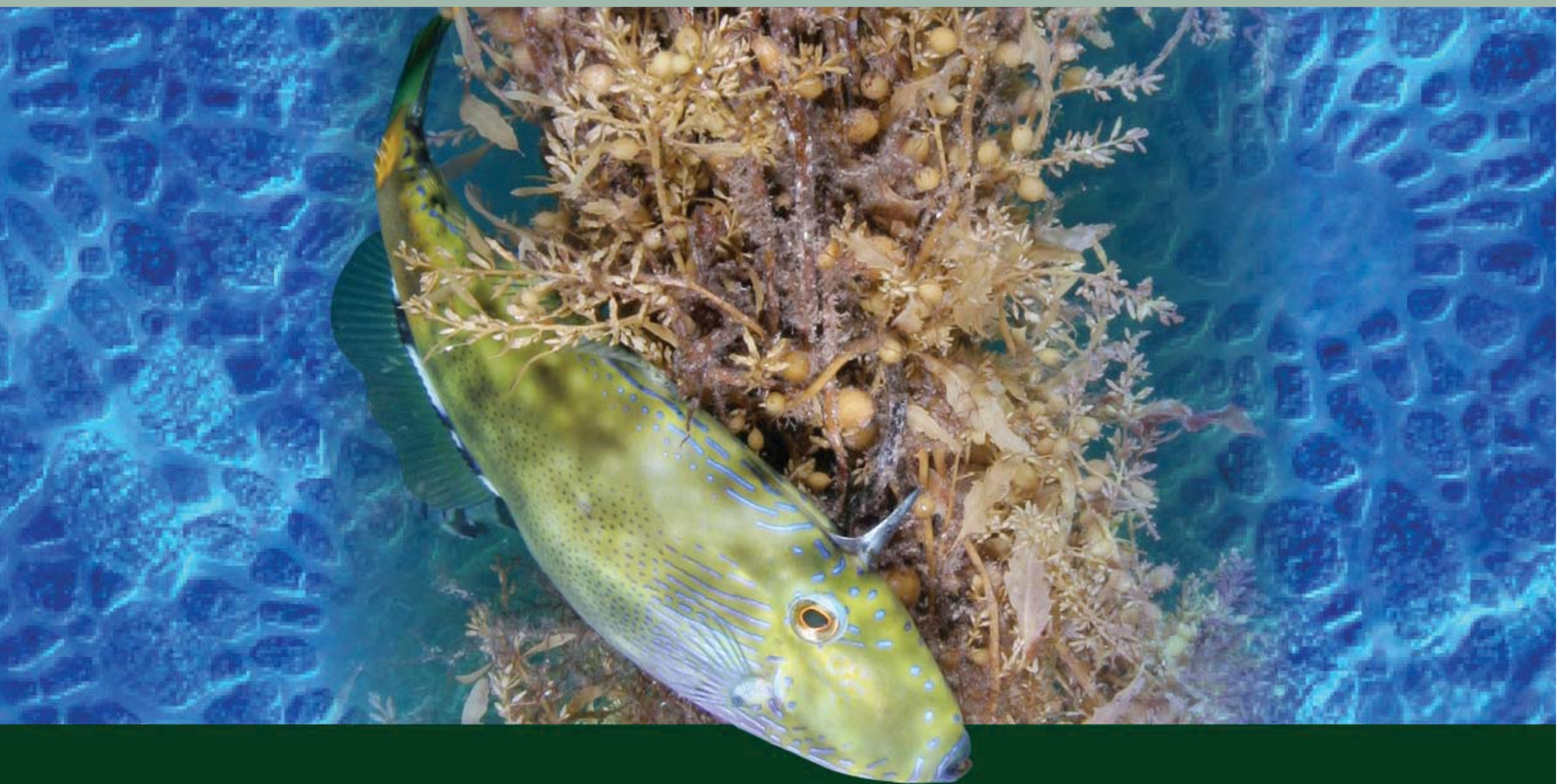
Coastal Carbon Sinks in South Australia

Technical Report 2011/02



Department of Environment and Natural Resources

Government of South Australia

Coastal Carbon Sinks in South Australia

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Executive Summary

This project has three broad aims:

- discuss the processes that drive carbon sequestration in South Australian coastal and marine benthic ecosystems to inform policy development and research opportunities
- estimate Carbon sequestration potential within the boundaries of South Australia's 19 Marine Parks (MPs) and South Australian coastal waters, and
- discuss some of the issues around carbon accounting of bio-sequestration linked to DENR programs

In this study, published sequestration rates have been combined with existing habitat mapping, to quantify annual Carbon sequestration. We estimate between 200,000 and 328,000 tonnes of Carbon is sequestered per year within all Marine Parks. As much as 580,000 tonnes is sequestered per year by coastal, estuarine and marine habitats as mapped across all SA. When converted to the units of Australia's carbon market, carbon dioxide equivalent units (CO_2-e), this Marine Parks estimate equates to between 733,000 and 1.2 million tonnes CO_2-e per year. Priced at $23 per tonne CO_2-e this has a value of between $17m and $27m. The state-wide upper estimate equates to over 2.1 million tonnes CO_2-e per year representing a value of $49m.

This is however, less of an exercise in obtaining absolute sequestration amounts and more an opportunity to suggest and describe issues that DENR policy may consider as areas of focus or potential research for longer term environmental benefits and carbon accounting.

These estimates are based on published sequestration rates for three major carbon sequestering vegetation communities; seagrass meadows, saltmarshes and mangrove systems. Maps are provided to illustrate how the estimates vary across SA's Marine Parks in relation to density of vegetation. Assumptions associated with this analysis include that the mapped areas match the models of measured sequestration rates from the literature. As a proof of concept, the study has shown potential to assist DENRs carbon accounting processes, visualisation and communication.

This study indicates that coastal ecosystems can sequester comparable amounts of carbon to terrestrial systems. Further, it discusses how these carbon sinks can be considered as more effective in removing carbon from the atmosphere on a per hectare basis than freshwater wetlands, which generate methane that offsets the carbon capture benefits. This illustrates the importance of carefully considering all components of the carbon cycle within any carbon accounting system. Selective inclusion or exclusion of components can lead to spurious assessments of net impacts.

This study has provided a broad brush approach with scope for refinement while suggesting numerous areas for research opportunity and potential policy response. It makes clear the benefits to SA from our Marine Parks and that sufficient protection must be afforded to these systems as degradation reduces their capacity to continue removing carbon from atmosphere and oceans.

It also provides a useful first point of reference for coastal carbon dynamics and literature (local and international) on the topic. As DENR considers the implications of carbon markets and pursues conservation activity along our coasts in response to the challenges of climate change, such methods and tools will need refinement, adoption and departmental support to play an effective role.

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Introduction

Background

The South Australian (SA) Department of Environment and Natural Resources (DENR) interest in the estimation of carbon in the environment is founded on an understanding of climate change driven by greenhouse gas emissions and carbon storage. The quantification of carbon sources and sinks is important in assessing impacts of and responses to climate change. With large areas of the South Australian land and seascape under its stewardship, DENR and the SA community therefore benefit from information, communication and accounting tools in relation to carbon sequestration.

The Australian Government's recent legislative changes under the 'Clean Energy Plan' provide for a 'Biodiversity Fund' aiming to "support landholders to undertake projects that establish, restore, protect or manage biodiverse carbon stores" (Australian Government [on-line1]). While these documents currently make no specific reference to coastal ecosystems, the skills and knowledge to estimate the contribution of coastal carbon will allow DENR to participate and potentially capitalise on opportunities that may arise from these and other initiatives.

The carbon estimates in this work are drawn from a somewhat limited body of literature on the subject. While care has been taken to appropriately model sequestration rates with mapped areas of coastal and benthic vegetation, differences do exist between the species composition of the mapping and the source (species) of sequestration rates.

Aims and Objectives

The aim of this paper is to synthesise available data sources into carbon estimates for MPs as a starting point for discussion particularly in relation to climate change policy development and opportunities for research. Methods and results may also have potential linkages with other carbon projects underway in DENR such as in the pastoral region (eg Trans Australia EcoLink), River Murray Forrest, soil management and cropping activities.

A further objective is to provide an initial point of reference for policy or research investigations on carbon flows in coastal environments.

Methodology

The broad carbon estimates in this work focus on gross Carbon sequestration rates of four ecosystem types or 'Carbon Classes'. This includes two main assumptions to arrive at the rates used.

Firstly, carbon emissions from these systems such as via methane generation are out of scope. Having said this, there are numerous studies that have observed lower methane fluxes in high salinity environments compared with freshwater wetlands (e.g. Akumu et al 2010, Verma et al 2002). They suggest the reason may be out competition for substrates by sulphate reducing bacteria (Lovely et al 1983, Abram et al 1978).

Secondly, sequestration rates described represent non-labile components of the resident carbon cycles. Labile carbon or carbon with relatively high turnover time (<10 years) is released to the atmosphere as carbon dioxide through decomposition and microbial activity. Conversely, carbon in the soil and buried biomass, can be unavailable to decomposition and therefore persist for hundreds or thousands of years. This type of carbon can be accounted towards greenhouse abatement (Australian Government [on-line2]) and is the focus of rates used here.

Carbon Classes

The main source of sequestration rates for this study comes from a publication on "The management of natural coastal carbon sinks" Laffoley & Grimsditch (2009). This identifies 5 coastal habitat types: Tidal Salt Marshes, Mangroves, Seagrass Meadows, Kelp Forests and Coral Reefs. Four of these occur in and around the South Australian coast (all but Coral Reefs). Kelp forest mapping is currently being trialled with the use of remote sensing but is not comprehensive enough to be included in the quantitative parts of the study. The four habitat types are hereafter referred to as ***carbon classes*** and table 1 shows the sequestration rates used for each of them.

carbon class	$gC/m^2/yr$	tC/ha/yr
saltmarsh	210	2.1
mangrove	139	1.39
seagrass	68-120	0.68 - 1.2
kelp	670 – 1300	6.7 – 13

Table 1: **annual carbon sequestration rates used for each carbon class in grams per square metre and metric tonnes per hectare.**

Following sections briefly explore the validity and reasoning behind these rates for use in SA, considering international and more local publications. A recent project to estimate carbon accumulation for landholders along the eastern shore of Gulf St Vincent compiled information as presented in Table 2. This table provides support for rates used in table 1 in that they are of an appropriate order at this broad level. Where white cells contain data, they show ranges or comments that represent the best available assessment of carbon for that system. Empty white cells indicate a value is likely but not apparent in literature (eg plankton biomass in mangroves, above ground biomass in grassland and saltbush country). Grey cells however indicate a value is not relevant to that landform/ecosystem, (eg planktonic biomass will not be present on a sand dune) or where the amount would be very small (eg above ground biomass on a sabkha is very sparse and slow growing, so may be a negligible amount annually). The authors note these judgements are subjective only and are open to debate (P.Coleman, pers. com.) The reference list provided in Appendix D was among the primary sources for Cook (2009) and is reproduced here with permission as a resource for further research.

	Soil carbon	Above ground biomass	Below ground biomass	Planktonic biomass
Back swamp	1.5 - 3.5 t C / ha /yr			
Chenier or dune	Up to 1.97 t C/ha/yr (higher rainfall area)			
Embankment	0 - 3.5 t C / ha / yr, dependant on bank usage, erosion, soil moisture, salinity and			
Grassland and saltbush	0.1 t C /ha/yr			
High saltmarsh		0.35 - 3.5 t C / ha / yr		
Mallee		0.23 - 4.45 t C / ha / yr		
Mangroves	0.89 - 1.8 t C /ha/yr	25t dry biomass / ha	20-100t dry biomass / ha	
Mid to low marsh	0.64 - 2.2 t C /ha/yr	15t dry biomass / ha	13 t dry biomass / ha	
Sabkhas	0 - 1.85 t C / ha / yr			
Seagrass beds	0.012 - 1.33 t C /ha/yr			
Stormwater treatment wetlands	4 - 7 t C / ha / yr			
Tidal flats	0.45-11.3 t C/ha/yr			
Tidal creeks	Potentially similar to tidal flats			

Table 2: carbon accumulation assessments from literature - derived from Cook (2009) (see appendix D for related reference list)

Saltmarsh

There are 21,676 ha of tidally influenced saltmarshes in DENRs mapping along the coasts of SA

Saltmarshes are intertidal ecosystems dominated by low growing herbs, shrubs and grasses tolerant of high salinity and poorly aerated soils (CRC-CZEWM, 2004). Chmura et al (2003) calculated that on average saltmarshes store 210 $g/m^2/yr$ below and above ground (in Laffoley & Grimsditch, 2009). This assessment is based on observations from North American and European examples where a mix of perennial grasses (eg Spartina spp), perennial broad leaved herbaceous plants (eg Atriplex spp) and perennial succulents (eg tecticornia) are generally dominant. In southern Australia, the mix of species in saltmarshes may contain more *sporobolus* and *juncus* species alongside samphires (*tecticornia spp*). However it is not vegetation growth that drives carbon sequestration in these habitats, rather it is the accretion of carbon rich soil sediments via tidal transport (Howe et al, 2009). In one Australian context, Howe et al showed that the Hunter River estuary saltmarshes have comparable sequestration rates (202 $g/m^2/yr$) to those of Chmura et al.

Intertidal marshes on delta flats can benefit from river sediment (including flood events) as well as daily tidal inundation depositing sediment from sea water, whereas saltmarshes open to the sea will have sequestration rates depending on amount of suspended particles in the water column and the speed and depth of inundation (including storm events). Sediment accretion rates in SA saltmarshes are not well known but techniques exist such as sediment elevation tables and spreading of chalk dust to mark stratum levels (P.Colemnan pers com). Opportunities may exist for SA to use existing coastal transects to monitor accretion rates in the field. Further information on this topic in a northern hemisphere context can be found at http://www.pwrc.usgs.gov/set/ . Studies of carbon sequestration in saltmarsh environments are few in international literature and in Australian literature, even rarer. It is however, an area of emerging importance as recognition increases of tidal marsh wetland restoration as a significant sequestration activity;

"*Unlike many freshwater wetlands, saltwater tidal marshes release only negligible amounts of methane, a powerful greenhouse gas; therefore, the carbon storage benefits of tidal salt marshes are not reduced by methane production. In addition, as sea levels rise, tidal marsh* *plains continue to build up to match the rise in water level, if suspended sediments are adequate, continually pulling carbon dioxide out of the air in the process.*" (Trulio et al, 2007)

Mangrove

There are 15,190 ha of tidally influenced mangroves in DENRs mapping along the coasts of SA.

Mangrove communities in SA are populated by one species - *Avicennia* marina (mangrovewatch.org, 2011). Known as among the southern most occurrences of mangroves on the globe, they are generally found seaward of saltmarshes and often interspersed with seagrass beds and mudflats.

Carbon sinks to consider in these systems are associated with burial of Carbon in sediments, and net growth of forest biomass. Burial in the soil profile represents long term sequestration, whereas increase in biomass through expansion or (re)planting is relevant only in the shorter term (e.g. tens of years) (Laffoley & Grimsditch, 2009).

Mangrove forests can end up with carbon in roots, branches and as litter fall, or exported as either CO_2 emissions or dissolved/particulate organic carbon. Amounts of debris and leaf litter are related to the structure of the forest – lower and more open canopies will gather less debris, whereas taller, more closed canopies are more likely to blanket larger amounts of carbon inputs on the forest floor. Growth and decay rates thus provide a major driver to sequestration potential.

The mangrove forest's complex root systems, which anchor the plants into underwater sediment, slow down incoming tidal waters allowing organic and inorganic material to settle into the sediment surface. Low oxygen conditions slow decay rates, resulting in much of the carbon accumulating in the soil. Studies of mangroves across the Indo-Pacific region found that on a per hectare basis, they have more carbon in their soil alone than most tropical forests have in all their biomass and soil combined (Donato et al 2011).

Openness to tidal movement is a further driver of sequestration rates. For example, areas with large tidal amplitudes have more opportunity for transport, both into and from mangrove systems, as already discussed for saltmarshes.

Howe et al (2009) makes the observation that landward migration of mangrove systems due to sea level rise is likely to displace saltmarsh communities that are often constrained by infrastructure such as coastal roads and levees. With barriers restricting access to areas for the saltmarshes to colonise, this change in vegetation cover may represent a net loss of sequestration capacity given mangrove sequestration rates at 66% of saltmarshes per unit area.

The value of 139 $g/m^2/yr$ is used in this study based on a number of studies across the world using various methods (Laffoley & Grimsditch, 2009). More research is needed to ascertain the confidence this value has in representing SA mangrove areas.

Seagrass

There are 685,744 ha of seagrass meadows in DENRs mapping off the coasts of SA

A report for the Adelaide Coastal Waters Study (Moore and Westphalen 2007) describes seagrass ecosystems as amongst the most productive plant systems on the planet on a per unit basis. Again with a paucity of local literature to draw on, this study sought to describe sequestration potential in these systems as well as quantify impacts from seagrass losses in South Australian waters.

Species in the *Posidonia australis* group (*P. angustifolia, P. australis, P. sinuosa*) are described as "probably the bulk of seagrass meadows in southern Australia". These species produce below ground "matte" formations that are estimated to store between 30 and 50% of the plants biomass below ground. This underground root system is likely to store carbon for "decades to centuries if the environmental conditions are maintained and seagrass plants continue to live above the stored carbon" (Moore and Westphalen 2007).

The report cited studies that estimate around 5,200 ha of seagrass meadows have been lost from Gulf St Vincent (GSV). This estimate looked only at coastal waters near Adelaide - current mapping shows expanses totalling nearly 80,000 ha in just the Upper GSV MP (see table 5). The map in appendix C2 illustrates the amount of seagrass meadows mapped outside designated MP boundaries.

Sequestration rates of 68-120 g/m^2/yr are described by Moore and Westphalen based on lower limit of 10% net primary production sequestered into long term storage (in matte formations) and an upper limit of 18%. These rates broadly match with the average rates for seagrasses of 83 g/m^2/yr given in Laffoley & Grimsditch (2009) based on Mediterranean species including *Posidonia oceanica*. However being a local study focussed on local species, this pilot uses the range to generate upper and lower estimates in favour of the Laffoley & Grimsditch rate.

Kelp

A variety of kelp species occurs in SA, particularly in the cooler waters of the South East coast such as the large kelp (*Macrocystis angustifolia*) and the bull kelp (*Durvillaea* potatorum). Sheltered waters and inlets of more northern waters also support a number of subtropical species where temperatures are high enough for them to survive (PIRSA 2003). While some mapping of reef habitats has occurred, it is insufficient in extent and lacks recording of vegetated state to assist quantitative assessment of overall sequestration potential.

Laffoley & Grimsditch (2009) describes *Macrocystus* net primary production of 670 – 1300 g/m^2/yr or 6.7 – 13 t/ha/yr. This indicates high potential for carbon storage through restoration and protection of kelp forests – and is included to provide a comparison with the other communities described. However, as mentioned above, area estimates and sequestration totals are not included in the scope of this pilot.

While the MP process is producing improved mapping of many benthic communities, research opportunities exist to better our understanding of the location and fraction of kelp carbon that is incorporated into long term stores such as marine sediments.

Mapping

The three relevant carbon classes were matched to existing habitat mapping data stored in DENR. Appendix A1 illustrates the use of these various data sources to show the extent of each carbon class within the Upper Spencer Gulf MP. The source datasets include:

a) Marine Park planning maps (MARINE.StateBenthicHabitats mapped at 1:10,000 scale, in 2008-2010)
b) estuaries inventory (MARINE.EstuaryHabitats mapped at an average of 1:30,000, in 2009) and
c) saltmarsh and mangrove mapping (COASTAL.SaltmarshMangroveHabitats effectively mapped at between 1:40,000 and 1:100,000 in 2005-2010)

A fourth dataset does exist (MARINE.BenthicHabitats) which mapped these ecosystems around the late 1990s from satellite imagery. The scale of this mapping (approximately 1:100,000) means it has a positional accuracy of lines between +/-100m and +/-1000m. While this was considered too coarse even for broad ecosystem estimates, the mapping does show significant areas of seagrass meadows that have been excluded from this work. This dataset records an area of approximately 851,000 ha in comparison to the total of 722,610 ha used in this analysis (see figure 1). Therefore, it can be said that results are an underestimate potentially by some 15%. It is worth noting that even this fourth dataset is not considered a comprehensive description of all of South Australia's benthic carboniferous habitats.

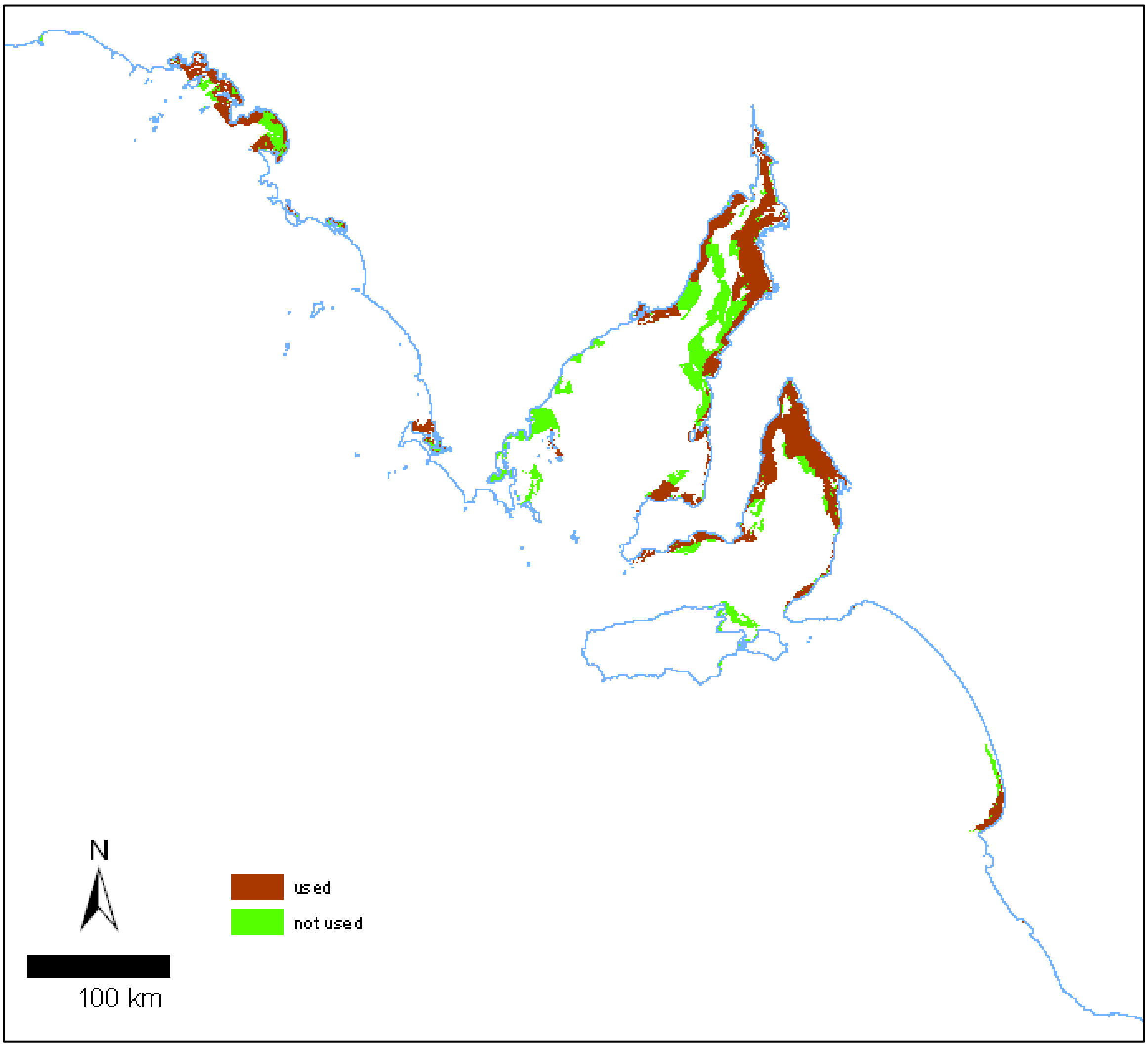

Figure 1: comparison of coastal carboniferous ecosystem mapping used in this study (dark red) and additional mapping not used (green) due to coarseness of scale. This indicates results are conservative.

Based on coverage and in order of decreasing capture scale, the three layers of habitat mapping were prioritised to identify areas of each carbon class. Dataset a) was the primary source of information, if there were gaps in that then dataset b) was used, and lastly, dataset c) was used as the third input if it added more area of any carbon class.

The tables in Appendix B give a break down of how much of each carbon class was represented in each dataset for the state. Descriptions of habitats within these datasets vary slightly, so each were aligned to carbon classes based on vegetation/habitat attributes as noted.

Datasets b) and c) also contain an indication of 'tidal class' for each mapped polygon, which allowed exclusion of areas above tidal influence where sequestration potential is limited (see Table 3).

Tidal Classes	
included	**excluded**
Intermittent Tidal	Non Tidal
Intertidal	Supratidal
Subtidal	Stranded Tidal
	Unkown

Table 3: **classes of tidal influence that were included and those indicating above tidal influence that were excluded.**

The aim was to use the Carbon sequestration rates in Table 1, to apportion to areas mapped of each carbon class. These rates, based on dry mass weights or other methods relate to 100% coverage of that class over a square metre. It is an assumption that 100% coverage as mapped equates to the same density of carboniferous matter (vegetation, roots or soil) as was used to derive sequestration rates. A pro rata method was then used to modify rates where the mapping records less than 100% coverage.

The three source layers deal with density of cover in distinct ways. In dataset a), a cover range is recorded, therefore in order to assign a value to pro rata the Carbon storage rate, median values were adopted, as in Table 4. Dataset b) has a density field with a single number which was adopted directly. Dataset c) does not have a coverage rating, rather a descriptive value for "integrity". Therefore, with advice from data custodians, coverage was assigned based on the Integrity field as noted in Table 5.

Cover range	Coverage % used
90-100	95
70-90	80
50-70	60
30-50	40
10-30	20
0-10	5

Table 4: cover ranges and percentages used for dataset a) MARINE.BenthicHabitats layer.

Integrity Type	Coverage % used
Intact	90
Uniform	85
Dieback	70
Degraded	60
Patchy	50
Prograding	50

Table 5: coverage percentages adopted for integrity field in dataset c) COASTAL.SaltmarshMangroveHabitats layer.

The pro rata sequestration rates were then applied to areas of each of the three carbon classes for the extent of the mapping within individual Marine Parks and aggregated for the three classes mapped outside MPs. Results and summaries are presented in the next section.

Carbon Dioxide Equivalent Units

To account for the differences in the warming effect of various greenhouse gases, carbon accountants often express emissions of various gases in CO_2 equivalent (CO_2-e) terms. This represents the amount of CO_2 that would have the same relative warming effect as the basket of greenhouse gases actually emitted (CO2australia [on-line]). This also works to provide a standard measure for activity where sequestration in a plant, ecosystem, soil profile etc is measured in tonnes of carbon. By multiplying those tonnes of carbon by 3.67 (Moore and Westphalen, 2007; Neumann et al 2011), it is effectively converting the weight of sequestered carbon into the weight of carbon dioxide (see **Table 6**).

carbon class	gC/m^2/yr	tC/ha/yr	tCO2-e/ha/yr
saltmarsh	210	2.1	7.7
mangrove	139	1.39	5.1
seagrass	68-120	0.68 - 1.2	2.5-4.4
kelp	670 – 1300	6.7 – 13	24.5-47.7

Table 6: sequestration rates presented as amounts of Carbon and corresponding Carbon Dioxide Equivalents.

While these estimates are in need of more local studies to increase confidence in their accuracy, they indicate that these coastal systems are comparable or exceed long term sequestration in terrestrial systems (Laffoley & Grimsditch, 2009, p.27).

Results for this project are given in both tonnes of Carbon and tonnes of CO_2-e for transparency and comparison.

Results

Four outputs from the methodology developed in this project are summarised below:

1) Total areas of carbon classes and annual sequestration estimates: Table 7 shows that using existing mapping across the whole of SA, the carbon classes described potentially sequester around half a million tonnes of Carbon per year. This equates to over 2 million tonnes of carbon dioxide equivalent units. When focussing on Marine Parks only (Table 8), the total is between 200,000 and 300,00 tonnes, equating to over 1 million tonnes of carbon dioxide equivalent units per year. Seagrass beds account for 95% of that.
2) Table 9 breaks down the rates above by MP. It is sorted to show MPs with greatest potential according to this method in descending order.
3) Maps of the Upper Spencer Gulf MP show the distribution of pro rata sequestration rates as lower estimate (appendix A2) and upper estimate (appendix A3)
4) Maps of the whole of SA coastal region (appendices C1, C2, C3) showing upper estimate pro rata Carbon sequestration rates. These also show where carbon class mapping is absent from MPs or occurs outside MPs

Carbon Class	Area (ha)	% of total Carbon Classes	Sequestration Range			
			lower (tC/yr)	upper (tC/yr)	lower (tCO2-e/yr)	upper (tCO2-e/yr)
Mangrove	15190	2	18,809	18,809	69,030	69,030
Saltmarsh	21676	3	40,295	40,295	147,882	147,882
Seagrass	685744	95	296,443	522,313	1,087,944	1,916,889
Total	722610	100	355,547	581,417	1,304,856	2,133,800

Table 7: total sequestration rates, in tonnes of carbon (tC) and tonnes of carbon dioxide equivalent units (tCO_2-e) per year per carbon class for <u>whole of SA</u>.

The Australian Governments recent CleanEnergyFuture legislation has installed a price of $23 per tonne of CO2-e. In those terms, the above results indicate an annual dollar value of between $30M and $49M for total lower and upper estimates respectively. Recall here that due to mapping limits discussed above, these figures are conservative by potentially up to 15%.

Carbon Class	Area (ha)	% of total Carbon Classes	Sequestration Range			
			lower (tC/yr)	upper (tC/yr)	lower (tCO2-e/yr)	upper (tCO2-e/yr)
Mangrove	10453	3	12,808	12,808	47,007	47,007
Saltmarsh	10086	2	18,884	18,884	69,304	69,304
Seagrass	391016	95	168,085	296,265	616,873	1,087,291
Total	411555	100	199,777	327,957	733,183	1,203,602

Table 8: total sequestration rates, in tonnes of carbon (tC) and tonnes of carbon dioxide equivalent units (tCO2-e) per year per carbon class for <u>all Marine Parks</u> in SA.

For the Marine Park estimates in Table 8, the 2012 carbon price indicates an annual dollar value of between $17M and $27M for total lower and upper estimates respectively.

Marine Park	Carbon Class	Park Area (ha)	Carbon Class Area		Sequestration Range			
			Area (ha)	% of Marine park	lower (tC/yr)	upper (tC/yr)	lower (tCO_2-e/yr)	upper (tCO_2-e/yr)
Upper Spencer Gulf	Mangrove		6,388	4	7,850	7,850	28,808	28,808
	Saltmarsh		5,963	3	11,153	11,153	40,932	40,932
	Seagrass		95,895	54	37,687	66,469	138,310	243,941
	Total	176,837	108,246	61	56,689	85,472	208,050	313,681
Upper Gulf St Vincent	Mangrove		2,035	2	2,422	2,422	8,890	8,890
	Saltmarsh		2,200	2	4,062	4,062	14,908	14,908
	Seagrass		79,901	80	34,273	60,564	125,782	222,271
	Total	99,490	84,135	85	40,757	67,049	149,579	246,068
Nuyts Archipelago	Mangrove		1,115	0	1,416	1,416	5,196	5,196
	Saltmarsh		605	0	1,159	1,159	4,255	4,255
	Seagrass		56,324	16	26,560	46,706	97,476	171,411
	Total	357,825	58,043	16	29,136	49,281	106,927	180,862
Franklin Harbour	Mangrove		799	1	987	987	3,624	3,624
	Saltmarsh		487	1	926	926	3,397	3,397
	Seagrass		31,588	51	15,762	27,780	57,847	101,952
	Total	61,478	32,874	53	17,675	29,693	64,868	108,972
Southern Spencer Gulf	Seagrass		28,917	9	11,446	20,180	42,008	74,061
	Total	304,939	28,917	9	11,446	20,180	42,008	74,061
Lower Yorke Peninsula	Saltmarsh		15	0	22	22	79	79
	Seagrass		23,717	27	10,060	17,706	36,919	64,980
	Total	87,940	23,731	27	10,081	17,727	36,998	65,060
Upper South East	Saltmarsh		9	0	16	16	59	59
	Seagrass		19,887	18	9,868	17,337	36,217	63,626
	Total	112,574	19,895	18	9,884	17,353	36,276	63,684
Thorny Passage	Saltmarsh		202	0	391	391	1,436	1,436
	Seagrass		18,579	7	7,435	13,098	27,286	48,070
	Total	248,851	18,781	8	7,826	13,489	28,722	49,506
Eastern Spencer Gulf	Saltmarsh		58	0	110	110	405	405
	Seagrass		13,367	18	5,860	10,326	21,505	37,897
	Total	76,138	13,425	18	5,970	10,436	21,910	38,302
Encounter	Saltmarsh		242	0	457	457	1,677	1,677
	Seagrass		10,664	3	4,338	7,655	15,919	28,094
	Total	313,386	10,905	3	4,794	8,112	17,596	29,771
West Coast Bays	Mangrove		65	0	84	84	307	307
	Saltmarsh		287	0	552	552	2,026	2,026
	Seagrass		7,794	10	2,919	5,137	10,711	18,852
	Total	80,778	8,145	10	3,554	5,773	13,044	21,185
Sir Joseph Banks	Mangrove		52	0	50	50	182	182
	Saltmarsh		19	0	36	36	131	131
	Seagrass		4,385	2	1,878	3,307	6,894	12,137
	Total	264,597	4,456	2	1,964	3,392	7,207	12,450
Non MPA	Mangrove		4,737	n/a	6,001	6,001	22,023	22,023
	Saltmarsh		11,590	n/a	21,411	21,411	78,578	78,578
	Seagrass		294,728	n/a	128,357	226,048	471,071	829,597
	Total	n/a	311,055	n/a	155,769	253,460	571,672	930,198
Far West Coast	*no data*	251,673						
Gambier Islands Group	*no data*	11,952						
Investigator	*no data*	119,321						
Lower South East	*no data*	53,497						
Neptune Island Group	*no data*	14,570						
Southern Kangaroo Island	*no data*	68,582						
Western Kangaroo Island	*no data*	100,971						

Table 9: total sequestration estimates of tonnes of carbon (tC) and tonnes of carbon dioxide equivalent units (tCO_2-e) per carbon class per Marine Park - ordered highest to lowest.

Discussion

Limitations (Opportunities for Research)

This method is an introductory investigation into estimation of Carbon sequestration potential in SA coastal and marine environments. While care has been taken to adopt methods from relevant literature and apply them soundly to existing mapping of coastal and benthic communities, it is less of an exercise in obtaining absolute sequestration amounts and more an opportunity to suggest and describe issues that DENR policy may consider as areas of focus or potential research for longer term environmental benefits and carbon accounting.

In addition to baseline knowledge gaps, their also remains the need to further understand the impacts of climate change on these systems. For example, impacts on tidal wetland fauna, sediment trapping, nutrient and carbon fluxes are currently not known with any certainty (Lovelock et al, 2009).

Overall, the accuracy and resolution of sequestration estimates used in this study are at the lower end of the scale. They are useful for comparing different habitats and areas, suitable for educational and public relations purposes. To improve this accuracy, a number of issues need investigating. This section sets out to frame these as research opportunities.

The main issue for consideration is differences between sequestration rates of species or communities as described in the literature and the species or communities represented by mapping. The Methodology section briefly described some of the differences, here we list a number of these as issues that would benefit from further research.

All Carbon Classes

1. The use of pro rata values to modify rates in literature according to ‘density’ or ‘coverage’ of mapped species needs more scrutiny. E.g. does it represent a fair assessment of the openness of a mangrove forest with respect to debris and leaf litter production? Or what does a sparse seagrass meadow mean in comparison to a dense meadow, in terms of below ground carbon density?
2. For inclusion in IPCC calculations or carbon markets of either voluntary or official nature, the length or term of sequestration is important. E.g. Are both above and below ground parts of systems accountable or should we concentrate on longer term soil sequestration?
3. Confidence in DENR habitat mapping as it stands is relatively high, however it does not take into account rates of change in habitats either in extent or ‘density’ – is this significant?

Seagrasses

4. What Net Primary Production (NPP) rates are appropriate? E.g. is there research to support modification of these on environmental gradients; to what extent does herbivory influence NPP?
5. Current literature on sequestration rates is predominantly concerned with plant biomass accumulation. More detailed models could also incorporate microbial and animal biomass. This could potentially include the generation of Calcium Carbonates ($CaCO_3$) by calcareous epiphytes that live among vegetated benthic communities. Additional research is therefore needed to progress confidence in understanding these differences and incorporating new models of sequestration.

Along with the pro rata question in 1, issues 4 and 5 are concerned with the detail of carbon flow/process models. In saltmarsh and mangrove habitats, there are opportunities for research into local examples of sequestration quantification, e.g. measuring soil accretion rates within networks of monitoring sites.

Issue 2 relates to carbon markets and while still maturing in Australian and global contexts, there is a case for capacity building in DENR to fully understand the components to inform information and carbon accounting processes as they come on line and DENR is required to participate.

Issue 3 is more of a technical challenge in how to maintain repeatable ways of mapping carbon classes in coastal environments.

Other benthic communities

During the development of this project, a number of other areas related to carbon sequestration were discussed. While too nebulous and under studied to include even in this initial quantification, they highlight areas for future research in understanding the dynamics of carbon in the SA coastal environment and potential opportunities to assist in climate change mitigation. Loosely relating to the field of biogeochemistry, it was noted this is an area of study currently with few participants.

Very briefly, these topics included coastal and benthic areas such as:

- Un-vegetated sea beds
- mud flats
- reefs
- shell fish beds (e.g. oysters, razorfish, scallops, mussels, etc.)
- carbonates in subtidal sandy and limestone formations

Carbon Accounting

The contribution of “Blue Carbon” (i.e. cycling through aquatic ecosystems) to climate change, is being discussed in literature and media. The World Bank has recently released a report titled "Mitigating Climate Change through Restoration and Management of Coastal Wetlands and Near-shore Marine Ecosystems," which finds that drainage and degradation of coastal wetlands emit significant amounts of carbon dioxide directly into the atmosphere and leads to decreased carbon sequestration (Crooks, et al 2011).

The report emphasised the need for: protecting coastal wetlands; creating incentives for avoiding their degradation and improving their restoration; and including the protection of these ecosystems in carbon emission reduction strategies and climate negotiations.

Investment in these activities can link to other climate strategies and carbon financing mechanisms, provided that protocols on accounting, verification and reporting of net carbon uptake can be agreed. Given the limitations and opportunities described above, it is clear that SA is some way off standardised measures for carbon accounting in coastal environments.

Moves are underway however to develop such tools around the world. For example a new methodology for calculating mangrove carbon storage, has now been adopted under the Clean Development Mechanism (CDM) of the UN Framework Convention on Climate Change (UNFCCC) Kyoto Protocol. This method describes carbon stocks and changes to degraded mangrove systems in an accountable way to attract investment for large scale regeneration and planting (IUCN, [on-line]).

It is envisaged that further coastal systems will have similar tools evaluated and developed over coming years for even wider use, as responses to the challenges and opportunities presented here are mounted.

Relative Impact

Statements or studies of emission and sequestration rates in the literature/media provide measures upon which to base comparisons, however variations in the units and formats presented often make such comparisons challenging (or impossible). A wide ranging 'oranges with oranges' comparison to assist debates about policy and management options should perhaps be the subject of a dedicated treatise, however this paper now provides a broad comparison with an analysis of a terrestrial system in South Australia and a brief discussion of some of the considerations when comparing the relative impacts of emission drivers and abatement strategies.

Carbon dioxide equivalents is a metric for performing comparisons, however appropriate scrutiny of the many levels of carbon storage and mobility in an ecosystem is paramount for robust information in this form.

In a study of Carbon sequestration and biomass production rates from agroforestry in the Murray-Darling Basin of SA, Neumann et al (2011) record average sequestration rates for woodlots at ~9.5 tCO_2-e per hectare per year. This varied greatly (from between less than 1 and 50 tCO_2-e/ha/yr) according to species, age of trees and availability of water (surface and ground). Focussing on biomass production above ground, this study left soil carbon out of the equation, but a figure of 30% is a reasonable estimate for inclusion (T Hobbs, pers comm.)

Table 2 showed that there are varying levels of understanding in the measurement techniques for above and below ground carbon in coastal ecosystems. This is possibly mirrored across the range of terrestrial ecosystems providing further challenges for comparative measures between conservation, remedial and direct action activities relating to carbon sequestration.

A further consideration in comparing total impacts of activities across ecosystems relates to the longevity of the sequestration. Different carbon stores above and below ground lock carbon up for varying amounts of time from short to long term. There is also the risk associated with exposed carbon assets e.g. any above ground biosequestration effort is only a fire away from having to start over, and coastal systems contain certain risks associated with sea level rise reducing or compromising potential gains.

It is important to note that greenhouse gas benefits are not a sole reason for comparing the value of ecosystem protection strategies. Rather, they add to biodiversity or ecosystem service benefits that are currently encapsulated in strategies such as NatureLinks and No Species Loss. It is noted by Lovelock et al (2011) that coastal areas are regions of high biogeochemical activity at the boundary of terrestrial and marine environments. And that although coastal and benthic ecosystems are dominated by low diversity plant communities they are highly productive and are habitat for a high diversity of animals, algae and microbes.

The treatment of "biodiverse carbon" is an emerging field currently focusing on terrestrial ecosystems. A key challenge is to develop biodiversity metrics to work in concert with carbon metrics (Connor and Patterson, 2011).

The CleanEnergyFuture legislation has resulted in a revaluing of ecosystems. It provides a dollar value to their carbon condition, providing a framework for transparent market activity. Not only does a price on CO_2 emissions provide potential income generation through sale of permits but the associated Biodiversity Fund has been created to support projects that establish, restore, protect or manage biodiverse carbon stores (including invasive species management). While coastal and benthic systems are not mentioned explicitly, areas of high conservation value including wildlife corridors, riparian zones and wetlands are. Australian Government [on-line1]

Conclusion

Implications for DENR policy and funding coastal conservation

This study shows that coastal and benthic environments should be considered by DENR when developing carbon sequestration policies and accounting mechanisms. Broadly, their contribution to carbon storage is comparable per hectare to terrestrial systems. Numerous areas of research remain in order to better understand the carbon dynamics in these environments, however it is clear that degradation or loss of such systems is not only an issue for conservation objectives and ecosystem services but also for carbon emission mitigation and sequestration opportunities.

This conclusion indicates potentially relevant issues for the Marine Park process such as informing decision making about amounts and types of land within the MP reserve system, adequacy of zoning configurations and future requirements of information for monitoring change in habitats. Results also add to other agency priorities such as NatureLinks, No Species Loss and coastal management responsibilities by assisting to inform measurement of ecological conditions at land/sea interfaces.

It should be stressed that coastal systems such a sea grass meadows should not as a result of this work be oversold as an answer to climate change, rather that carbon sequestration services in these ecosystems is a further reason to preserve their natural processes.

Opportunities to offset carbon emissions through protection of coastal carbon sinks will require rigorous monitoring and associated accounting procedures. This project indicates that a mapping program to comprehensively understand our coastal carboniferous ecosystems at appropriate scales would provide a firm information base. It is suggested that to engage with emerging carbon markets, methods and tools for carbon accounting will need development and support in coming years. This project helps to identify some of the principles that may contribute to such methods.

Outputs of this project quantify potential carbon sequestration inside and outside the Marine Parks and allow comparison with terrestrial ecosystems. This project has therefore demonstrated that habitat mapping can help to progress the development of methods for estimating, validating and monitoring carbon capture. With further work, linkages to sequestration estimates in terrestrial systems will provide a more comprehensive information base upon which to build DENRs contribution to the South Australian Government’s Climate Change agenda.

With an estimated value of coastal Carbon sequestration in SA in the order of $40M a year, the CleanEnergyFuture legislation is providing a new model for valuing a core responsibility of DENR and new opportunities to protect and enhance our coastal and near shore regions through mechanisms to distribute Commonwealth Carbon tax revenues.

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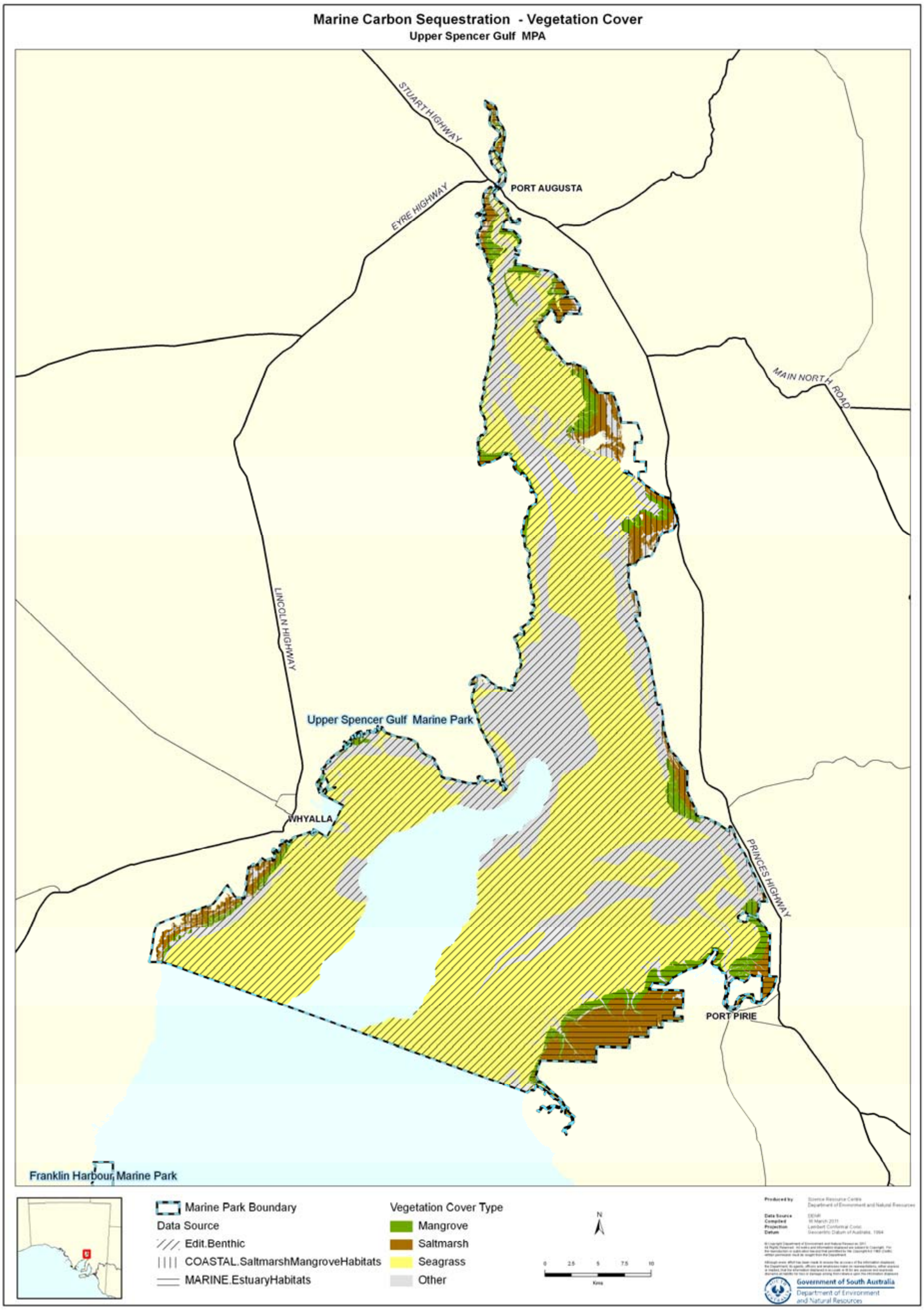
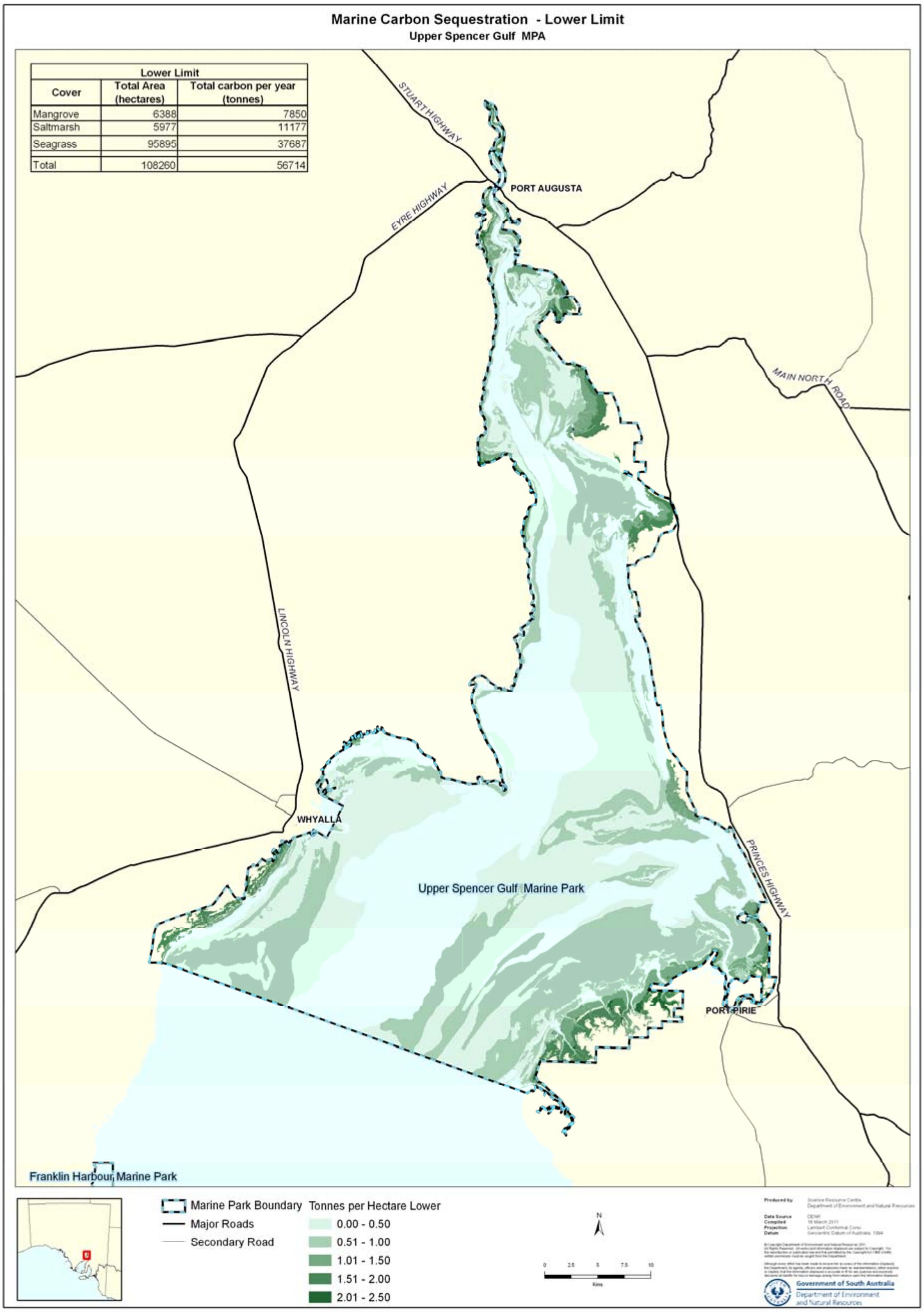
Appendices

Appendix A1 Carbon Classes and Mapping Data sources – Upper Spencer Gulf MP

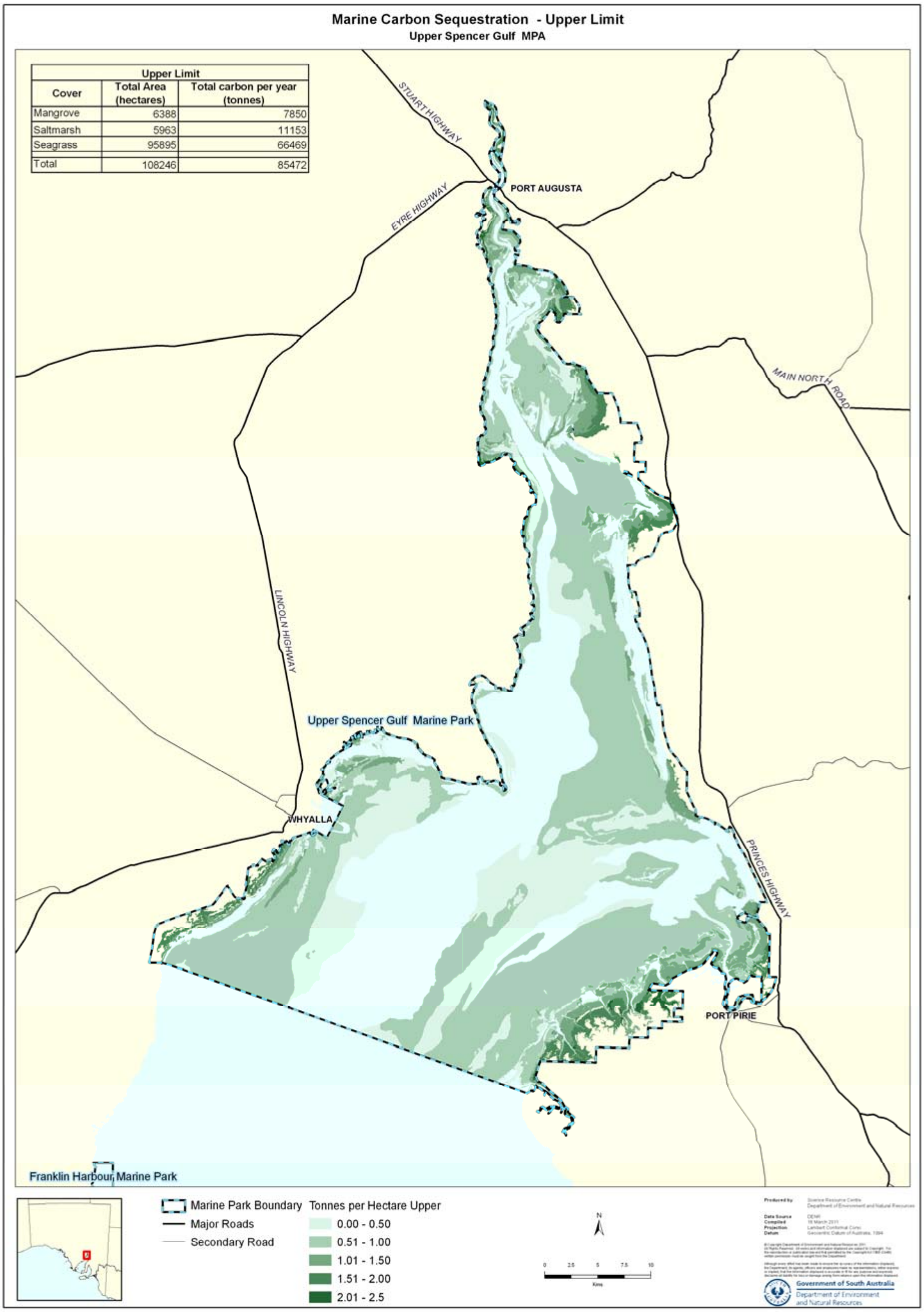


Appendix A2: Annual Carbon Sequestration Lower Limit – Upper Spencer Gulf MP



Lower Limit		
Cover	Total Area (hectares)	Total carbon per year (tonnes)
Mangrove	6388	7850
Saltmarsh	5977	11177
Seagrass	95895	37687
Total	108260	56714

Appendix A3: Annual Carbon Sequestration Upper Limit – Upper Spencer Gulf MP



Appendix B: Carbon Class Areas from Data Sources

Areas of carbon classes mapped from each source data layer and as a total. Carbon classes have been assigned according to vegetation/habitat attribution in source layers.

Area Mapped (ha)	source layer	a) Benthic Habitats	
	source habitat	Saltmarsh / Mangrove	Seagrass
Carbon Class	Mangrove	368	
	Saltmarsh		
	Seagrass		680930
Total	ha	368	680930
	% overall	0.1%	94.2%

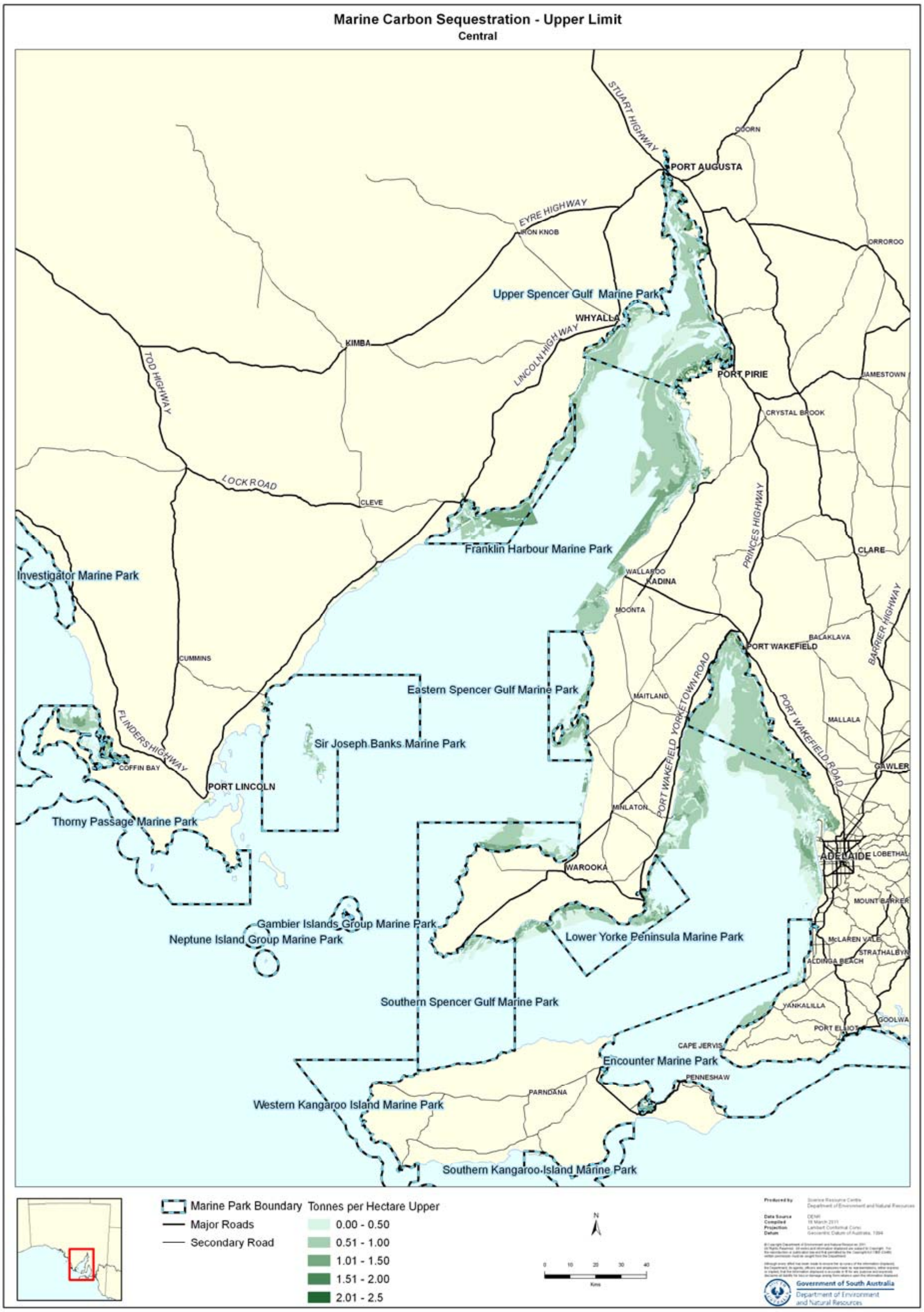
Area Mapped (ha)	source layer	b) Estuary Habitats				
	source habitat	Mangrove	Samphire	Samphire +/- Atriplex +/- Grassland	Seagrass	Seagrass / Algal
Carbon Class	Mangrove	10144				
	Saltmarsh		13297	21		
	Seagrass				1637	1846
Total	ha	10144	13297	21	1637	1846
	% overall	1.4%	1.8%	0.0%	0.2%	0.3%

Area Mapped (ha)	source layer	c) Saltmarsh Mangrove Habitats			
	source habitat	Mangrove	Samphire	Seagrass	Seagrass / Algal
Carbon Class	Mangrove	4677			
	Saltmarsh		8358		
	Seagrass			1166	165
Total	ha	4677	8358	1166	165
	% overall	0.6%	1.2%	0.2%	0.0%

Area Mapped (ha)	source layer	Grand Total	
	source habitat	ha	%
Carbon Class	Mangrove	15190	2.1%
	Saltmarsh	21676	3.0%
	Seagrass	685744	94.9%
Total	ha	722610	100.0%
	% overall	100.0%	

Appendix C1: Annual Carbon Sequestration Upper Limit – Western SA

Appendix C2: Annual Carbon Sequestration Upper Limit – Central SA



Appendix C3: Annual Carbon Sequestration Upper Limit – SouthEastern SA

Appendix D: Related Reference List

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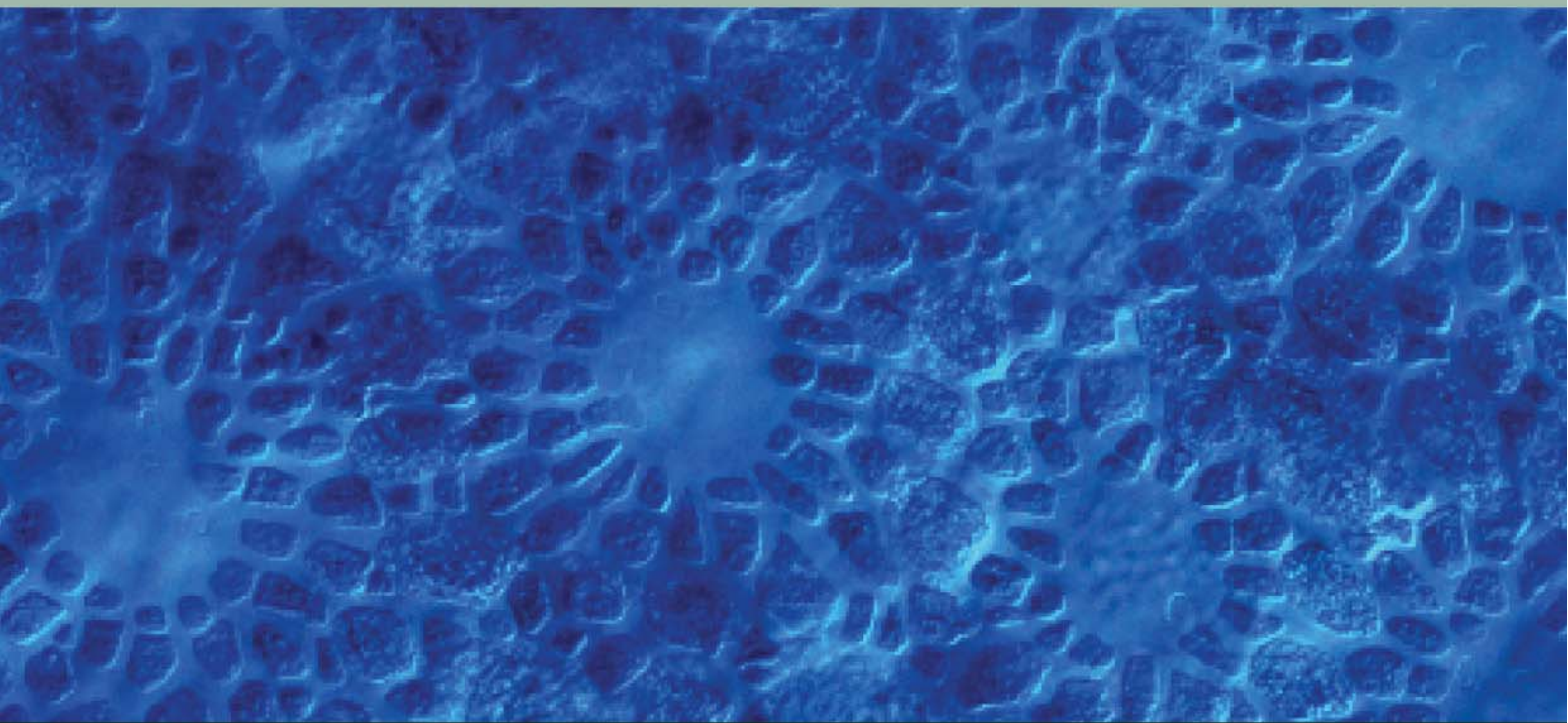

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