein, all others from Foster et al. 2019. For accumulation rates and stocks, lower and upper estimates reflect the difference due to the uncertainties in the area of each ecosystem type.

3.2 Effects of disturbance on soil organic carbon stocks and accumulation rates

Seagrass Case studies

In both seagrass case study sites, there was measurable short-term (since 1950) organic carbon accumulation at the vegetated, undisturbed sites while the adjacent disturbed seagrass sites had no measurable short-term accumulation. Long-term (>700 yrs) C_{org} accumulation was measurable at all seagrass sites, including the disturbed sites, but again the rates were higher at the undisturbed sites.

At Port Broughton, where the disturbance was due to historical dredge-mining, the stock in the top 1 m of the undisturbed meadow was 9.1±1.1 kg C_{org} m^{-2}, more than twice that of the impacted meadow (4.2±0.89 C_{org} m^{-2}; Figure 4). At the Adelaide Semaphore site, where the disturbance was due to historical eutrophication, the mean C_{org} stocks in the undisturbed site was about 40% greater than in the disturbed site

(4.4±0.29 v 3.0±0.66 kg C_{org} m^{-2}). The differences in the control sites at Port Broughton and Semaphore are likely due to differences in the hydrodynamic regimes, with Port Broughton more depositional and so more likely to accumulate sediment and organic carbon than Semaphore, which is more exposed.

Like the carbon stocks, the carbon accumulation rates were also higher in the undisturbed sites for both seagrass case studies (Table 5). At Port Broughton, the short-term (since 1950s) C_{org} accumulation rate was 17.7±4.1 g C_{org} m^{-2} y^{-1} in the undisturbed. At the disturbed site, an accumulation rate could not be determined because the cores were mixed and could not be dated but the radioisotope inventories indicated a much lower level of sediment (and, therefore, carbon) accumulation. At Semaphore, the undisturbed site had a mean short-term carbon accumulation rate of 2.7±1.1 g C_{org} m^{-2} y^{-1} while the disturbed site had no net accumulation over the same period. Similar trends were found for the long-term accumulation rates, though these were lower than the short-term rates (a common finding that can reflect human-induced increases in coastal sedimentation in more recent times, increasing remineralisation of carbon over time or methodological issues associated with sediment mixing processes).

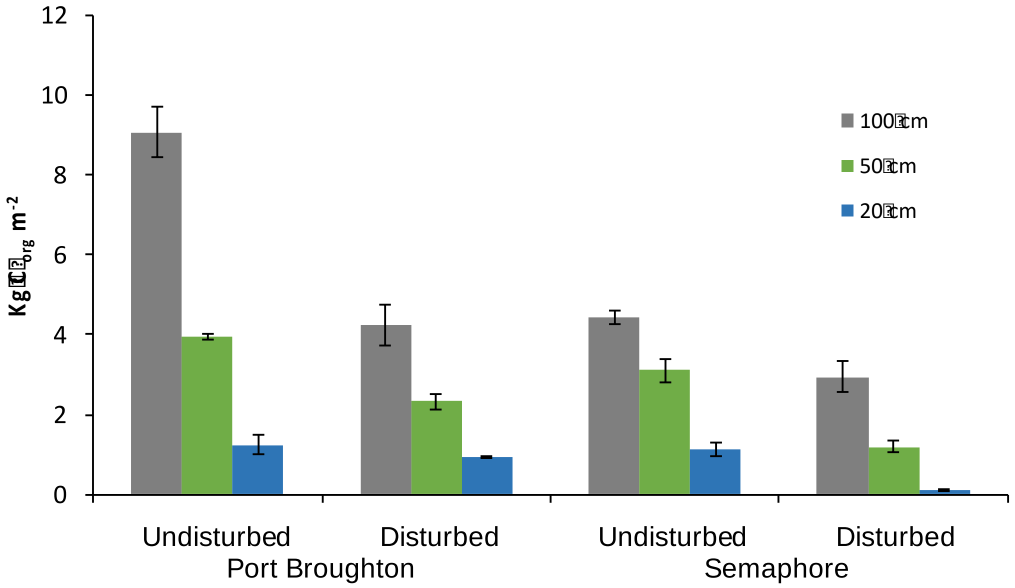

Figure 4. Soil C_{org} stocks for different soil depths in disturbed and undisturbed seagrass meadows at Port Broughton (disturbance = dredge mining) and Semaphore (disturbance = eutrophication).

Table 5. Mean soil C_{org} accumulation rates in disturbed and undisturbed seagrass and mangrove soils at South Australian study sites. ? indicates that rate could not be determined due to mixing or unreliable radiocarbon dating.

Habitat	Site	Condition	Soil C_{org} accumulation rate (g C_{org} $m^{-2}y^{-1}$)	
			Short-term (since 1950s)	Long-term (>700 yr BP)
Seagrass	Port Broughton	Undisturbed	17.65±4.13	7.91±0.48
		Disturbed (dredging)	?	?
	Semaphore	Undisturbed	2.70±1.145	2.50±0.37
		Disturbed (eutrophication)	0	1.12±0.22
Mangrove	Torrens Island	Undisturbed	34.41±18.623	10.48±4.44
	Mutton Cove	Disturbed - 1 yr recovery	17.87±1.145	5.48±1.12
		Disturbed - 14 yr recovery	12.21±5.110	3.82±1.76

Mangrove case study

For the mangrove case study sites, the undisturbed site had greater soil C_{org} stocks than the disturbed sites and the C_{org} accumulations rates were about 2-3 times higher in the undisturbed site depending on the time period over which they were assessed.

The mean C_{org} stocks at Torrens Island, the undisturbed mangrove site, was 19.3±3.18 kg C_{org} m^{-2} (Figure 5), which was not significantly different to the stock in either of the disturbed mangrove sites at Mutton Cove, where the 14 years recovery site had a stock of 13.85±5.74 and 1 year recovery site had a stock of 21.6±3.01 kg C_{org} m^{-2}. However, when the stocks were compared over the top 50 cm and the top 20 cm of soil, then those in the Torrens Island control sites were significantly higher than either of the impacted sites.

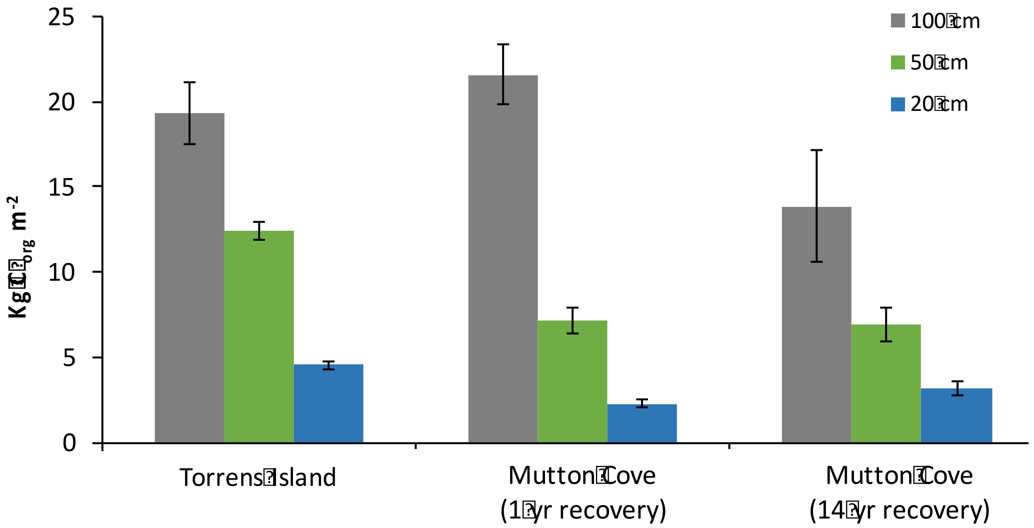

Figure 5. Soil C_{org} stocks for different soil depths in disturbed (Mutton Cove) and undisturbed (Torrens Island) mangrove habitat. Mangroves had been lost at Mutton Cove due to isolation from tidal flows in the 1960s. Reintroduction of controlled flows associated with a restoration program at the site allowed recovery of mangroves, estimated to be 14 years and 1 year old in the two study areas within the Mutton Cove site.

The undisturbed mangrove site, Torrens Island, had a mean soil C_{org} accumulation rate of 34.4±19.0 g C_{org} m^{-2} y^{-1}, which was significantly higher than at either of the disturbed mangrove sites (Table 5). At the disturbed mangrove site which had seen 14 years of recovery, the estimated mean C_{org} accumulation rate was 12.2±5.1 g C_{org} m^{-2} y^{-1}, about one-third that of the control site and at the disturbed site with one year of regrowth the it was 17.9±1.7 g C_{org} m^{-2} y^{-1}, about half that of the undisturbed site. The disturbed sites were not significantly different to each other. For long-term (>700 y BP) accumulation rates, the mean rate for the Torrens Island control site was 10.5±4.4 g C_{org} m^{-2} y^{-1}, about 2-3 fold greater than either the 14 year recovery or 1 year recovery sites, with rates of 3.8±1.8 and 5.5±1.1 g C_{org} m^{-2} y^{-1}, respectively.

4 What does this mean?

This study adds significant additional estimates to the South Australian blue carbon setting. Historical disturbance to seagrass and mangrove habitat has reduced their blue carbon stocks and accumulation rates, strongly suggesting that carbon sequestration can be enhanced through ecosystem restoration. Conservation will both maintain sequestration and avoid emissions. There are also methodological issues that need to be resolved if blue carbon programs are to be developed within the existing crediting and accounting frameworks.

Blue carbon stocks and accumulation in South Australia

The approximately 1 million hectares of blue carbon ecosystems in South Australia represents 6-7% of the total area of blue carbon ecosystems in Australia. The South Australian blue carbon ecosystems contain at least 64 - 77 million tonnes of C_{org} in the top 1 m of soil and each year sequester about 110,000 - 140,000 tonnes of C_{org}. This equates to about 4-5% of Australia's total blue carbon stocks and 2-3% of Australia's annual blue carbon sequestration.

The stocks and accumulation rates of carbon in South Australian blue carbon ecosystems are lower than the averages reported from Australia as a whole and those previously reported for South Australia (Kelleway et al. 2017). The mean C_{org} stocks in South Australian blue carbon ecosystems were about 6, 14 and 14 kg C_{org} m^{-2} for seagrass, mangrove and tidal marshes, respectively, or about 54%, 57% and 83% of the national averages, respectively. The mean sequestration rates in South Australian blue carbon ecosystems were about 11, 39 and 31 g C_{org} m^{-2} yr^{-1} for seagrass, mangrove and tidal marshes, respectively, or about 30%, 31% and 80% of the national averages. The relatively low values we have measured in South Australia may be due to:

- naturally lower carbon concentration in SA soils, possibly reflecting the generally lower nutrient status, and thus productivity, of the SA coastal zone, which, in the areas we sampled, is semi-arid;
- the historical bias towards sampling blue carbon habitats in SA with low carbon stocks. Our study focused on sampling of disturbed habitats or exposed coastal locations, which are likely to have lower stocks and accumulation rates; and
- methodological issues associated with the earlier estimates (which used data from that could not be corrected for soil compression during collection, and so would have over-estimated the stocks in any given soil depth); and
- Previous over-estimation of the area of blue carbon habitats in South Australia, which have now been revised downwards based on newer mapping products (Foster et al. 2019).

While the compilation of existing data and the addition of the data collected in the current study sites has increased the knowledge of South Australian blue carbon resources, the values presented here are not representative of all locations in the State. Deriving a reliable estimate of the State's blue carbon stocks and accumulation rates will require a strategic, state-wide sampling program, and/or spatial modelling based upon known drivers of variability, of all blue carbon habitats across a representative range of locations and environmental settings.

Implications for carbon crediting and greenhouse gas accounting opportunities in SA

At a regional scale, surface soil C_{org} stocks of mangrove and tidal marsh sites were similar, indicating that wetland vegetation type does not have an effect on surface soil C_{org} stocks in temperate vegetated coastal wetlands. Within some specific sites, however, differences were found, attributable partly to difference in vegetation type but mainly to geomorphic settings and environmental conditions (differences in distance from the coast and hydrology), which is consistent with previous studies (Chmura et al. 2003, Livesley & Andrusiak 2012, Adame et al. 2015, Hayes et al. 2017, Lewis et al. 2018). For broad-scale assessments of blue carbon stocks, such as state-wide inventories, it can be assumed that tidal marsh and mangrove ecosystems have a similar organic carbon stock in the surface soils. However, at smaller spatial scales, such as the assessment of potential project sites, it is important to acknowledge the significant differences that may occur within and between sites; limiting sampling intensity to one or a few location(s) may be unrepresentative of organic carbon stocks across mangrove and tidal marsh ecosystems spanning different geomorphic settings.

The differences in organic carbon stocks between disturbed and undisturbed sites for both seagrass and mangrove habitat indicates a potential for both avoided emissions and enhanced sequestration activities in

South Australian coastal carbon ecosystems. The findings indicate that some, if not all, of the carbon accumulation capacity of seagrass and mangrove sites can be lost following disturbances, though this will likely vary according to disturbance type and intensity. The historical losses of blue carbon ecosystem extent in South Australia have been reported for specific impacts and locations. These include estimates of 84 km^2 for tidal marsh (Macreadie et al. 2017 and refs therein), 2.73 km^2 for mangroves (SWG 2011 and references therein) and 187 km^2 for seagrass (Seddon et al. 2000, Tanner et al. 2014). If these historical losses could be restored, then based on the state-wide mean accumulation rates, the ongoing annual accumulation of carbon would be in the order of 2,000 – 50,000 t $CO_{2\text{-eq}}$ y^{-1} (Table 6).

Table 6. Estimated enhanced CO_2 sequestration based on restoration of historical losses of blue carbon habitat in South Australia.

Ecosystem	Short–term Accumulation (t C_{org} km^2 y^{-1})		losses (km^2)	Lost annual accumulation			
				t C_{org} y^{-1}		t $CO_{2\text{-eq}}$ y^{-1}	
	Mean	range		Min.	Max.	Min.	Max.
Seagrass	10.9	0.9 - 30.7	187	168	5741	618	21069
Tidal marsh	31.1	4.3 – 94.1	84	361	7904	1326	29009
Mangrove	38.8	9.3 – 97.1	3	28	291	102	1069
Total				**557**	**13,937**	**2,046**	**51,147**

The potential for avoided emissions associated with conservation of blue carbon habitats is significantly higher than those associated with enhanced sequestration (Table 7). Based on the stocks reported here, the potential avoided emissions associated with conservation of South Australian blue carbon habitats could be as high as 40,000 t $CO_{2\text{-eq}}$ km^{-2} for seagrass, 92,000 t $CO_{2\text{-eq}}$ km^{-2} for tidal marsh habitat and 83,000 t $CO_{2\text{-eq}}$ km^{-2} for mangrove habitat, which does not include the above-ground biomass carbon in mangroves. Were BC ecosystems included in Australia's Climate Solutions Fund, these avoided emissions would have a potential value of between $12,000 and $1.1 m per km^2 (or $120 - $11,000 per ha.).

Table 7. Estimated avoided CO_2 emissions per unit area based on conservation of blue carbon habitat in South Australia.

Ecosystem	Stock (t C_{org} km^2)		Potential avoided emissions (t $CO_{2\text{-eq}}$ km^{-2})			
			Lower estimate (50% remineralised)		Upper estimate (100% remineralised)	
	Mean	Range				
Seagrass	6.1	2,300– 10,900	4,221	20,002	8,441	40,003
Tidal marsh	14.0	600 – 25,000	1,101	45,875	2,202	91,750
Mangrove	14.5	2,700 – 22,700	4,955	41,655	9,909	83,309

The generally lower carbon stocks and accumulation rates in seagrass ecosystems compared to tidal marshes and mangroves is consistent with national surveys (Kelleway et al. 2017), indicating that, on a per unit area basis, there is a greater opportunity for blue carbon benefits in the mangrove and tidal marsh ecosystems of South Australia. However, the limited area of tidal marsh and mangrove will restrict the total number of projects. In contrast, the significantly larger area of seagrasses and the large extent of historical losses afford opportunities an order of magnitude higher in terms of total stock of carbon. For all blue carbon habitats, however, the sampling reported in this study is likely to under-estimate the stocks and sequestration rates of organic carbon in undisturbed ecosystems because of the focus on disturbed areas and areas with high levels of hydrodynamic energy. Consequently, our estimates of the potential abatement potential following restoration of disturbed sites is likely conservative.

Remaining uncertainties

A number of uncertainties remain which could significantly affect the estimates of blue carbon stocks and accumulation rates in South Australia. It is possible that any future approved methodology for blue carbon crediting in the ERF could require these uncertainties to be addressed. Two important uncertainties that could affect the estimated abatement associated with potential South Australian blue carbon projects are:

- Calcification rates in blue carbon ecosystems. The precipitation of carbonate in blue carbon ecosystems through the action of calcifying organisms can result in a net emission of CO_2. In blue carbon ecosystems with high rates of calcification this may offset some of the net sequestration of CO_2 (Saderne et al. 2019) and so may need to be accounted for in any method; and
- The fate of the OC following habitat loss. Estimating the abatement potential in blue carbon projects requires an assumption about the amount of the carbon that will be remineralised following disturbance (i.e. the emission factor). It is assumed that actions to prevent carbon losses will reduce these emissions and be eligible for crediting. This may not be the case if some of the lost carbon is either highly refractory and cannot be remineralised or if it is re-buried before it can be remineralised. Currently emissions factors have not been determined for South Australian ecosystems. In this study we used two estimates of the potential emissions following disturbance (50% and 100% of the lost carbon is remineralised – see Table 7). Any future projects would need to validate these assumptions or determine site/project-specific emission factors. Applying assumed emissions factors will generally result in a discounting of the carbon crediting, to offset uncertainties associated with the estimates.

Recommendations:

- **It is recommended that a strategic assessment of blue carbon stocks and accumulation rates in South Australia be undertaken, targeting currently under-represented habitat types and identifying areas known to have suffered historical disturbances or which are likely to experience future disturbance.**

  This study was restricted to three specific case studies of potential blue carbon CO_2 abatement potential. The case studies confirmed the potential of restoration or conservation of blue carbon habitat to enhance carbon sequestration rates or to avoid emissions of greenhouse gases. The next step in the pathway towards implementing a blue carbon strategy is to obtain a better understanding of the State-wide opportunity for blue carbon activities and the financial tools by which these could be implemented.

  The State-wide opportunity for blue carbon will be a function of the extent of blue carbon habitat that is potentially available for crediting activities. Under possible future financial mechanisms (e.g. should the ERF extend to include a blue carbon method), this will be, primarily, areas of blue carbon habitat that have either been disturbed, and so represent an opportunity for enhanced carbon sequestration through rehabilitation, or areas which are threatened by future development and represent an opportunity for avoided emissions through conservation. The viability of such projects will depend on the extent of these areas, development of government blue carbon financing mechanisms, and the future price of carbon credits.

  The next step in a 'road-map' for the assessment and development of blue carbon opportunities in South Australia is to assess the distribution of the blue carbon habitats and their condition, in order to identify priority areas or 'hot-spots' for potential abatement projects. A sampling program is recommended, which should:

- Map and classify the blue carbon ecosystems, specifically identifying not only the presence of the habitat but also its condition (undisturbed, previously disturbed, currently disturbed) and the depositional nature of the habitat (sheltered/depositional v unsheltered/erosional);
- In representative sites of the above mapping categories, assess the organic carbon stocks and accumulation rates, stratified by:
  - Previously disturbed v undisturbed;
  - Sheltered/depositional vs exposed/erosional (especially for seagrass);
  - Different seagrass habitats – particularly, enhancing the database on *Amphibolis* spp.
- From the above, map the blue carbon resource, identifying the priority areas for blue carbon project opportunities (that is, areas with the potential to meet additionality requirements), and estimate the magnitude of abatement they could provide. This may be best achieved through a combination of geomorphic-based modelling at State or sub-State level (e.g. Rogers et al. 2019) coupled with overlays of known historical and planned land-use

- **It is recommended that future assessments of blue carbon accumulation rates use a combination of radio-isotope and surface elevation table (SET) techniques**.

  Carbon crediting methods require some form of verification of the carbon accumulation in a project site, and this requires an estimate of the carbon sequestration rate. Typically, a higher price is paid when site-based measurements are used, but these cost more to collect. The alternative is to use modelled values or values estimated from similar sites in the region, but the carbon credits will be discounted relative to using site-based measurements. Despite this discounting, the relatively high costs of determining site-specific sediment and carbon accumulation rates can make the use of models appealing. At this time, FULCAM (the national inventory model) does not include a method for blue carbon ecosystems. More data are required, at least initially, to produce a robust model of soil carbon accumulation rates. Carbon prices reduce with increasing uncertainty, so a poorly validated model do not necessarily help, as they provide low levels of confidence in the carbon estimates, especially for South Australia which appears to have conditions and accumulation rates quite different to those places where most of the available data are derived from. Therefore, any future blue carbon assessment in South Australia might be best served by continuing to include direct measurements of carbon accumulation rates.

  The two common approaches to determining soil carbon accumulation rates rely on either radio-isotope based approached or surface elevation tables (SETs). In this study, radio-isotope (^{210}Pb dating) technique yielded carbon accumulation rates at about 50% of the sites studied. At the remaining sites, mixing of the sediment prevented reliable estimates being developed, though the method did provide insights into the sedimentation processes occurring at the sites. SETs have the advantage of not being susceptible to the problems of soil mixing. However, they do not reveal the processes occurring at the site in the way that ^{210}Pb method can, and in our study they provided highly variable accumulation rates, both spatially and temporally, indicating that longer (possibly decadal) timescales and/or greater replication may be needed to generate reliable estimates of carbon accumulation rates. Using a combination of the methods is likely to provide greater certainty of obtaining accumulation rates, in a reasonable time period, and understanding the processes occurring at a site.

- **It is recommended that, subject to the release of an approved blue carbon method within the ERF, appropriate studies be undertaken to determine the emissions factors associated with disturbance of South Australian blue carbon ecosystems.**

  The case studies reported here confirm that there is a loss of sedimentary organic carbon following disturbance to the seagrass and mangrove ecosystems assessed. We have used these losses to estimate potential abatement opportunities. However, these estimates require assumptions regarding the baseline emissions from blue carbon habitats and the potential emissions (i.e,.

conversion of disturbed soil carbon into CO_2 and other greenhouse gases) following disturbance. Currently, there are no direct measures of the baseline emissions or post-disturbance emissions and almost no information on emissions of methane and nitrous oxide. Improved understanding of emissions will improve the certainty around predicted and measured abatement and will influence the extent of credits that may be obtained for blue carbon actions and the cost-benefit analysis of potential projects.

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Appendix 1. Summary details of all blue carbon ecosystem cores collected and reported in this study

Core ID	location	Ecosystem	Vegetation	sampling date	Site type	Depth sampled (surface/ deep)	Dated short-term (Y/N)	Dated long-term
A1	Barker Inlet	seagrass	*P. sinuosa*	Dec. 2014	Baseline	Deep	N[a]	Y
A2	Barker Inlet	seagrass	*P. sinuosa*	Dec. 2014	Baseline	Deep	N[a]	Y
A3	Barker Inlet	seagrass	*Z. nigracaulis*	Dec. 2014	Baseline	Deep	N[b#]	N[c#]
A4	Barker Inlet	seagrass	*P. sinuosa*	Dec. 2014	Baseline	Deep	N[b#]	Y
A5	Barker Inlet	unvegetated		Dec. 2014	Baseline	Deep	Y	Y
A6	West Beach	unvegetated		Dec. 2014	Baseline	Deep	N	Y
A7	Semaphore	seagrass	*P. sinuosa*	Dec. 2014	Baseline	Deep	N[b#]	Y
A8	West Beach	unvegetated		Dec. 2014	Baseline	Deep	N	Y
A9	West Beach	seagrass	*Z. nigracaulis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A11	West Beach	seagrass	*A. antarctica*	Dec. 2014	Baseline	Deep	N[b#]	Y
A12	Port Pirie	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	Y	Y
A13	Port Pirie	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	Y	Y
A15	Port Pirie	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	Y	Y
A28	Whyalla	unvegetated		Dec. 2014	Baseline	Deep	N	N
A29	Whyalla	unvegetated		Dec. 2014	Baseline	Deep	N	N
A30	Whyalla	unvegetated		Dec. 2014	Baseline	Deep	N	N
A31	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	N[c#]
A32	Whyalla	seagrass	*P. australia/P. sinuosa*	Dec. 2014	Baseline	Deep	N[a]	Y
A33	Whyalla	seagrass	*P. australia/P. sinuosa*	Dec. 2014	Baseline	Deep	N[b*]	N[c#]

A34	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A35	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A36	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A37	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[a]	Y
A38	Whyalla	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A39	Whyalla	seagrass	*P. australia + P. sinuosa*	Dec. 2014	Baseline	Deep	Y	Y
A26	Port Broughton	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	Y
A27	Port Broughton	seagrass	*P. australis*	Dec. 2014	Baseline	Deep	N[b#]	N[c#]
PB1	Port Broughton	unvegetated		June 2017	Disturbed	Deep	N[a]	N
PB2	Port Broughton	unvegetated		June 2017	Disturbed	Deep	N[a]	N
PB3	Port Broughton	unvegetated		June 2017	Disturbed	Deep	N[a]	N
PB4	Port Broughton	seagrass	*P. australis*	June 2017	Undisturbed	Deep	N[b*]	N[c*]
PB5	Port Broughton	seagrass	*P. australis*	June 2017	Undisturbed	Deep	Y	N[c*]
PB6	Port Broughton	seagrass	*P. australis*	June 2017	Undisturbed	Deep	N[b*]	Y
AS1	Semaphore	unvegetated		June 2017	Disturbed	Deep	N[a]	Y
AS2	Semaphore	unvegetated		June 2017	Disturbed	Deep	N[a]	N[c*]
AS3	Semaphore	unvegetated		June 2017	Disturbed	Deep	N[a]	N[c*]
AS4	Semaphore	seagrass	*P. sinuosa*	June 2017	Undisturbed	Deep	Y	N[c#]
AS5	Semaphore	seagrass	*P. sinuosa*	June 2017	Undisturbed	Deep	N[b*]	N[c#]
AS6	Semaphore	seagrass	*P. sinuosa*	June 2017	Undisturbed	Deep	N[b*]	N[c#]
A17	Port Augusta	mangrove	*A. marina*	Dec. 2014	Baseline	Deep	N[b#]	Y
A18	Port Augusta	mangrove	*A. marina*	Dec. 2014	Baseline	Deep	N[b#]	N
A21	Whyalla	mangrove	*A. marina*	Dec. 2014	Baseline	Deep	N[b#]	Y
A24	Port Broughton	mangrove	*A. marina*	Dec. 2014	Baseline	Deep	N[b#]	Y
A25	Port Broughton	mangrove	*A. marina*	Dec. 2014	Baseline	Deep	N[b#]	Y

TI1	Torrens Island	mangrove	*A. marina*	June 2017	Undisturbed	Deep	Y	N[c*]
TI2	Torrens Island	mangrove	*A. marina*	June 2017	Undisturbed	Deep	Y	Y
TI3	Torrens Island	mangrove	*A. marina*	June 2017	Undisturbed	Deep	Y	N[c*]
GMD4	Mutton Cove	mangrove	*A. marina*	Nov. 2017	Disturbed	Deep	N[b*]	N[c#]
GMD5	Mutton Cove	mangrove	*A. marina*	Nov. 2017	Disturbed	Deep	N[b*]	N[c#]
GMD6	Mutton Cove	mangrove	*A. marina*	Nov. 2017	Disturbed	Deep	N[b*]	N[c#]
GMD1	Mutton Cove	mangrove	*A. marina*	June 2017	Disturbed	Deep	Y	N
GMD2	Mutton Cove	mangrove	*A. marina*	June 2017	Disturbed	Deep	Y	N
A16	Port Augusta	tidal marsh	*Sarcocornia*	Dec. 2014	Baseline	Deep	N[b#]	Y
A19	Port Augusta	tidal marsh	*Sarcocornia*	Dec. 2014	Baseline	Deep	N[b#]	Y
A20	Whyalla	tidal marsh	*Sarcocornia*	Dec. 2014	Baseline	Deep	Y	Y
A22	Port Broughton	tidal marsh	*Sarcocornia*	Dec. 2014	Baseline	Deep	N[b#]	Y
A23	Port Broughton	tidal marsh	*Sarcocornia*	Dec. 2014	Baseline	Deep	N[b#]	Y
MCD1	Mutton Cove	tidal marsh	*Sarcocornia /A. marina*	June 2017	Disturbed	Deep	N[b*]	N[c#]
MCD2	Mutton Cove	tidal marsh	*Sarcocornia /A. marina*	June 2017	Disturbed	Deep	Y	N[c#]
MCD3	Mutton Cove	tidal marsh	*Sarcocornia /A. marina*	June 2017	Disturbed	Deep	N[b*]	N[c#]
Surface (216 cores[d])	Clinton, Port Augusta, Port Broughton, Port Gawler, Mutton Cove, Port Paterson, Port Pirie, Port Wakefield, Torrens Island	tidal marsh and mangrove	*Sarcocornia /A. marina*	spring 2016, spring 2017	Undisturbed	Shallow	N	N

[a] no excess ^{210}Pb

[b] mixed or not analysed

[c] mixed, unreliable or not analysed

[d] see Asanopoulos et al. (2019) for details

[*] carbon accumulation rate estimated based on average sediment accumulation rate for site

[#] carbon accumulation rate estimated based on average sediment accumulation rate for ecosystem

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