BIOGRIP soil and water node
ENVIRONMENTAL BIOGEOCHEMISTRY FIELD SAMPLING COURSE :
Blue carbon

Andrew Ndhlovu

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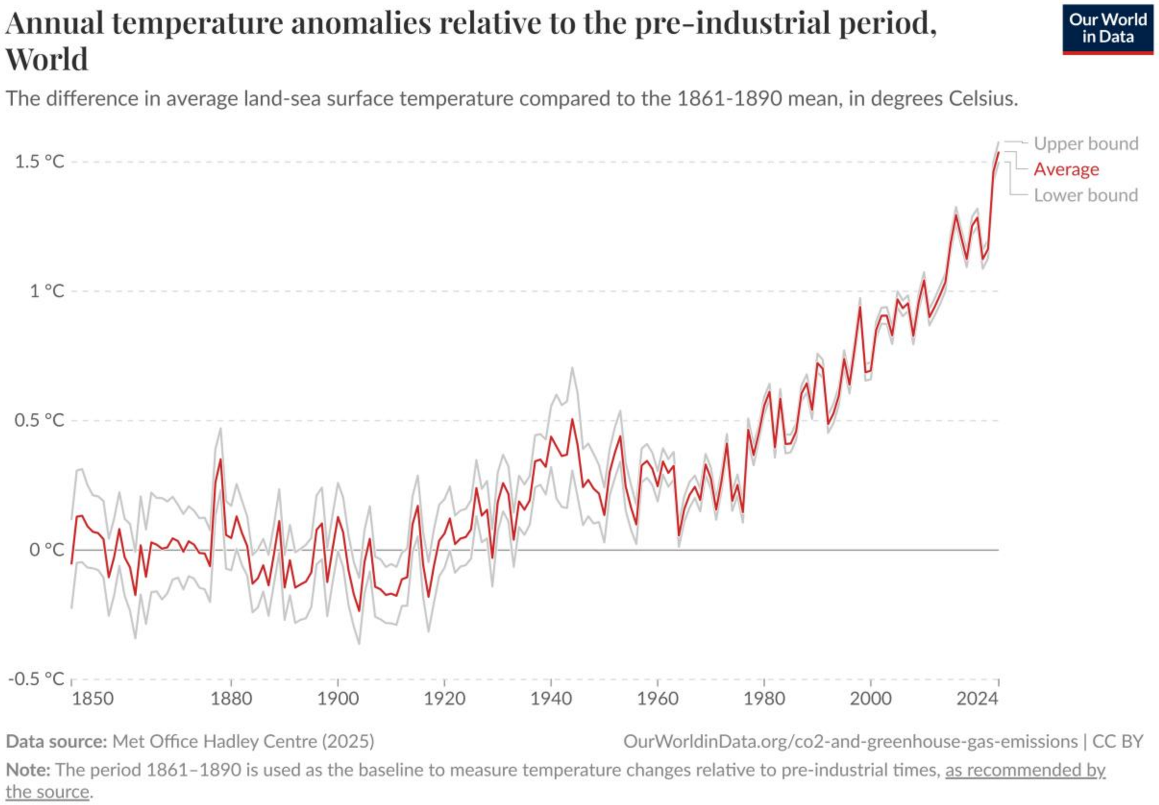
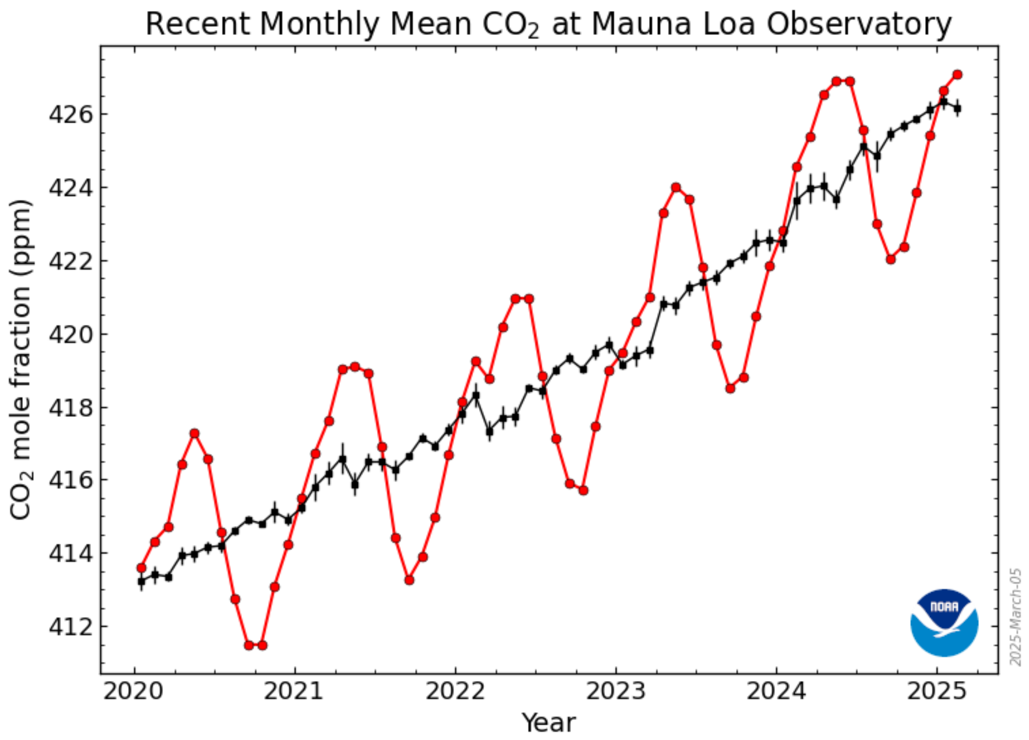
PROJECT
SEASTORE

CO_2 emissions continue to drive temperature increase





Global temperatures driven by CO_2 continue to increase and breach Paris Agreement targets

Natural climate solutions (NCS) are cost-effective with co-benefits

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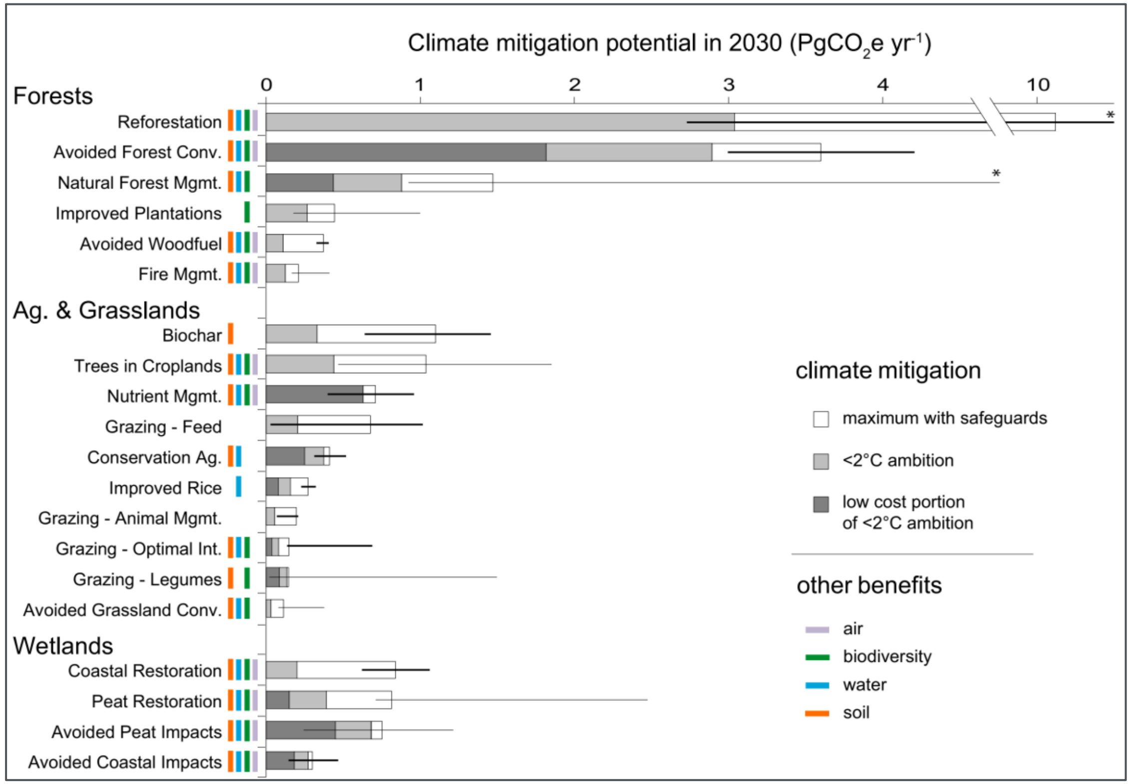
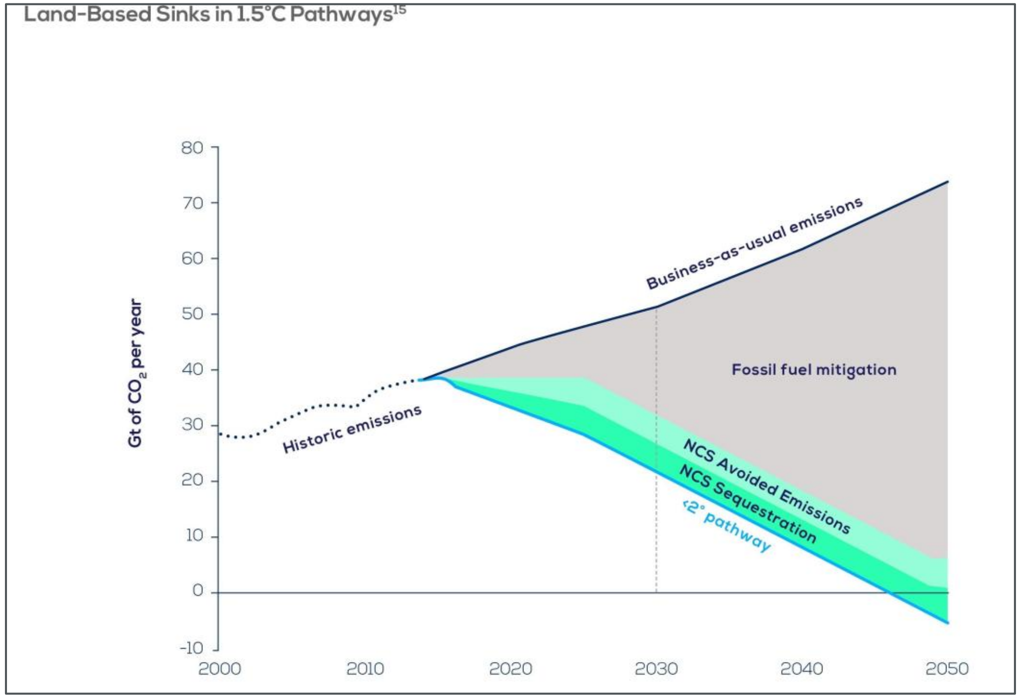


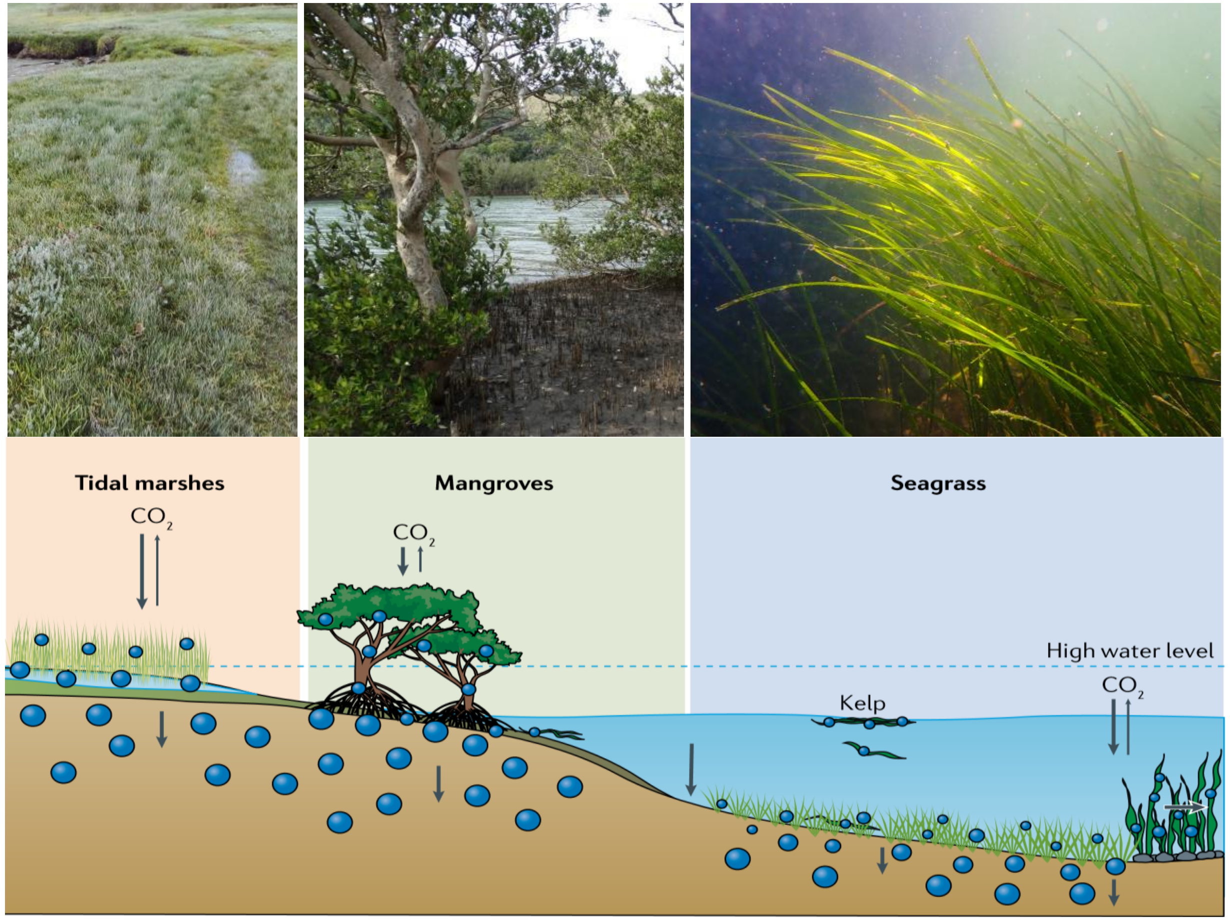
Unit	Meaning	Alternative units	Conversion
Mg	megagram	[metric] ton	1 Mg = 10^6 g = 1 t
Gg	gigagram	kiloton	1 Gg = 10^9 g = 10^3 t = 1 kt
Tg	teragram	megaton	1 Tg = 10^{12} g = 10^6 t = 1 Mt
Pg	petagram	gigaton	1 Pg = 10^{15} g = 10^9 t = 1 Gt

Griscom et al., 2017 *PNAS*

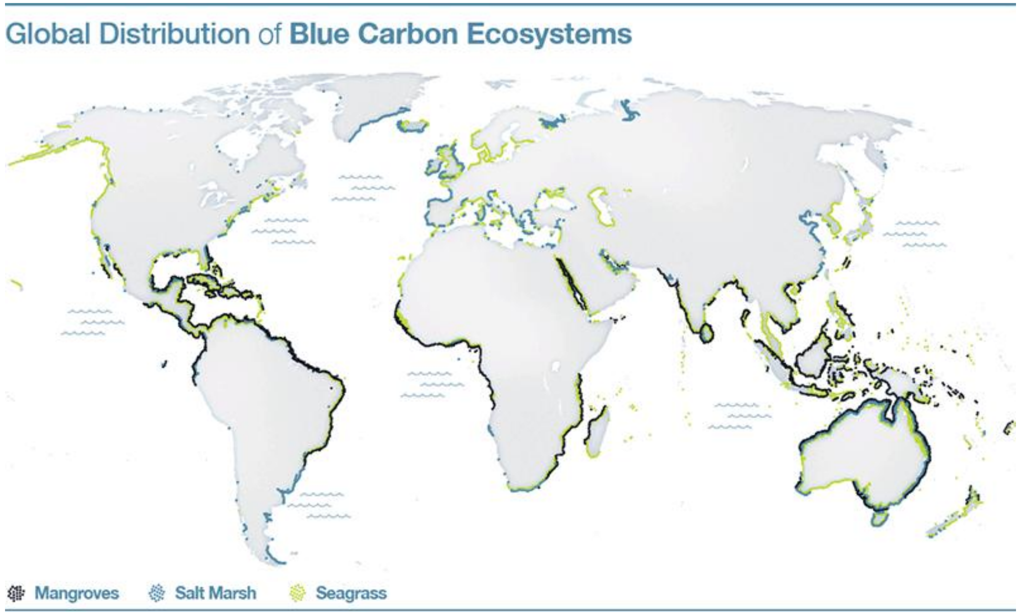


Conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions can provide over one-third of the cost-effective climate mitigation by 2030

Blue carbon: A natural climate solution



Blue carbon is the carbon stored in vegetated coastal ecosystems (mangroves, salt marshes, seagrasses and potentially kelp) [Proposals to expand definition]



Occupy ~0.5% of the sea floor but contribute >50% of global carbon burial in the oceans

Nellemann et al., 2009 *UNEP*; McLeod et al., 2011 *Front. Ecol. Environ.*

Blue carbon ecosystems (BCEs) store more carbon than terrestrial ecosystems

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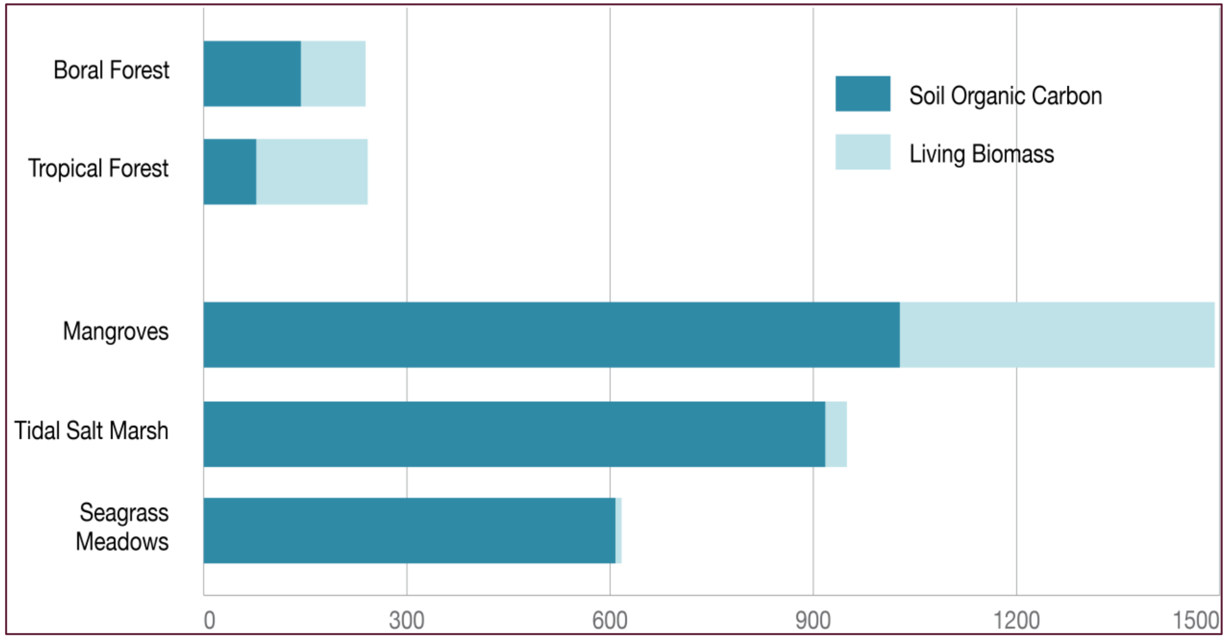
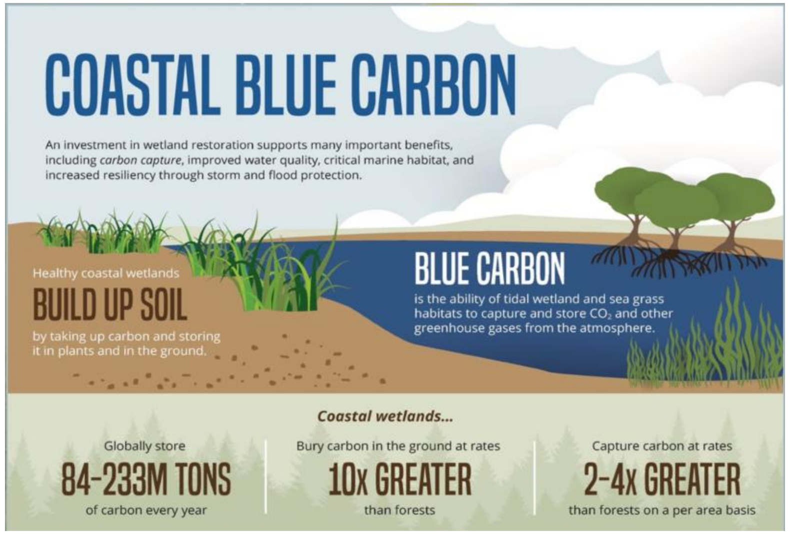
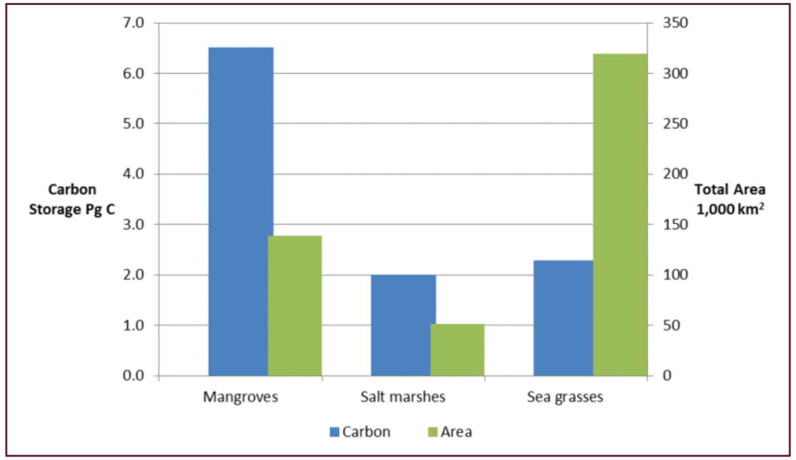


Megagrams (Tonne) of carbon per hectare (Mg C/ha)

- Higher carbon storage per unit area than green carbon
- Up to 32 650 Tg (106) C stored covering ~36–185 million ha
- Safe from fire, no saturation and stored for millennia

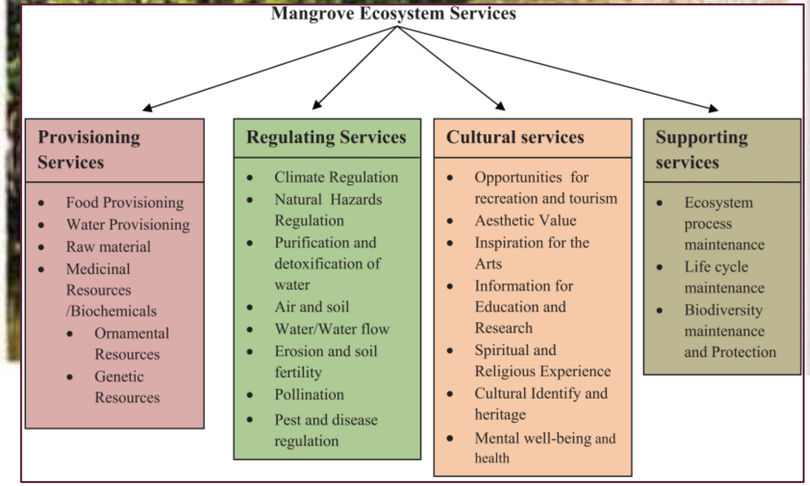




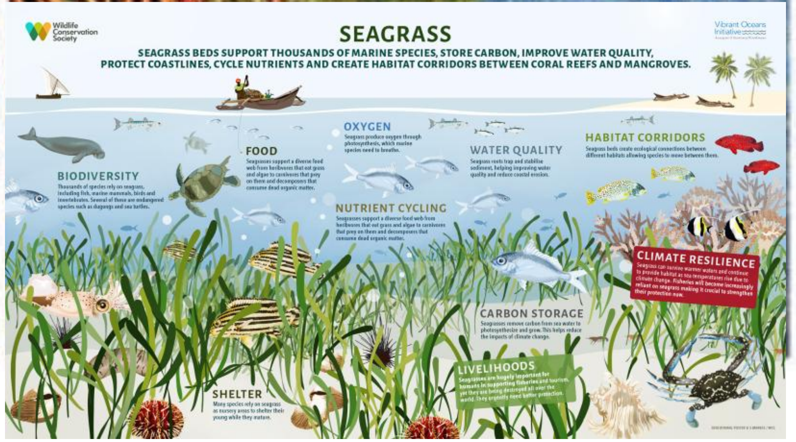
Howard et al., 2014 *IUCN*; Macreadie et al., 2021 *Nat. Rev. Earth & Env*; Siikamäki et al., 2013; *Env: Sci. and Pol. for Sust. Dev*

BCE ecosystem services

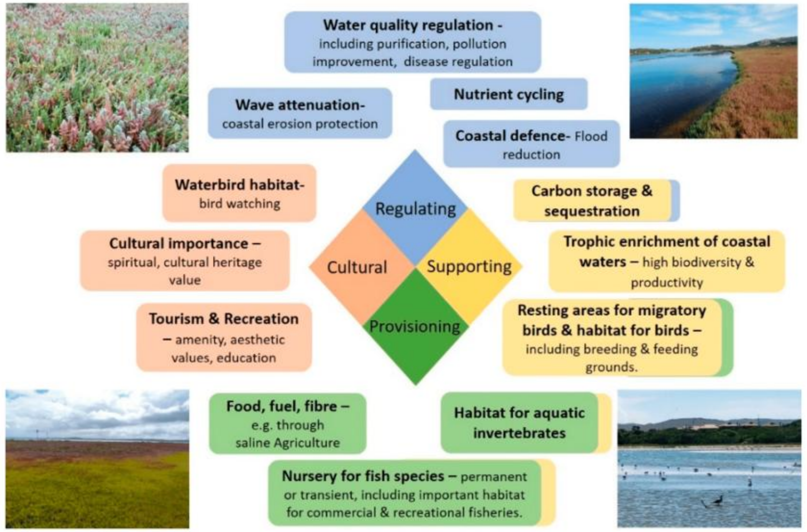
Mangrove



Seagrass



Salt marsh



Adams, 2020, *Estuarine, Coastal and Shelf Science*; Mitra, 2020, *Mangrove Forests in India*

Blue carbon a nature-based solution for climate change mitigation and adaptation

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Nature-based solutions

MITIGATION AND ADAPTATION

Nature-based solutions are actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience and biodiversity benefits (UNEA-5 2022).

Natural climate solutions

MITIGATION

NCS refers to 20 conservation, restoration and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands and agricultural lands (Griscom et al. 2017).

Ecosystem-based adaptation

ADAPTATION

The use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. EbA aims to maintain and increase the resilience and reduce the vulnerability of ecosystems and people in the face of the adverse effects of climate change (CBD 2018).

Blue carbon

Loss of BCEs is loss of co-benefits, reduces mitigation potential and increases CO_2 emissions

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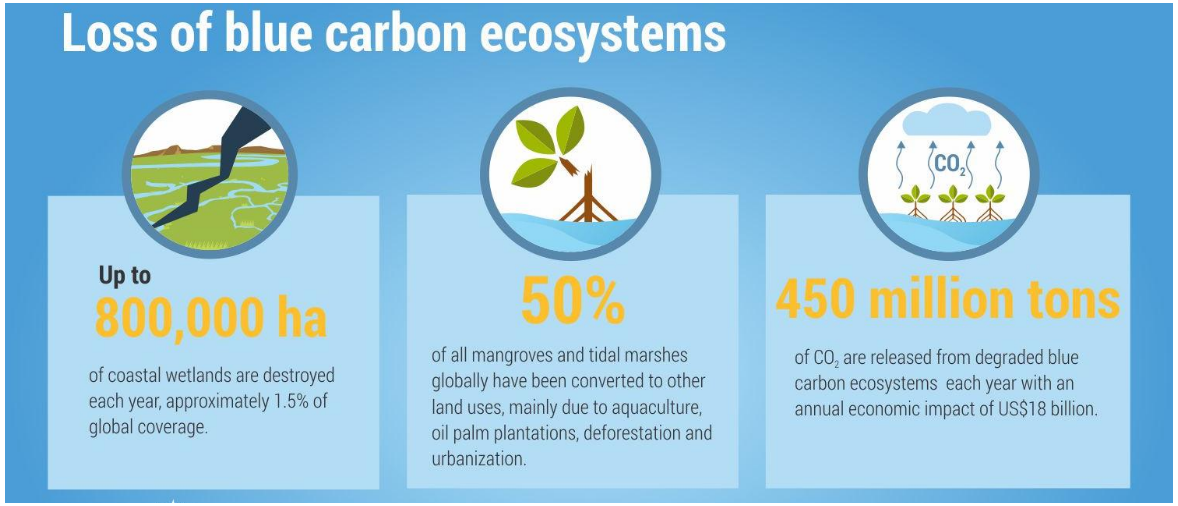
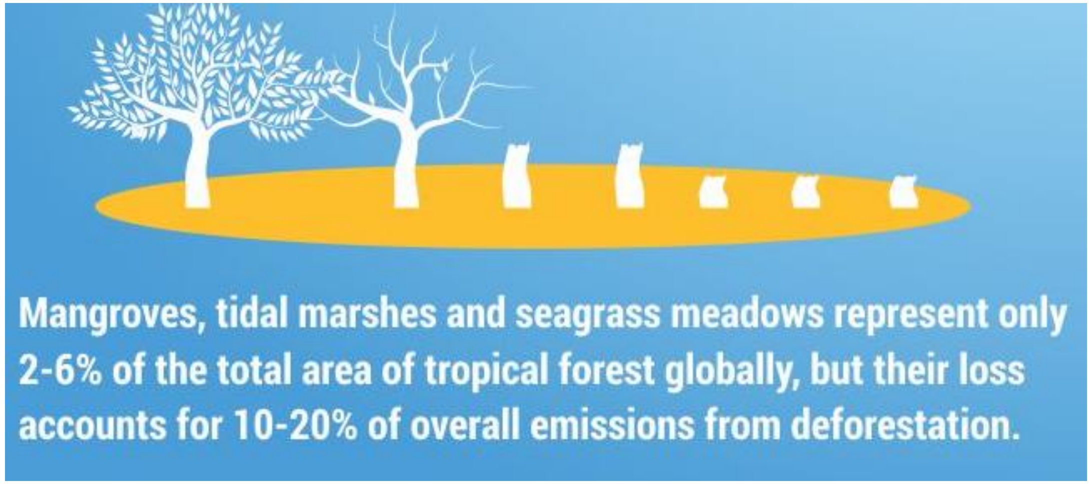




https://science.upd.edu.ph/uncertain-future-looms-for-philippine-southeast-asian-mangroves/

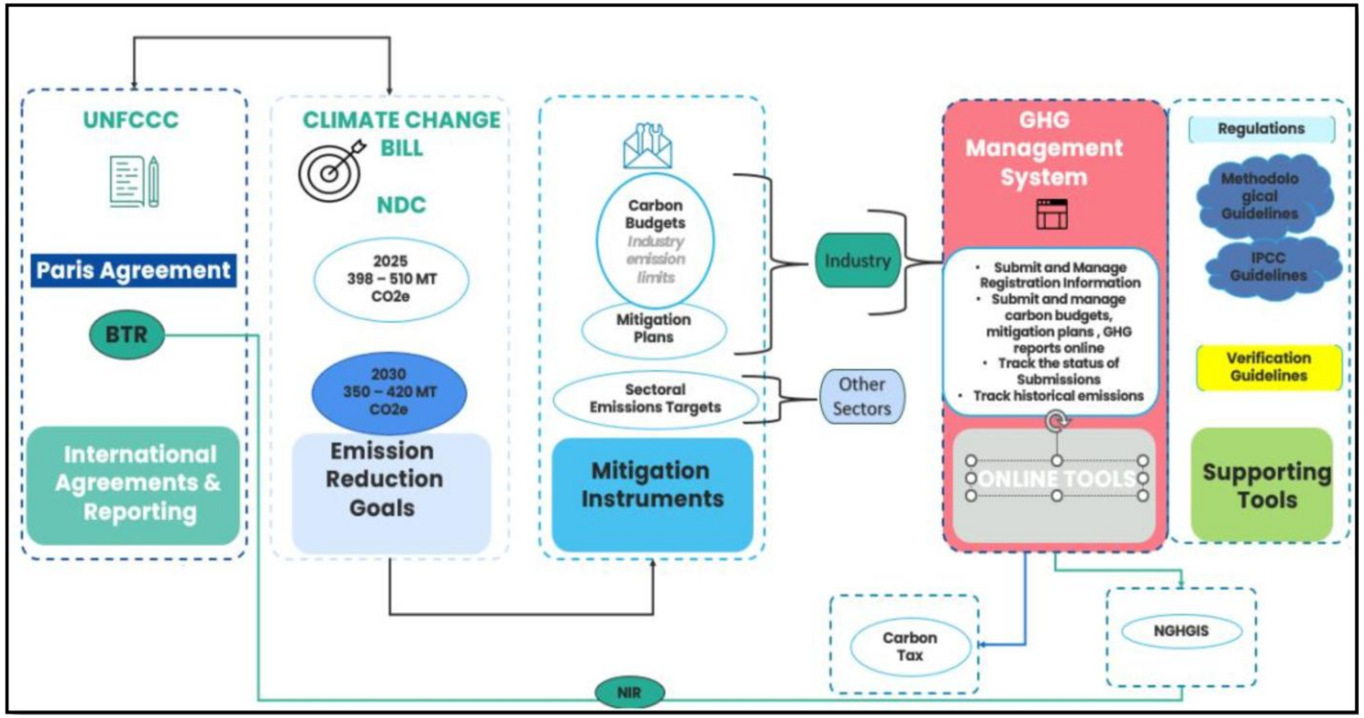
news.un.org/en/story/2014/09/479602-new-un-report-warns-devastating-effects-ongoing-destruction-mangrove-forests

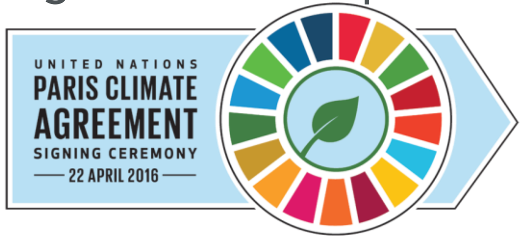
https://www.savebuzzardsbay.org/news/study-shows-westport-rivers-losing-salt-marshes-at-an-accelerating-rate

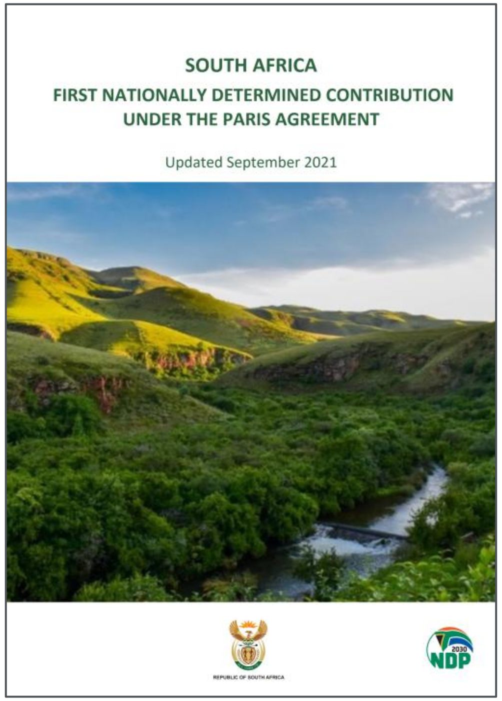
Why should we measure blue carbon stocks

Quantify carbon stored in BCEs to assess their potential for climate change mitigation and adaptation

- Inclusion into national greenhouse gas inventories
- NDC reporting
- Carbon trading markets






SOUTH AFRICA

FIRST NATIONALLY DETERMINED CONTRIBUTION UNDER THE PARIS AGREEMENT

Updated September 2021

What is measured?

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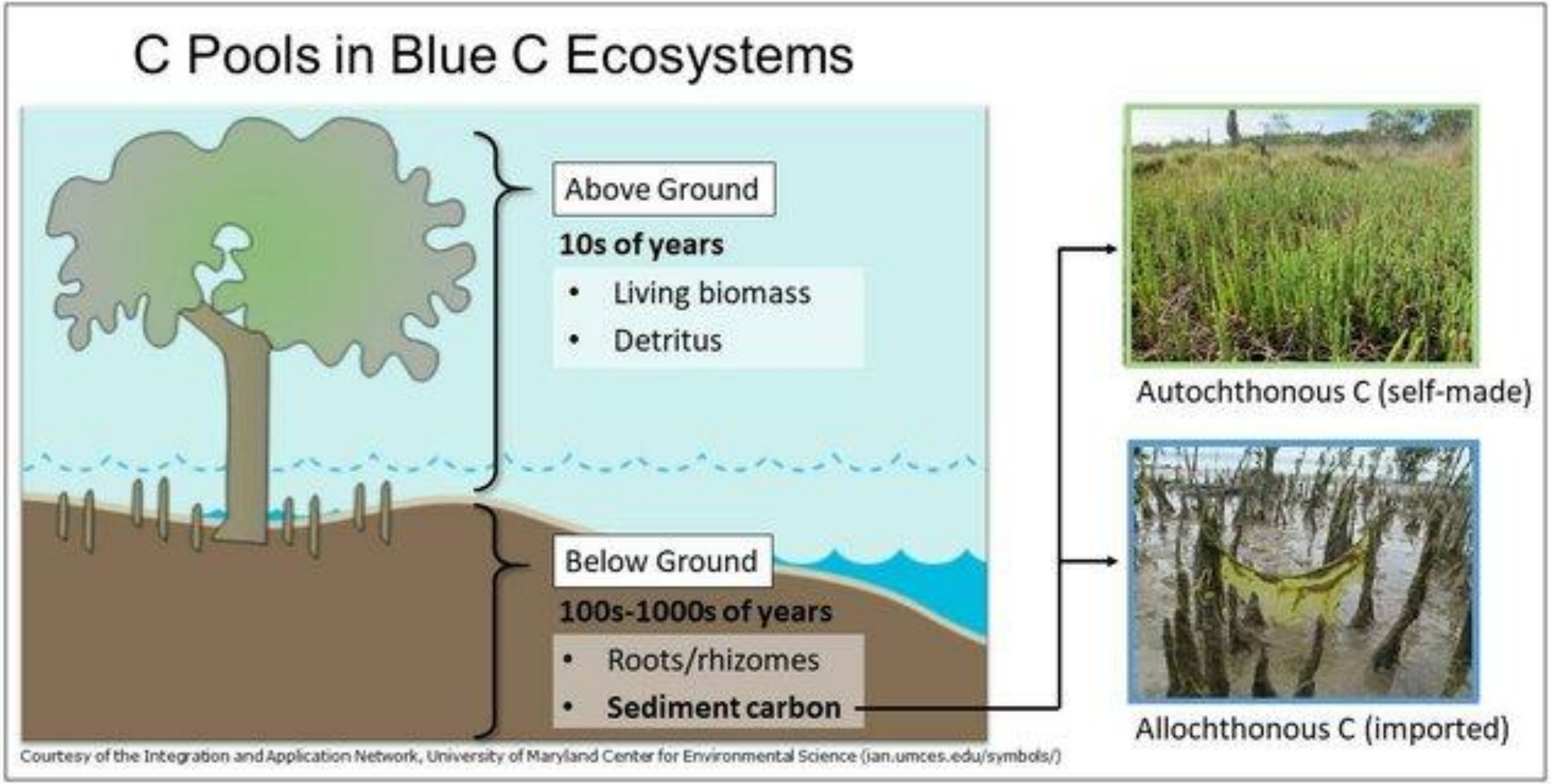

Global effort to assess BCE stocks are ongoing

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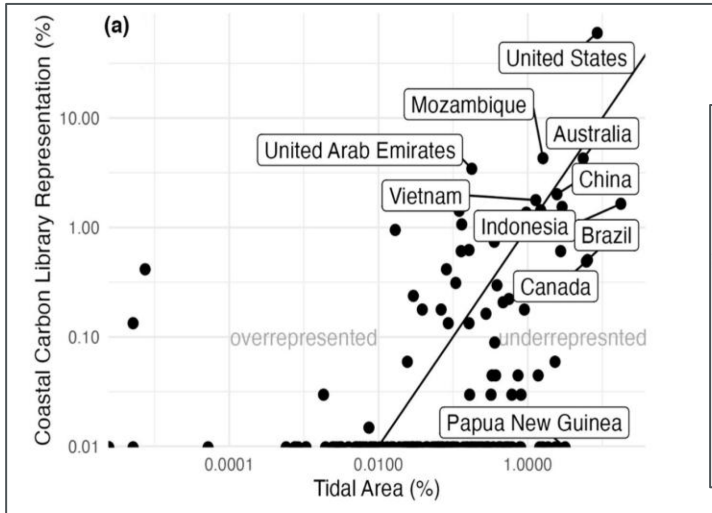

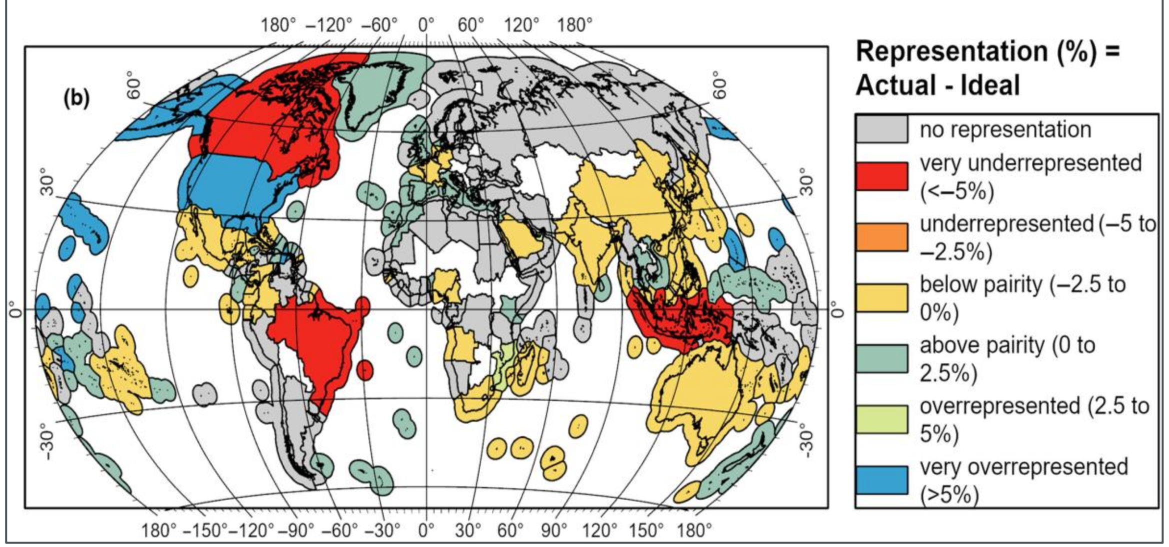

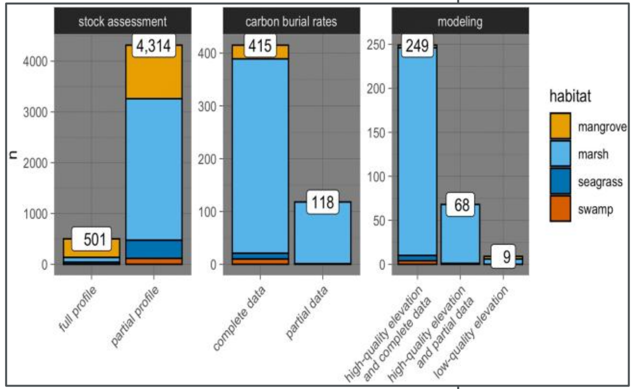

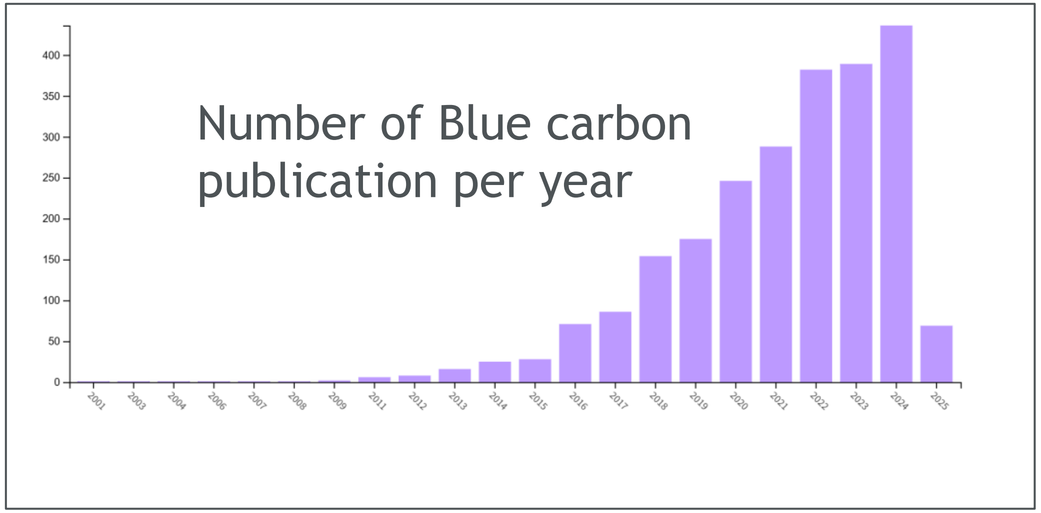

Global Change Biology, Volume: 30, Issue: 1, First published: 30 December 2023, DOI: (10.1111/gcb.17098)

REVIEWS

Check for updates

Blue carbon as a natural climate solution

Peter I. Macreadie[1], Micheli D. P. Costa[1], Trisha B. Atwood[3], Daniel A. Friess[4,5], Jeffrey J. Kelleway[6], Hilary Kennedy[7], Catherine E. Lovelock[2], Oscar Serrano[8,9] and Carlos M. Duarte[10]

One Earth

Review

Variable Impacts of Climate Change on Blue Carbon

Catherine E. Lovelock[1,*] and Ruth Reef[2]

Status of BCE research in South Africa

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South African coastline: A natural laboratory

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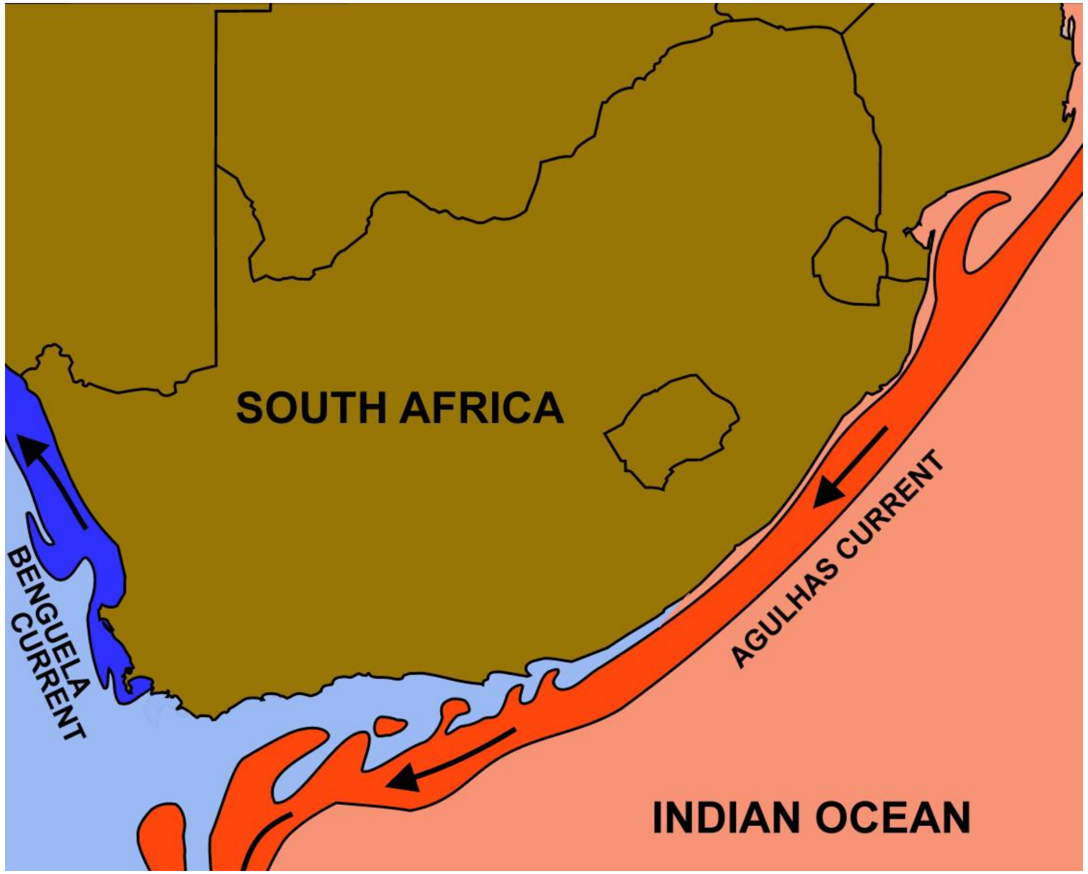

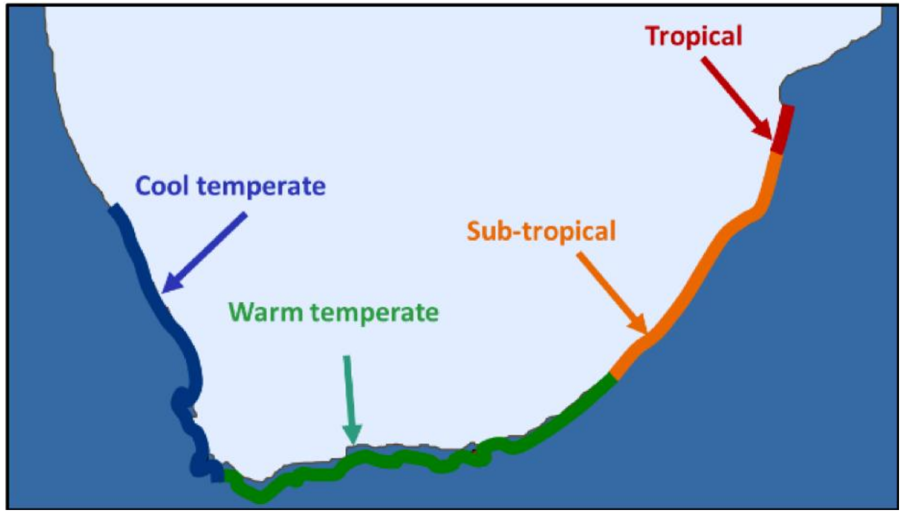

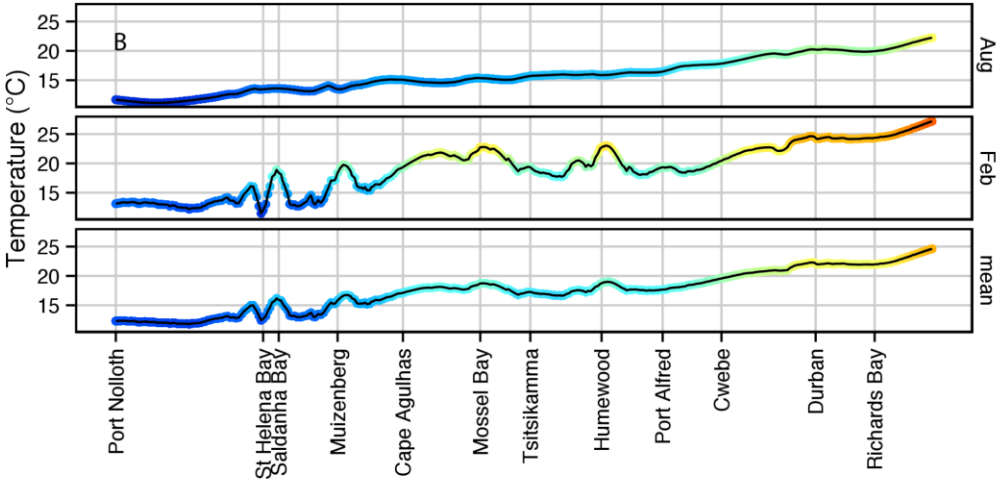

Interpolated situ temperature data

- Cool-warm temperature coastline gradient (~3000 km)
- Four biogeographical regions

South African BCEs (18555 ha)

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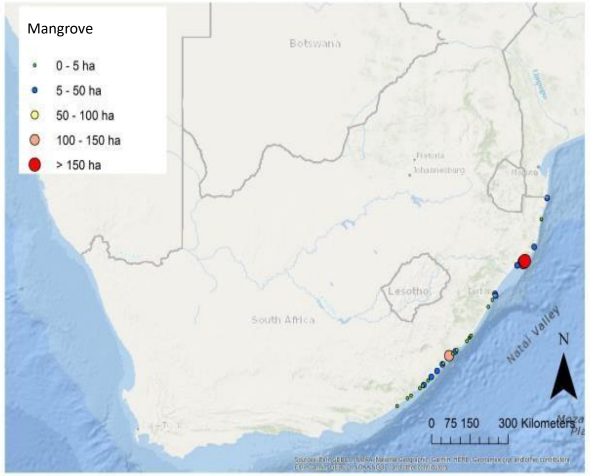

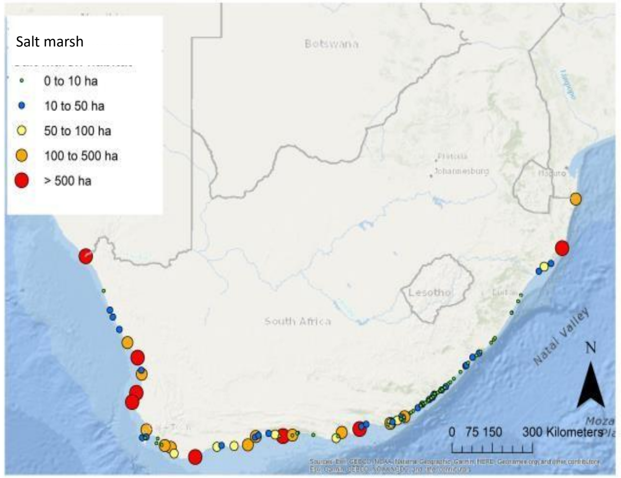

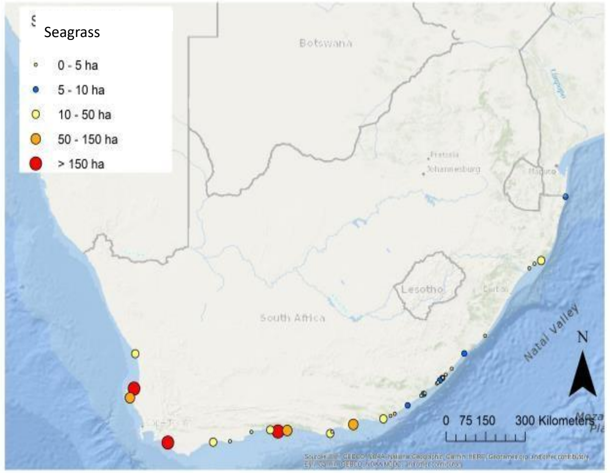

Mangrove ~2087 ha (32 estuaries) Salt marsh ~14713 ha Seagrass ~1755 ha (37 estuaries)

Raw et al., 2023, *Science of The Total Environment*

Methods for assessing blue carbon stock (2014)

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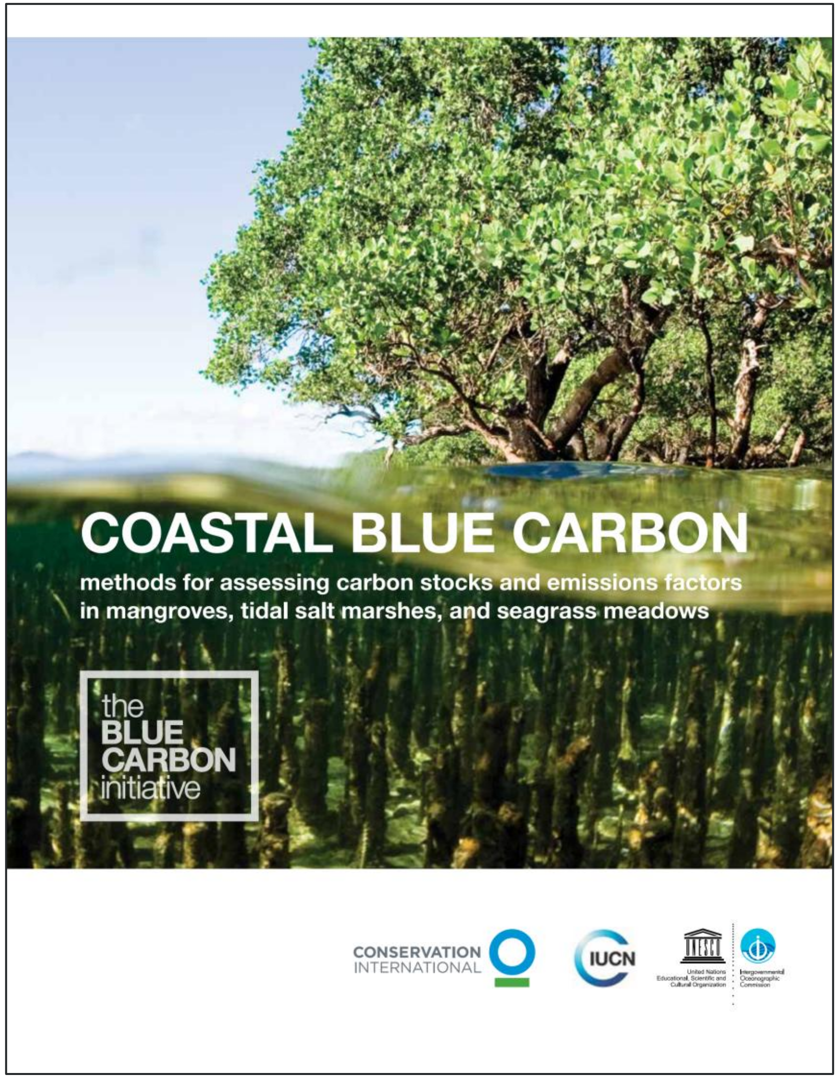
Overview

Subject to Final Copyedit

2013 SUPPLEMENT TO THE 2006 IPCC GUIDELINES FOR NATIONAL GREENHOUSE GAS INVENTORIES: WETLANDS

Methodological Guidance on Lands with Wet and Drained Soils, and Constructed Wetlands for Wastewater Treatment

Wetlands Supplement (Pre-publication Version) O.1



https://www.thebluecarboninitiative.org/manual

IPCC Tiers – The IPCC has identified three tiers of detail in carbon inventories that reflect the degrees of certainty or accuracy of a carbon stock inventory (assessment).

Tier 1 – Tier 1 assessments have the least accuracy and certainty and are based on simplified assumptions and published IPCC default values for activity data and emissions factors. Tier 1 assessments may have a large error range of +/- 50% for aboveground pools and +/- 90% for the variable soil carbon pools.

Tier 2 – Tier 2 assessments include some country or site-specific data and hence have increased accuracy and resolution. For example, a country may know the mean carbon stock for different ecosystem types within the country.

Tier 3 – Tier 3 assessments require highly specific data of the carbon stocks in each component ecosystem or land use area, and repeated measurements of key carbon stocks through time to provide estimates of change or flux of carbon into or out of the area. Estimates of carbon flux can be provided through direct field measurements or by modeling.

First RSA blue carbon study (2019)

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CLIMATE CHANGE AND SOUTH AFRICA'S BLUE CARBON ECOSYSTEMS

Report to the
WATER RESEARCH COMMISSION

by

JB Adams[1,2], JL Raw[1,2], SP Mbense[1,2], TG Bornman[2,3], A Rajkaran[4], L van Niekerk[5]

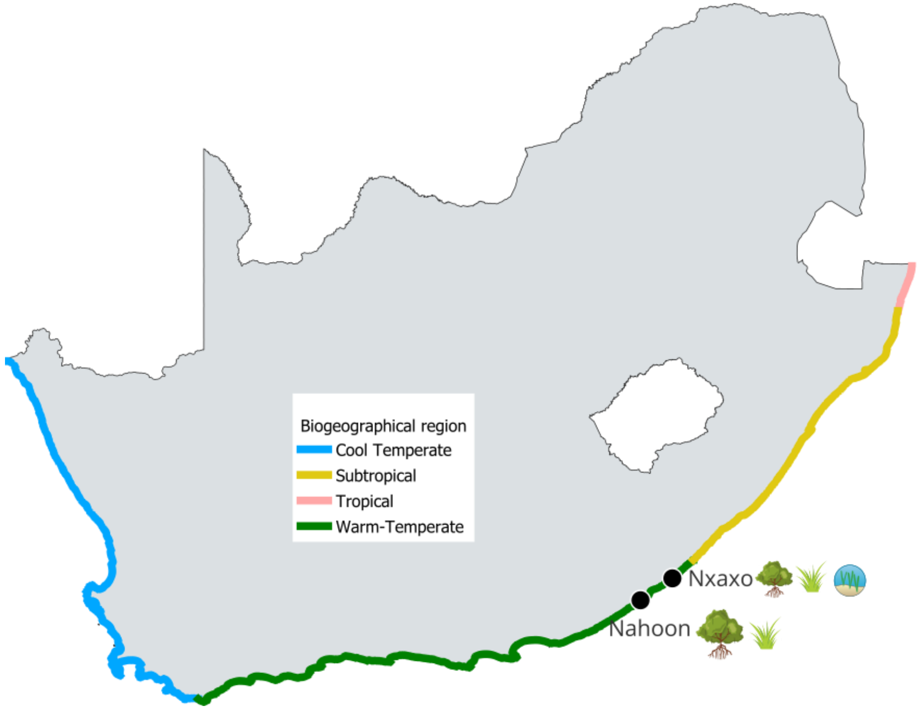
[1]DST/NRF Research Chair in Shallow Water Ecosystems, Nelson Mandela University
[2]Department of Botany & Institute for Coastal and Marine Research, Nelson Mandela University
[3]South African Environmental Observation Network (SAEON), Elwandle Coastal Node
[4]Department of Biodiversity and Conservation Biology, University of the Western Cape
[5]Council for Scientific and Industrial Research (CSIR), Stellenbosch

WATER RESEARCH COMMISSION

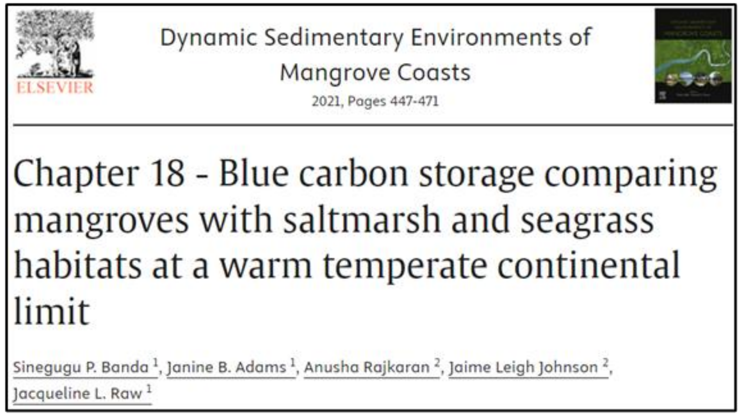
WRC Report No. 2769/1/19
ISBN 978-0-6392-0116-0

February 2019

- Determined the extent of blue carbon ecosystems in South Africa and estimated blue carbon storage using the IPCC assessment methods.
- Quantified the loss of blue carbon habitats and associated ecosystem services
- Predicted responses of blue carbon ecosystems to climate change in the form of sea-level rise and increased global temperatures



Nxaxo Estuary (2019)

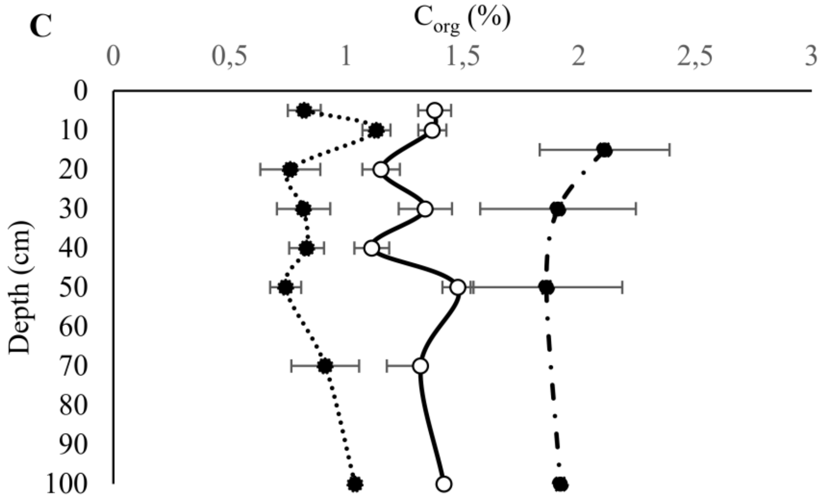

ELSEVIER

Dynamic Sedimentary Environments of Mangrove Coasts

2021, Pages 447-471

Chapter 18 - Blue carbon storage comparing mangroves with saltmarsh and seagrass habitats at a warm temperate continental limit

Sinegugu P. Banda [1], Janine B. Adams [1], Anusha Rajkaran [2], Jaime Leigh Johnson [2], Jacqueline L. Raw [1]



	Total carbon (Mg C ha^{-1})	Area (ha)	Total carbon for soil carbon pool (Mg C)
Salt marsh	2.61 ± 0.19	10.9	28.55 ± 2.1
Seagrass	1.67 ± 0.01	0.04	0.06 ± 0.01
Mangroves	228.05 ± 27.99	9.5	2166.48 ± 265.91

Sediment (1 depth) and biomass (above- and belowground) collected for all BCEs

Organic Carbon: LOI (8 hours at 550°C) + CHN elemental analyzer

Nahoon Estuary (2019)


Science of the Total Environment 842 (2022) 156955

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

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Blue carbon and nutrient stocks in salt marsh and seagrass from an urban African estuary

Lucienne R.D. Human [a,b,*], Jessica Els [a,b,c], Johan Wasserman [b,c], Janine B. Adams [b,c]

- Sediment subsections: 0-15 cm; 15-30 cm; and 30-50 cm
- LOI: muffle furnace at 550°C for 6 h

	Salt Marsh	Ecotone	Mangrove
Average (±SD) Carbon per 0.5 m core ($MgC.ha^{-1}$)	109.62 ± 22.0	114.50 ± 12.8	110.14 ± 11.0
Habitat area (ha)	1.45	0.71	2.55
Total Carbon (MgC)	158.94± 31.9	81.29 ± 9.1	280.86 ± 28.1

Swartkops Estuary (2022)

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Blue carbon and nutrient stocks in salt marsh and seagrass from an urban African estuary

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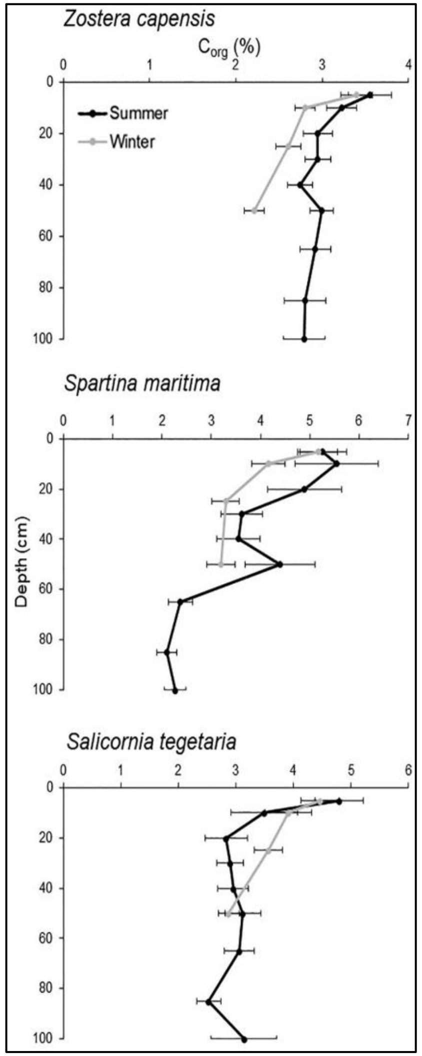
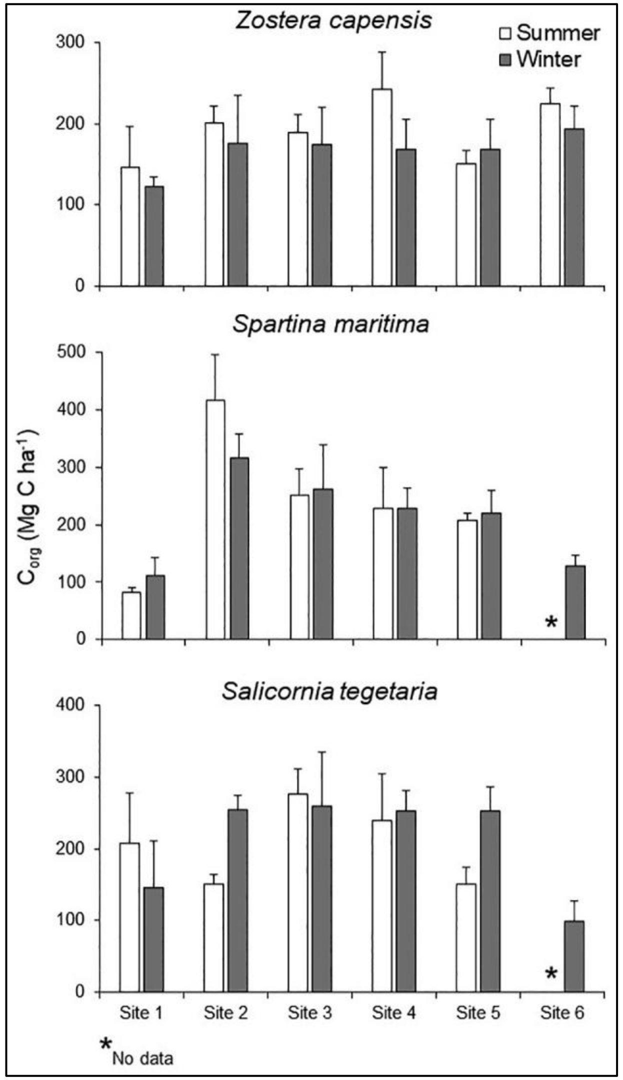
LOI : Ashing furnace at 550 °C for 8 h to determine the percent loss on ignition (%LOI) + Elemental analysis

Species	Season	C:N	C:P	N:P	N:Biomass	P:Biomass
Z. capensis	Summer	58.45	15.35	0.26	0.02	0.09
	Winter	5.21	6.21	1.20	0.13	0.11
S. maritima	Summer	8.27	14.56	1.48	0.02	0.01
	Winter	9.72	14.62	1.54	0.03	0.01
S. tegetaria	Summer	28.09	10.93	0.40	0.01	0.03
	Winter	9.02	16.40	1.83	0.05	0.03

Species	Area (ha)	Sediment carbon content		Total C (Mg C)
		$\%C_{org}$	Mg C ha^{-1}	
Zostera capensis	62.3	2.94 ± 0.39	181.37 ± 45.41	11,299.09 ± 2828.88
Spartina maritima	96	4.31 ± 0.87	225.45 ± 101.12	21,643.07 ± 9706.24
Salicornia tegetaria	27.32	3.49 ± 0.7	210.67 ± 72.19	5755.62 ± 1972.12





Knysna, Swartkops and Nxaxo (2023)

Estuarine, Coastal and Shelf Science 284 (2023) 108296

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

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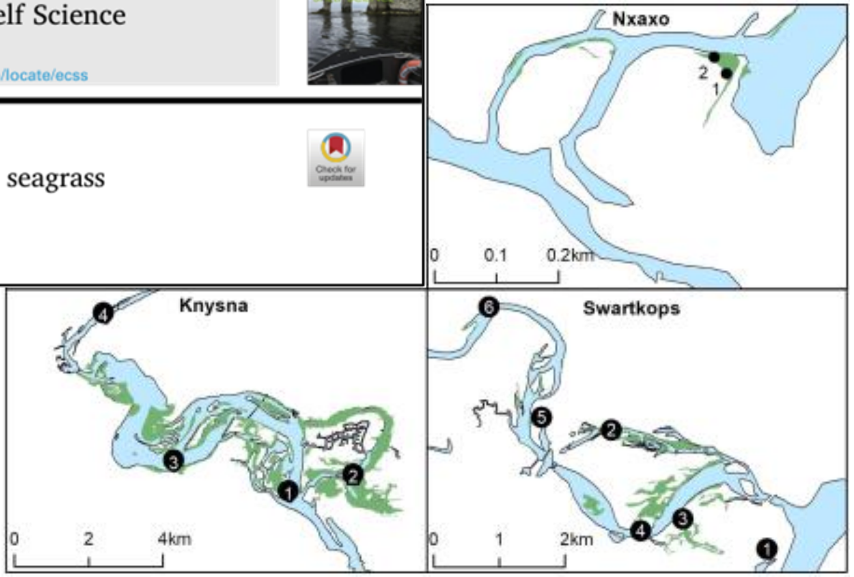
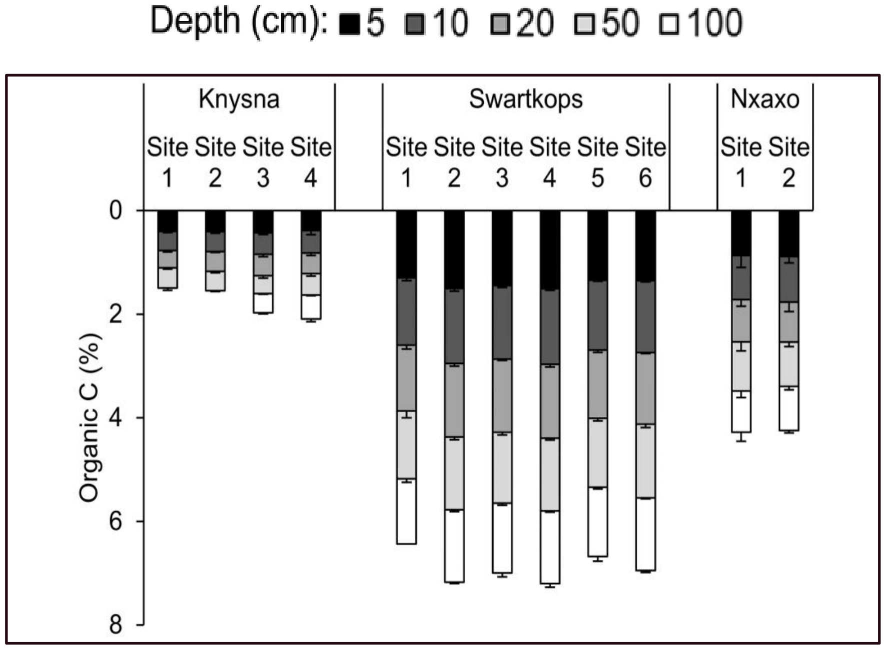
Blue carbon stocks in southern Africa's Endangered seagrass *Zostera capensis*

J. Wasserman[a,b,*], L.R.D. Human[a,c], J.B. Adams[a,b]





	Habitat area (ha)	Sediment C (Mg C ha^{-1})	Total sediment C pool (Mg C)	Biomass C (Mg C ha^{-1})		Total biomass C pool (Mg C)	Total C pool (Mg C)
				Aboveground	Belowground		
Knysna	353	56.18 ± 31.16	18921.03 ± 10615.25	1.02 ± 0.04	1.56 ± 0.7	911.19 ± 384.29	19832.22 ± 10999.5
Swartkops	44.7	280.69 ± 84.56	12454.25 ± 3726.01	1.47 ± 0.85	0.6 ± 0.36	92.56 ± 53.89	12546.81 ± 3779.91
Nxaxo	0.04	115.45 ± 33.9	4.5 ± 1.31	1.66 ± 0.66	1.34 ± 0.57	0.12 ± 0.05	4.62 ± 1.36
Mean	–	177.65 ± 122.29	–	1.35 ± 0.73	1.04 ± 0.69	–	–

Sampling progress (2023)

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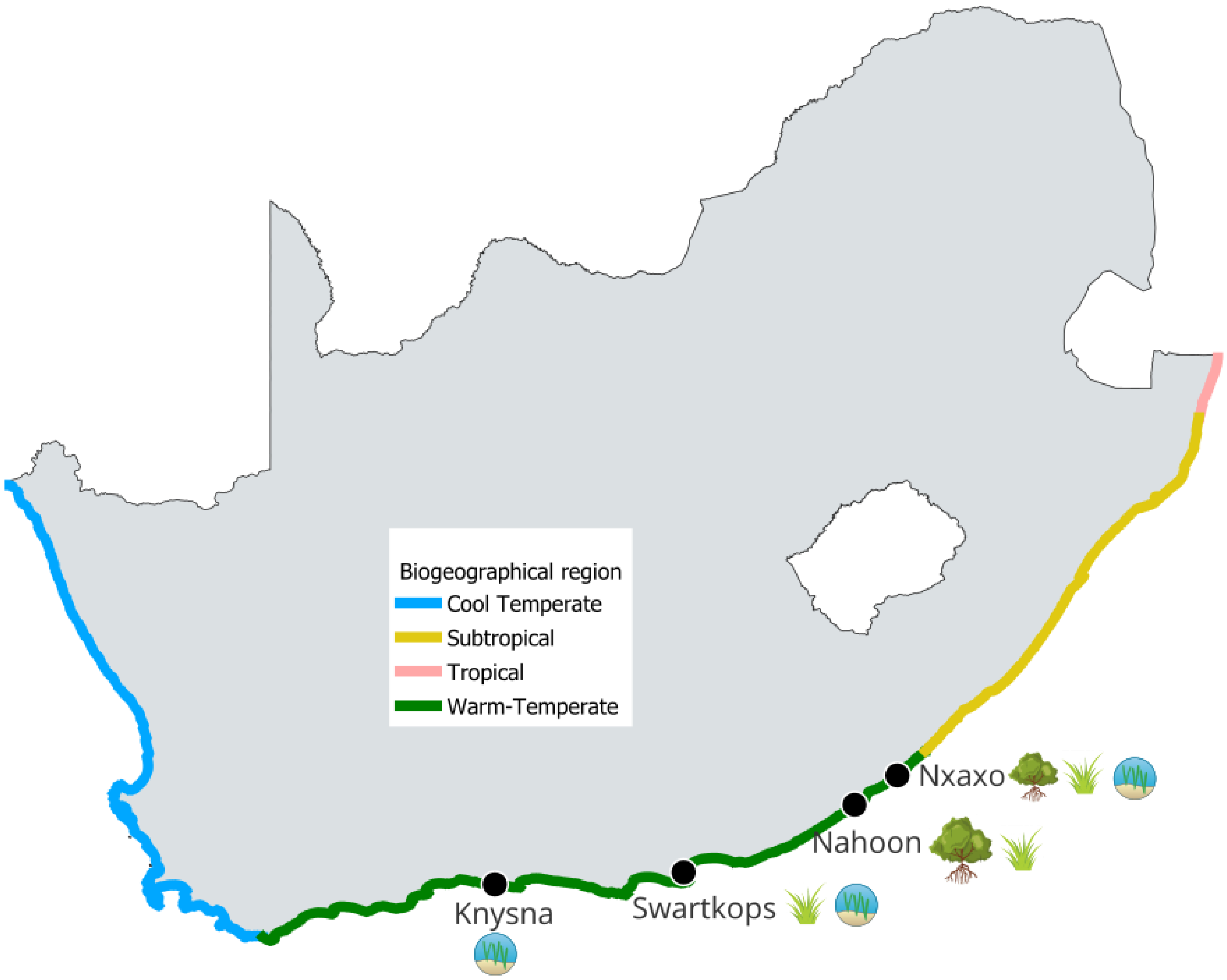

First national estimate of blue carbon stocks in South Africa (2023)

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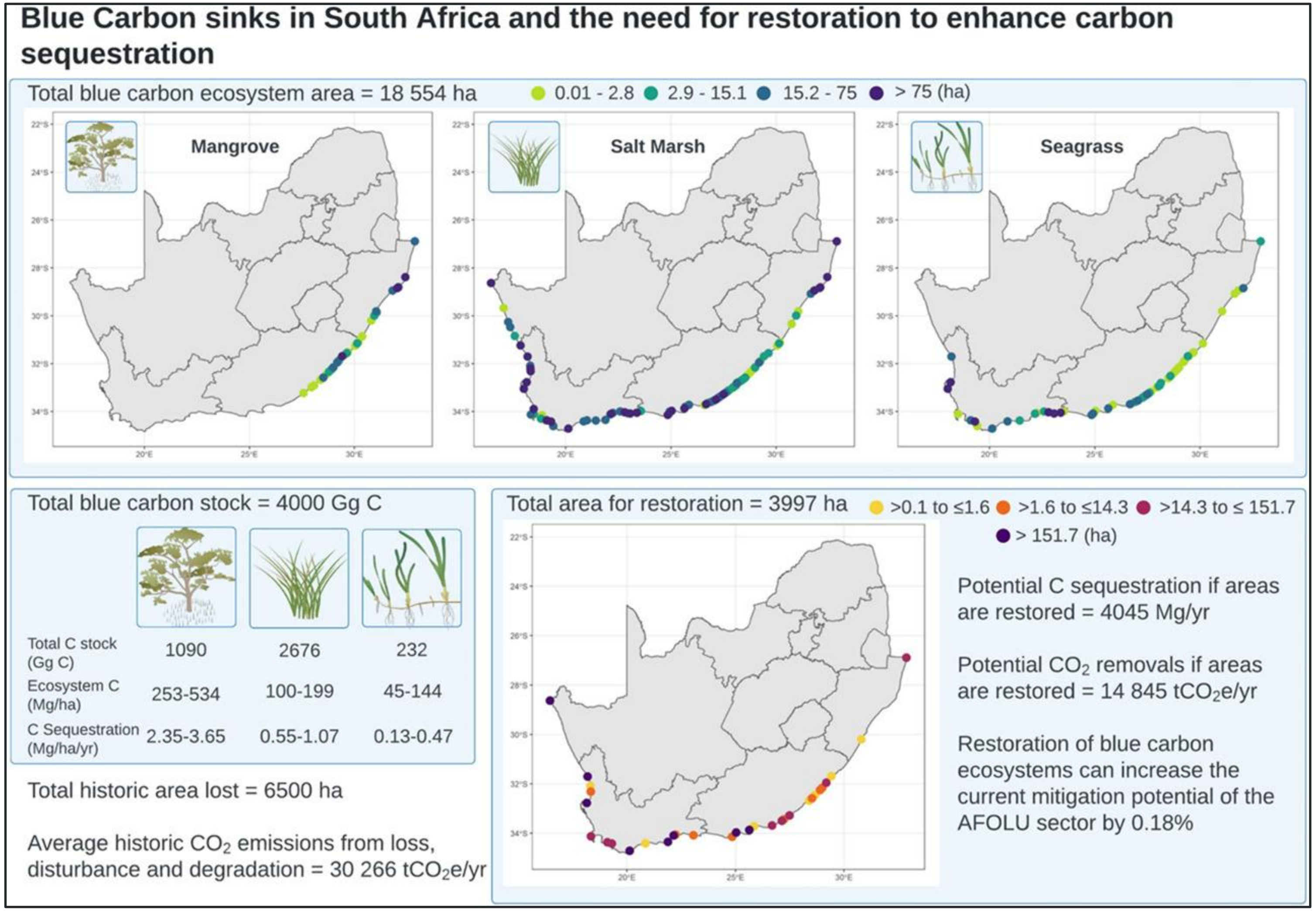

Used existing data to estimate national BC

1. Total carbon storage
2. CO_2 emissions from losses
3. Potential for restoration to enhance carbon sequestration

Seagrass
Total stocks: 228 Gg C
Carbon sequestration: 0.8 Gg C yr^{-1}

Recommended BCEs should be included in Agriculture, Forestry and Other Land Use (AFOLU) climate change response plans

Raw et al., 2023 *Science of the total Environment*

Many issues relating to the measurement of carbon fluxes and storage have yet to be resolved

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Carbon Removal Using Coastal Blue Carbon Ecosystems Is Uncertain and Unreliable, With Questionable Climatic Cost-Effectiveness

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TOPICAL REVIEW

How can blue carbon burial in seagrass meadows increase long-term, net sequestration of carbon? A critical review

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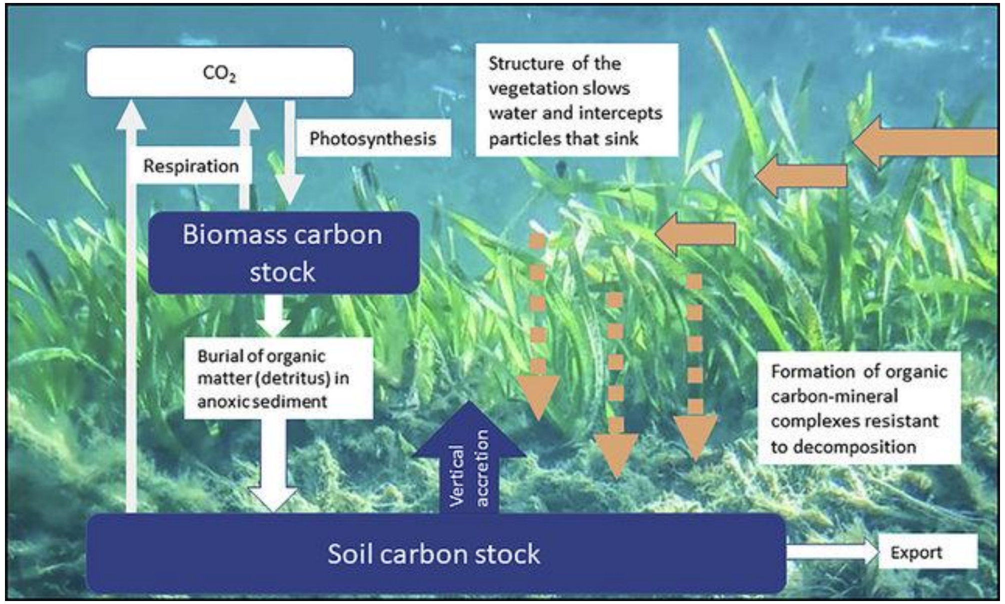
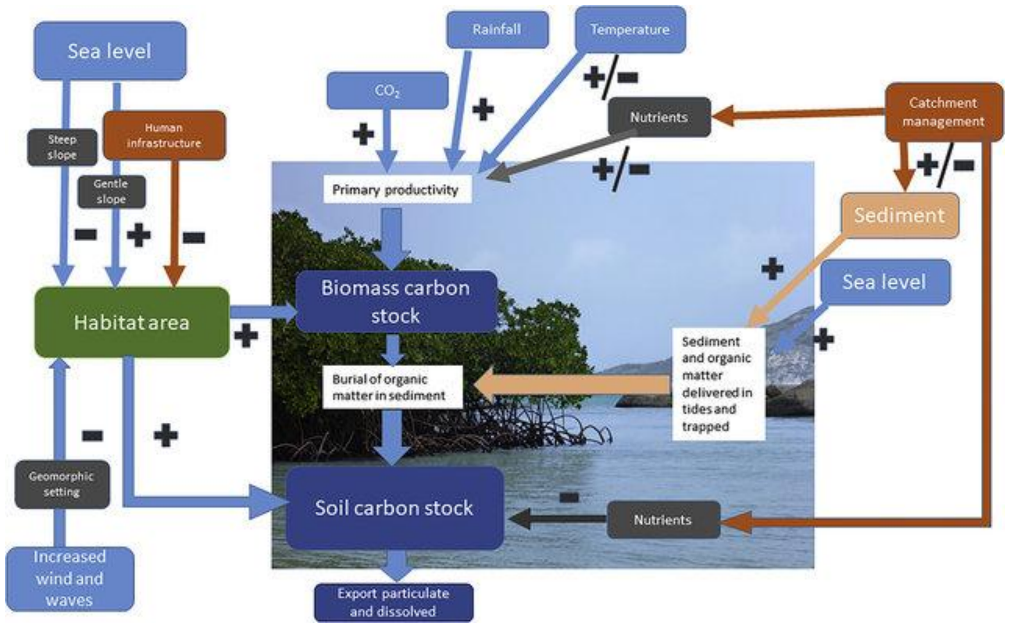
1. High variability in carbon burial rates
2. Errors in determining carbon burial rates
3. Lateral carbon transport
4. Fluxes of methane and nitrous oxide
5. Carbonate formation and dissolution
6. Vulnerability to future climate change
7. Vulnerability to non-climatic factors



Need to investigate and disentangle factors driving seagrass blue carbon variability

Spatial scale	Factors of soil C_{org} variability	Mechanisms	Effect in soil C_{org} stocks	Reference
Local	**Meadow properties**			
	Species composition	Determine below- and-above ground biomass, refractory nature of the seagrass debris and the efficiency at enhancing the sedimentation of allochthonous C_{org}.	Large species develop higher stocks	Serrano et al., 2019
	Water depth	Decrease in seagrass productivity due to limited irradiance. Can reduce exposure to hydrodynamic energy and enhance depositional conditions.	↑↓	Serrano et al., 2014; Lavery et., 2013; York et al., 2018
	Hydrodynamic energy	Enhanced export and erosion with increased energy.	↓	Röhr et al. 2016; Samper-Villarreal et al. 2016; Salinas et al., 2020
	Sediment grain size	Fine sediment content favors C_{org} preservation in seagrass soils by increasing anoxic conditions and protecting organic particles from microbial organic matter mineralization.	↑	Mayer 1994; Burdige 2007; Miyajima et al. 2017
	Allochthonous C_{org}	Increase the magnitude of the soil C_{org} deposits.	↑	Ricart et al. 2020; Kennedy et al., 2009
	Habitat geomorphology			
	Coast	Exposed to high hydrodynamic energy from waves, tides and currents, enhancing C_{org} erosion and export.	↓	Carruthers et al. 2002, 2007
		Subtidal environments up to 40 m: light limitation due to water depth.	↓	Duarte 1991
	Estuary	Low hydrodynamic energy from river and tidal flow: depositional environment.	↑	Depositional environment
		Intertidal to shallow depths: exposed to solar radiation, desiccation and high temperatures leading to potential decline in seagrass productivity.	↓	Carruthers et al. 2002, 2007
		Subject to terrigenous and anthropogenic inputs: light limitation due to turbidity, higher accumulation of allochthonous C_{org}, higher exposure to pollution	↑↓	Kilminster et al. 2015, Carruthers et al. 2002, 2007
	Bioregion			
Large	Tropical *vs.* Temperate	High precipitation: -Enhance allochthonous C_{org} and fine sediment accumulation. -Enhance turbidity and drops in salinity, compromising seagrass productivity and survival.	↑↓	Ridler et al. 2006; Chollett et al. 2007
		High temperature: -Enhance C_{org} remineralization.	↓	Pedersen et al. 2011
		High solar radiation: -Compensate light limitation: enhance seagrass productivity. -Combined with high temperature and tidal exposure compromises seagrass productivity and survival.	↑↓	Stapel et al., 1997

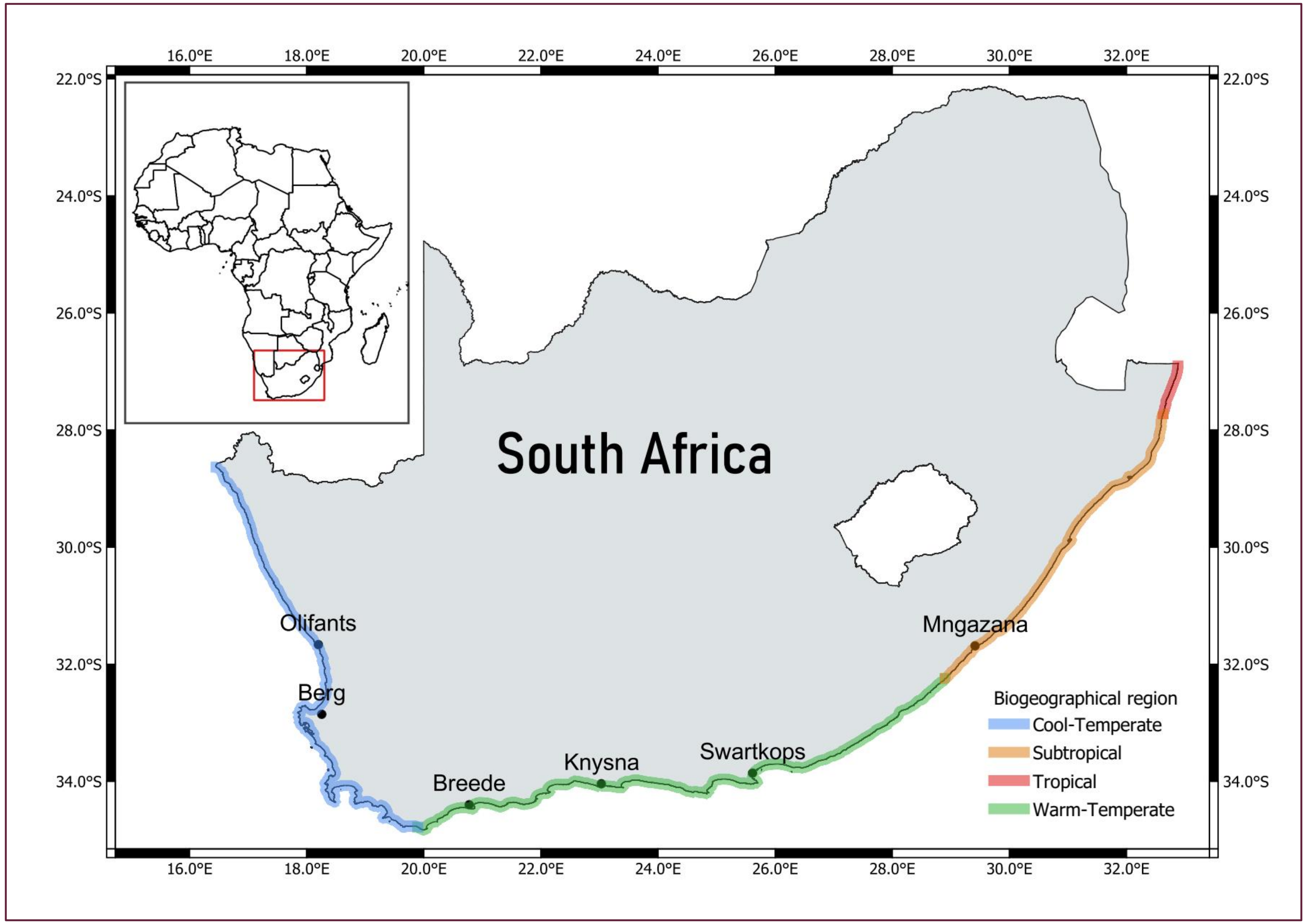


Mazarrasa et al., 2021 *Global Biogeochemical Cycles*; Lovelock and Reef, 2020 *One Earth*

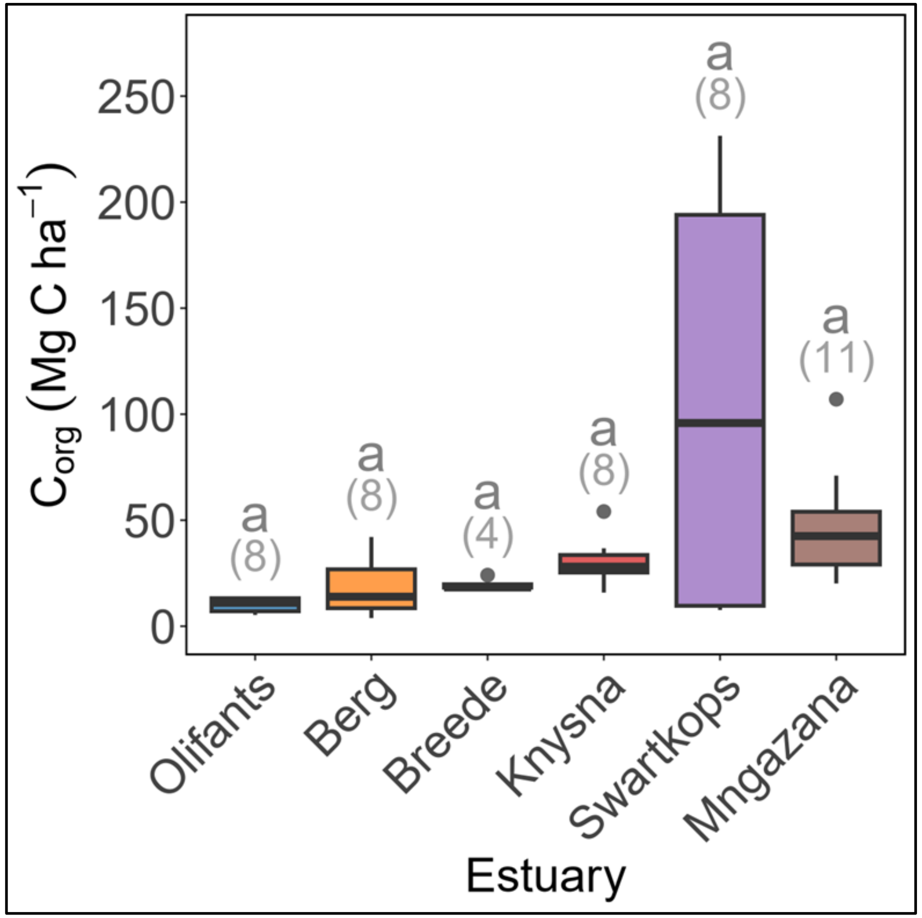
Seagrass: Research at the von der Heyden Lab

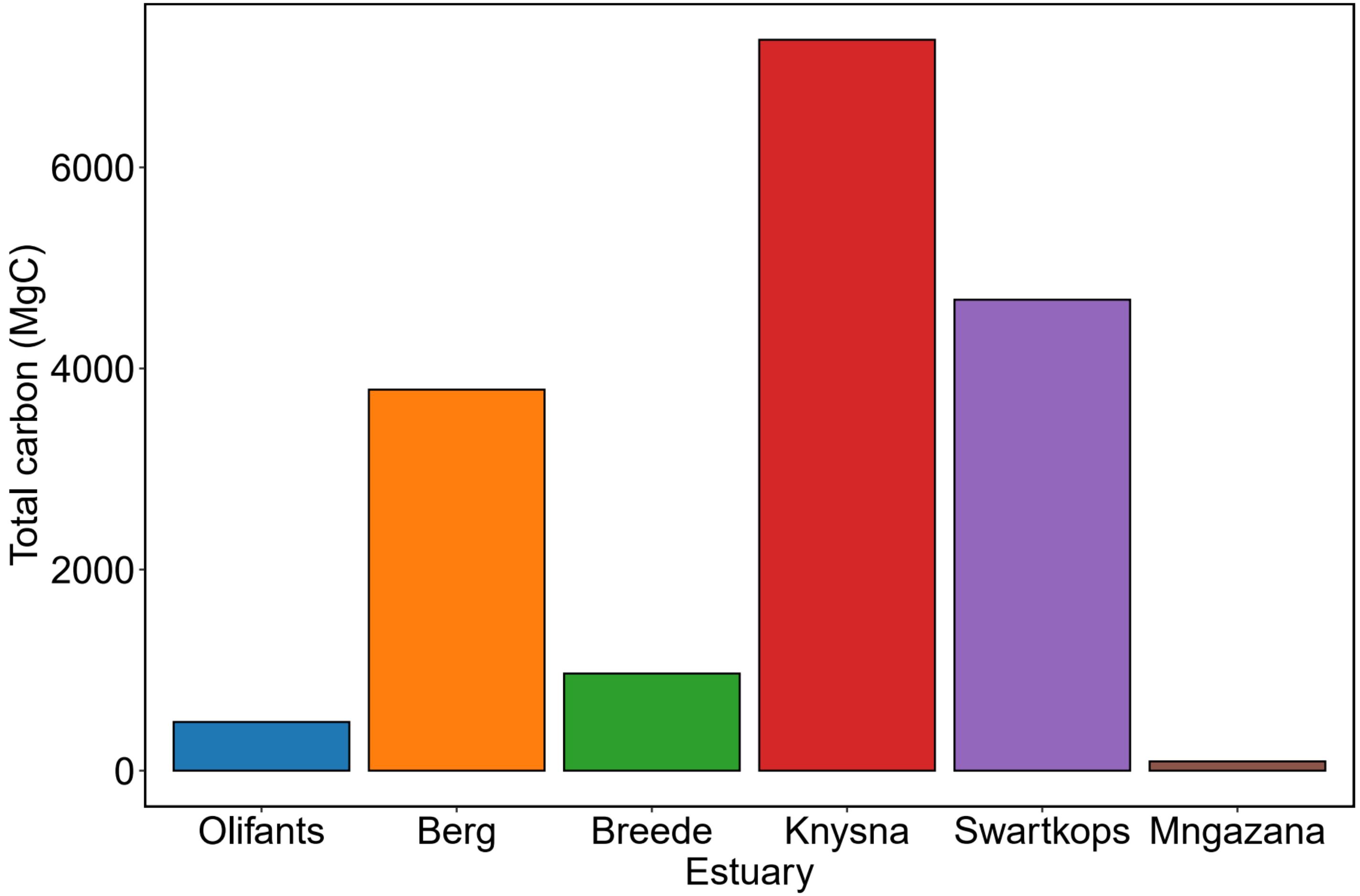
Research questions

1. Do carbon stocks differ in *Z. capensis* meadows along the cool-warm gradient of its distribution
2. Can large-scale environmental factors explain the variability in sediment *Z. capensis* C stocks
3. Are shoot counts and leaf lengths good predictors of C stocks



Variability in total carbon stocks





- Highest variability at Swartkops due to wastewater inputs, carbon stocks corroborated in other studies
- No significant differences in Corg stocks due to high intra-estuarine variability

Modelling environmental variables to explain the variability of *Zostera capensis* carbon stocks

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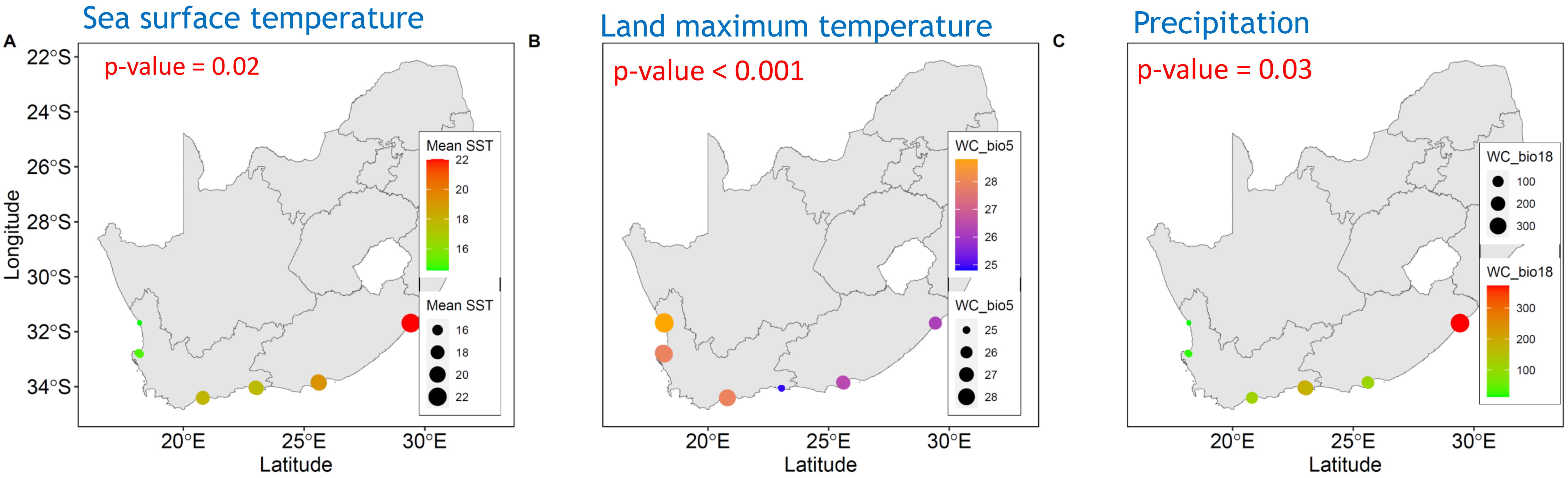

- Models are significant when the eutrophic site is removed
- High variability is driven by factors at local scales but large-scale environmental factors are important

Ndhlovu et al., 2024 *Science of the total Environment*

Seagrass-salt marsh ecotone: drivers of variability

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Plant Soil
https://doi.org/10.1007/s11104-024-06953-8

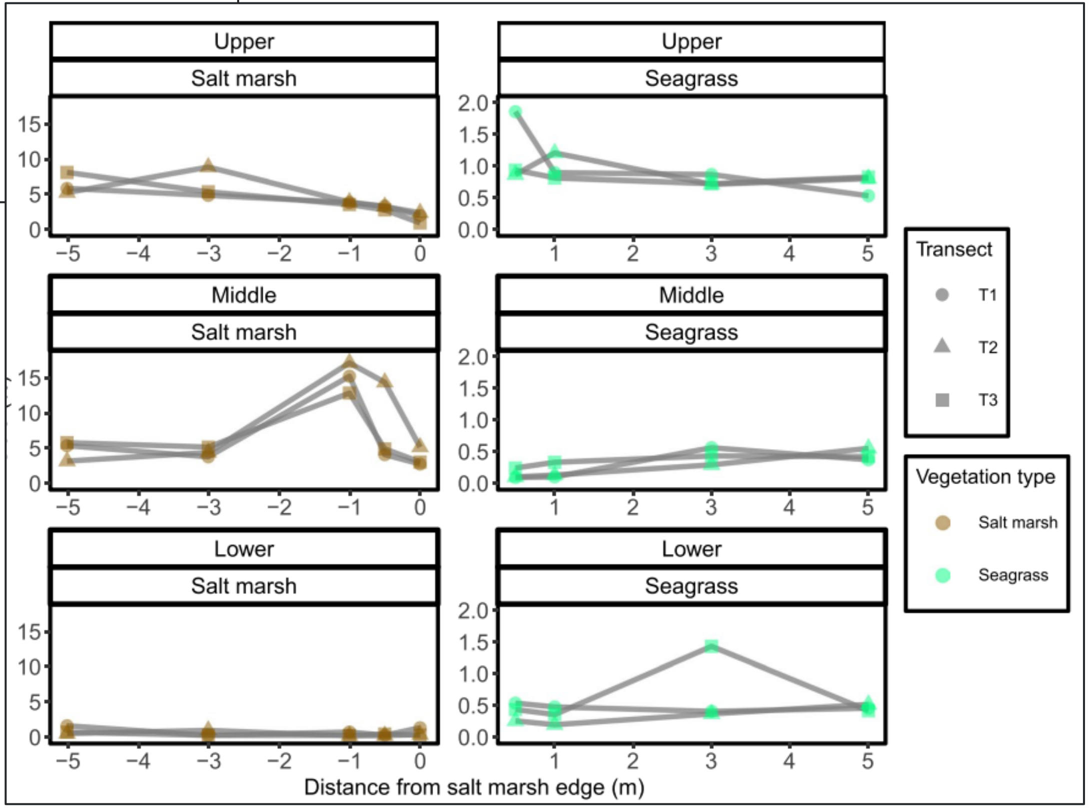
RESEARCH ARTICLE

Check for updates

Blue carbon dynamics across a salt marsh-seagrass ecotone in a cool-temperate estuary

Tiaan Engelbrecht · Sophie von der Heyden · Andrew Ndhlovu

Fixed effects	Estimate	Std. error	t-value	p-value
(Intercept)	-1.13	1.08	-1.05	0.35
Shoot density	0.00	0.01	0.82	0.46
Leaf length (cm)	0.01	0.00	1.93	0.39
Number of leaves per shoot	0.20	0.21	0.96	0.13
%N	5.79	1.52	3.81	**0.02**



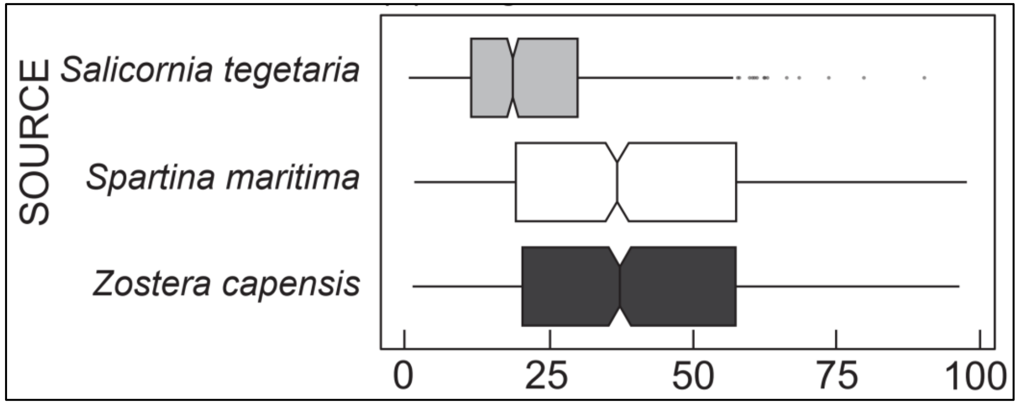
Lateral carbon transport in seagrass

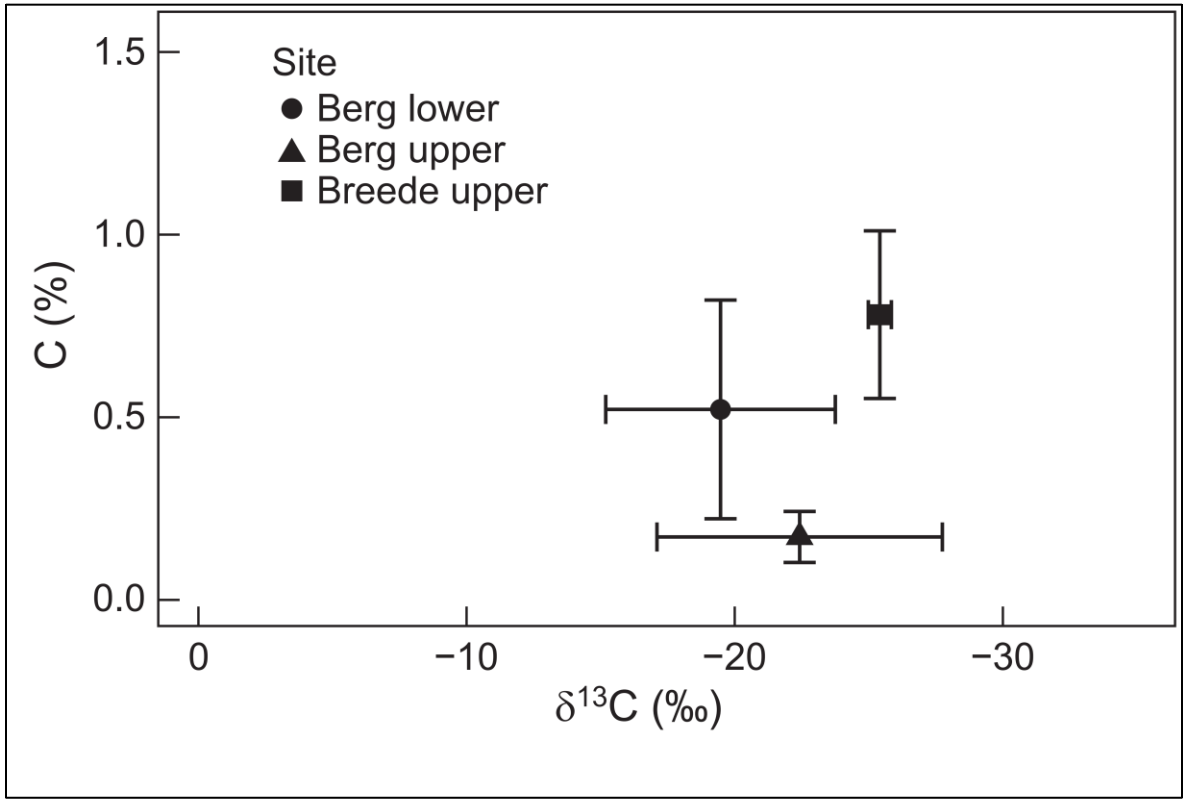

African Journal of Marine Science

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tams20

Partitioning the sources of sediment organic carbon in South African seagrass meadows

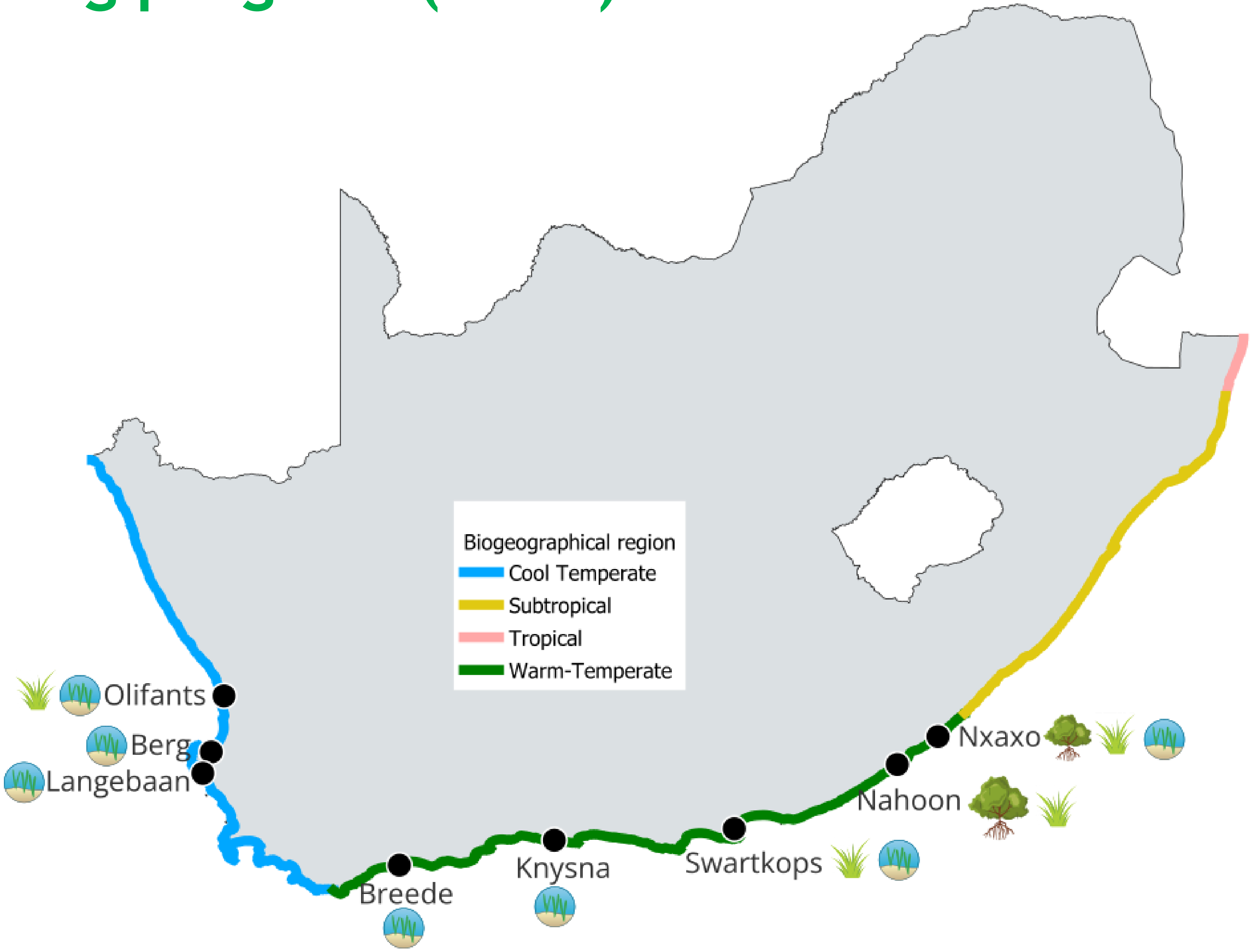
A Bossert, S von der Heyden, J Colling & A Ndhlovu





Site	Sediment δ^{13}C signature (‰)	*Zostera capensis* δ^{13}C signature (‰)	*Salicornia tegetaria* δ^{13}C signature (‰)	*Sporobolus virginicus* δ^{13}C signature (‰)	*Spartina maritima* δ^{13}C signature (‰)	Macroalgae δ^{13}C signature (‰)	Autochthonous C_{org} contribution (%)	Allochthonous C_{org} contribution (%)
Breede upper	−25.41 (SD 0.43)	−15.02 (SD 0.74)	−29.94 (SD 0.25)	−27.38 (SD 0.42)	–	–	<42	>58
Berg upper	−22.42 (SD 5.32)	−16.37 (SD 0.86)	−26.36 (SD 0.70)	–	–	−15.90 (SD 0.84)	<35	>65
Berg lower	−19.47 (SD 4.28)	−13.35 (SD 0.90)	−28.00 (SD 0.56)	–	−15.01 (SD 0.33)	–	<39	>61

Sampling progress (2025)



Seagrass as a GHG inventory in SA

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Requirements for a South African seagrass carbon budget

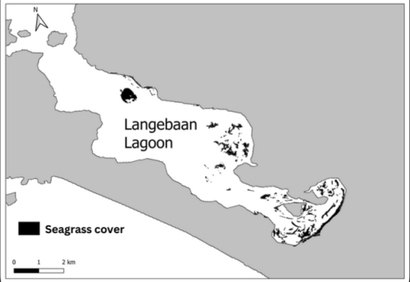
Area cover

WHAT HAS BEEN ACHIEVED

- Seagrass intertidal distributions mapped for 37 estuaries

WHAT IS REQUIRED

- Inclusion of subtidal meadows
- Account for patch dynamics and seasonal variability



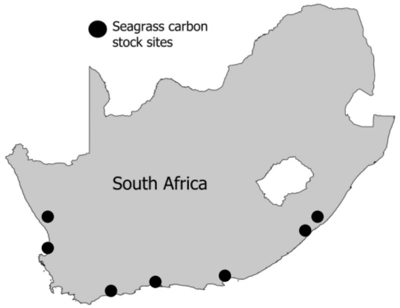
Carbon stock

WHAT HAS BEEN ACHIEVED

- 7 seagrass populations have carbon stock assessments

WHAT IS REQUIRED

- Calculate carbon stocks across remaining 30 populations
- Assess carbon stock variability across estuaries



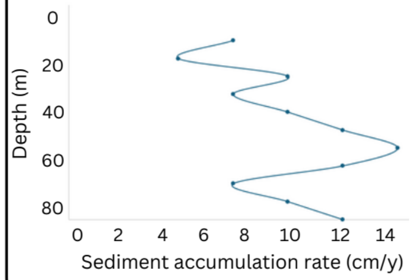
Sediment accretion rate

WHAT HAS BEEN ACHIEVED

- Only assessed in Knysna Estuary

WHAT IS REQUIRED

- Use carbon dating to establish average rates of sediment accretion across and within South African estuaries



Bossert et al., Submitted

Financing seagrass restoration through carbon trading

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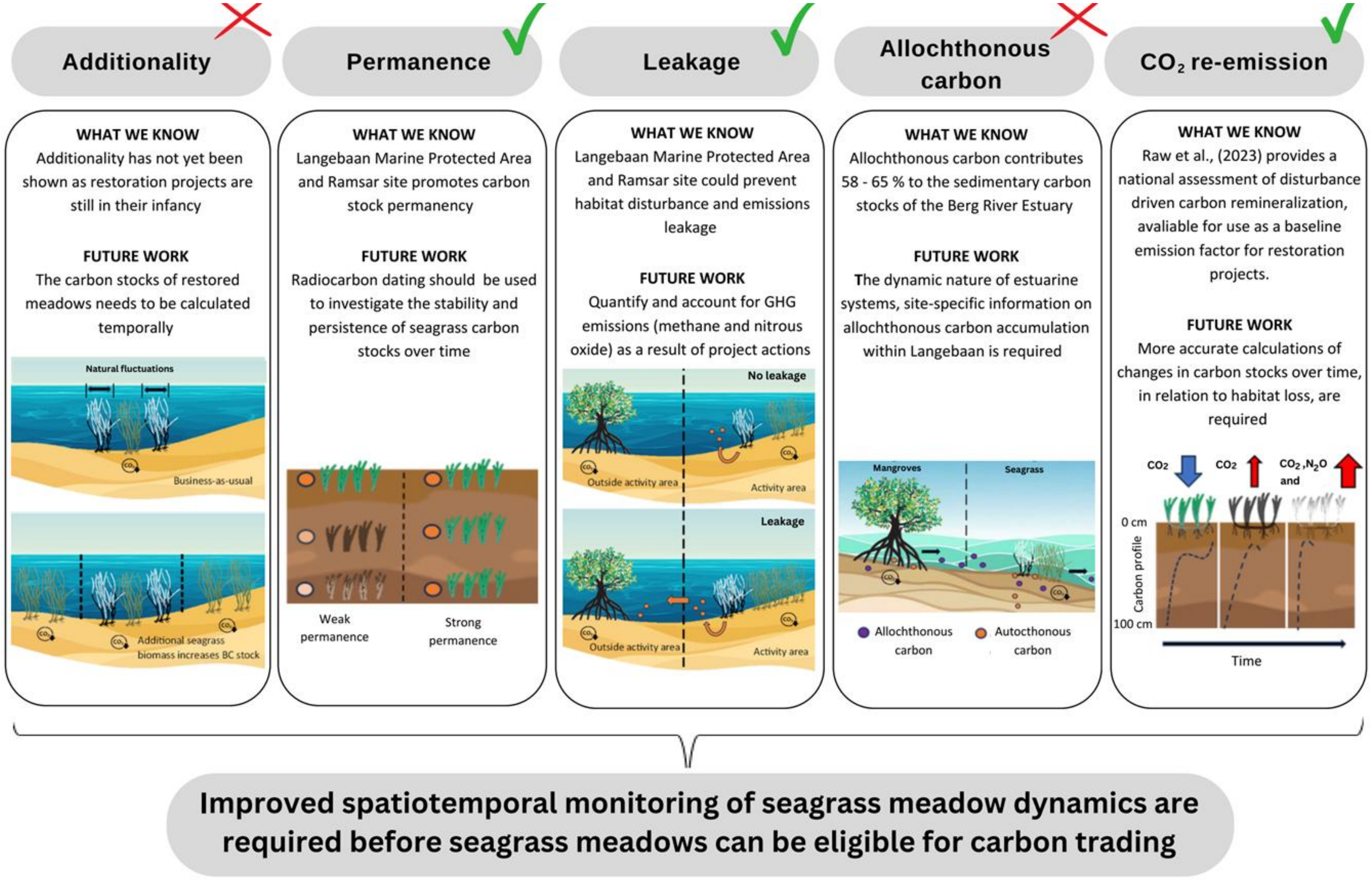

Bossert et al., Submitted

Looking ahead: We need more data

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Status and Future of Blue Carbon Assessments in Dynamic Estuarine Environments

Outcome: Holistic approach needed for Blue Carbon studies measuring across different estuary habitat types as seagrass, salt marsh and mangroves overlap with reeds, sedges, & forested wetlands

Blue Carbon Ecosystems	Other estuarine habitats	Emerging BC ecosystems
• Seagrass • Mangrove • Salt marsh	Reeds, sedges, forested wetlands Ecotonal terrestrial ecosystems: grass, shrub & forests	Seaweeds / kelps Biofilms / mudflats Supratidal microbialite pools

Priorities to investigating if estuarine habitats & emerging BCEs have:
(1) long-term organic carbon storage in their soils, and
(2) low Greenhouse Gas emissions – due to high primary productivity & low decomposition rates in waterlogged soils

Priority questions for future Blue Carbon research in South Africa

- How to improve the quantification of BCE carbon stocks in ecosystems and regions that are data-deficient?
- What must be done regarding conservation/management / restoration of BCEs in the face of climate change?
- How to develop a monitoring system to determine current and future threats to BCEs and monitoring programmes to track changes?
- How can we design and implement restoration and a national estuary protection plan for BCEs?

Adams et al., Submitted