SCOPING STUDY:

A Blue Carbon Sinks Assessment for South Africa

forestry, fisheries
& the environment

Department:
Forestry, Fisheries and the Environment
REPUBLIC OF SOUTH AFRICA

Prepared by:

Nelson Mandela University and Council for Scientific and Industrial Research

NELSON MANDELA UNIVERSITY

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Foreword

Not many people are aware of the role of blue carbon in climate change mitigation and adaptation, especially the potential benefits of these ecosystems that are found within protected estuaries along the South African coastline

In recent years, global attention on blue carbon has focused on the conservation and protection of blue carbon ecosystem such as mangroves swaps, salt marshes and seagrasses. Their contribution to climate mitigation and adaptation, as well as a reduction in greenhouse gas emissions, is largely due to their significant carbon stock content, both in the biomass and in the soil. Blue carbon ecosystems can contain as much as ten times more carbon content per unit area than terrestrial ecosystems. South Africa has joined countries across the globe in the development of policies and strategies to address the degradation of blue carbon ecosystems and to tap into its vast climate change mitigation potential.

The 'Scoping Study for a Blue Carbon Sinks Assessment in South Africa' was initiated by the Department of Forestry, Fisheries and the Environment. It is the first attempt to map and understand the distribution of these ecosystems along the country's coastline so that carbon stocks within the mangrove swamps, salt marshes and seagrass ecosystems could be quantified. Findings indicate that amount of carbon contained intact and functional ecosystems decrease commensurate with exposure to disturbances such as over-abstraction, lack of maintaining freshwater flows in estuaries or increased effluent flowing in these ecosystems.

The development of Estuary Management plans will contribute to the effective management of these important ecosystems and ensure that recreational and other activities along estuaries do not further degrade systems that have the potential to reduce carbon emissions while contributing to economic growth in sectors such as tourism and fishing.

The blue carbon ecosystems have a critical role in supporting the country's efforts to fulfil our revised Nationally Determined Contribution to reduce greenhouse gas emissions under the Paris Agreement. While more research is needed to fully understand the contribution of these ecosystems to adaptation and mitigation, this study is important to understanding the distribution of blue carbon stocks, the drivers of emissions from these ecosystems and how these stocks of the carbon can contribute to South Africa's climate change mitigation objectives.

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Contents

List of Tables

List of Figures

List of Text Boxes

List of Appendices

List of Acronyms

AFOLU	Agriculture, Forestry and Other Land Use
AGC	Aboveground Carbon
BGC	Belowground Carbon
BUR	Biennial Update Report
C	Carbon
C_{org}	Organic Carbon
CBA	Critical Biodiversity Area
CBD	Convention on Biological Diversity
CCBS	Climate, Community, and Biodiversity Standard
CDM	Clean Development Mechanism
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DBH	Diameter at Breast Height
DEA	Department of Environmental Affairs, South Africa
DFFE	Department of Forestry, Fisheries and the Environment, South Africa
DWS	Department of Water and Sanitation, South Africa
EFR	Estuarine Flow Requirement
EFZ	Estuarine Functional Zone
EIA	Environmental Impact Assessment
EMP	Estuary Management Planning
ENSO	El Niño-Southern Oscillation
EPA	Estuarine Protected Area
ESA	Ecological Support Area
EWR	Ecological Water Requirement
GHG	Greenhouse Gas
GPP	Gross Primary Production
GS	Gold Standard
IBA	Important Bird and Biodiversity Area
ICM	Integrated Coastal Management
IET	International Emissions Trading
IPCC	Intergovernmental Panel on Climate Change
ISM	Intertidal Salt Marsh

IUCN	International Union for Conservation of Nature
LOI	Loss On Ignition
LULUCF	Land Use, Land-Use Change and Forestry
MINTEC	Ministerial Technical Committee for Environment
MPA	Marine Protected Area
MRV	Measurement, Reporting and Verification
MSL	Mean Sea Level
NAMA	Nationally Appropriate Mitigation Action
NBA	National Biodiversity Assessment of 2018
NDC	Nationally Determined Contribution
NEE	Net Ecosystem Exchange
NECB	Net Ecosystem Carbon Budget
NEMA	National Environmental Management Act
NEP	Net Ecosystem Production
NPP	Net Primary Production
NTCSA	National Terrestrial Carbon Sink Assessment
OECD	Organisation for Economic Co-operation and Development
OECMs	Other Effective area-based Conservation Measures
PAMs	Policies and Measures
PES	Payments for Ecosystem Services
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RQO	Resource Quality Objective
RSET	Rod Surface Elevation Table
RSLR	Relative Sea-Level Rise
SA-LEDS	South Africa’s Low-Emission Development Strategy 2050
SAEON	South African Environmental Observation Network
SANBI	South African National Biodiversity Institute
SEEA	System of Environmental-Economic Accounting
SEEA EA	System of Environmental-Economic Accounting, Ecosystem Accounting
SDG	Sustainable Development Goal
SLR	Sea-Level Rise
SSM	Supratidal Salt Marsh
UN	United Nations
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
VCS	Verified Carbon Standard
WAM	With Additional Measures
WEM	With Existing Measures
WOM	Without Measures
WWF	World Wildlife Fund
WWTWs	Wastewater Treatment Works

Glossary of Terms and Key Words

Accretion – The accumulation of mineral and organic matter that is transported by hydrodynamic flows (riverine or tidal). Vertical buildup of the sediment increases the relative elevation of the substrate.

Aerobic – An aerobic environment is one that is characterised by the presence of free oxygen (O_2). In coastal ecosystems, aerobic conditions in the soil promote decomposition of organic carbon.

Afforestation – The process of introducing trees (or tree seedlings and saplings) to an area that is not forested, usually performed as a restoration action for degraded forest areas.

Allochthonous Carbon – Carbon produced in one location and deposited in another. In blue carbon ecosystems this carbon is transported to the ecosystem by hydrodynamic action of waves, tides and river flow. The carbon can originate from terrestrial or marine environments.

Allometric Equations – Allometric equations are used to establish a quantitative relationship between key characteristics that can be easily measured directly (such as stem height and diameter) to other properties that are difficult to measure directly (such as biomass).

Anaerobic/Anoxic – An anaerobic/anoxic environment is one that is characterised by the absence of free oxygen (O_2). In coastal ecosystems, anaerobic/anoxic conditions in the soil prevent decomposition of organic carbon.

Autochthonous Carbon – Carbon produced and deposited in the same location. In blue carbon ecosystems, this type of carbon originates from vegetation uptake of CO_2 which is converted to plant tissue through photosynthesis and then decomposed in the soil.

Biodiversity – The diversity of genes, species and ecosystems on Earth, and the ecological and evolutionary processes that maintain this diversity.

Blue Carbon – The carbon stored in mangroves, salt marshes and seagrass meadows within the soil, the living biomass above ground (leaves, branches, stems), the living biomass below ground (roots) and the non-living biomass (leaf litter and dead wood).

Carbon Inventory – An accounting of carbon gains and losses emitted to or removed from the atmosphere/ocean over a period of time. Policy makers use inventories to establish a baseline for tracking emission trends, developing mitigation strategies and policies and assessing progress.

Carbon Dioxide Equivalent (CO_2e) – The universal unit of measurement used to indicate the global warming potential (GWP) of each of the six Kyoto greenhouse gases. It is used to evaluate the impacts of releasing (or avoiding the release of) different greenhouse gases.

Carbon Neutral – A country, company, process, etc. that does not emit more carbon dioxide than it captures. An entity could be carbon neutral because it does not emit any carbon dioxide in the first place, but 'carbon neutral' more often refers to an entity or process that emits some carbon dioxide but removes just as much carbon dioxide from the atmosphere via carbon removal.

Carbon Offset – A reduction in emissions of carbon dioxide or other greenhouse gases made in order to compensate for emissions made elsewhere. Offsets are measured in tonnes of carbon dioxide-equivalent (CO_2e).

Carbon Pool – Carbon reservoirs such as soil, vegetation, water and the atmosphere that absorb and release carbon. Together carbon pools make up a carbon stock.

Carbon Sequestration – The long-term removal or capture of carbon dioxide from the atmosphere to slow or reverse atmospheric CO_2 levels which will mitigate or reverse global warming. Carbon sequestration occurs naturally through photosynthesis in blue carbon ecosystems.

Carbon Stock – The total amount of organic carbon stored in a blue carbon ecosystem of a known size. A carbon stock is the sum of one or more carbon pools.

Climate Change – A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

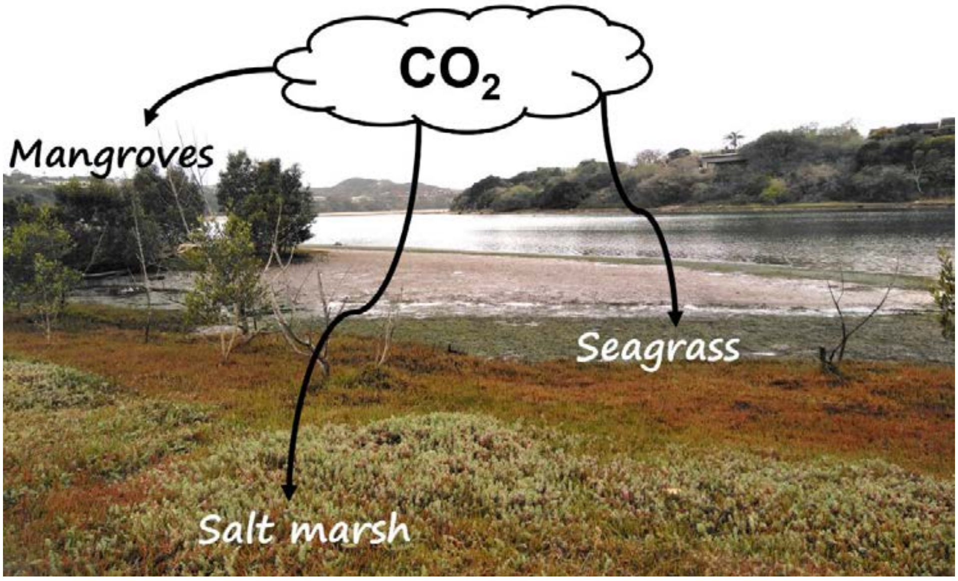
Compaction – The process by which soils progressively lose porosity (become compacted and dense) as a result of pressure on the surface (such as with disturbance by trampling).

Delta – A coastal landform comprised of sediments (clay, silt, sand, gravel or detrital material) that have been transported by a river and deposited at the mouth. Deltas form at the coastal interface where riverine sediment supplied to the coastline is not removed by tides or waves.

Deposition – The geological process that involves the layering down of sediment, soil and rocks to a substrate or landmass. This material has generally been transported to the place of deposition by wind or water. Sediment can be transported as pebbles, sand or mud.

Ecosystem – A community of living organisms in conjunction with the non-living components of their environment, interacting as a system.

Ecosystem Services – The benefits that people obtain from ecosystems, including provisioning services (such as food and water), regulating services (such as flood control), cultural services (such as recreational benefits) and supporting services (such as nutrient cycling, carbon storage) that maintain the conditions for life on Earth. Ecosystem services are the flows of value to human society that result from a healthy stock of ecological infrastructure. If ecological infrastructure is degraded or lost, the flow of ecosystem services will diminish.



Carbon Sequestration (Photo: J Raw)

Emission Reduction Scenario – Scenario describing plausible future emission trajectories to reflect the likely quantity and trend of greenhouse gas emissions released for a given period, including variances related to levels of economic growth, the structural makeup of an economy, demographic development and the effect of emission reduction policies.

Epiphyte – A photosynthetic organism (plant or algae) that uses another plant as a substrate for growth and support. Epiphytes are not parasitic to the supporting plants. In blue carbon ecosystems, epiphytic algae are common on the leaves of seagrasses, the aerial roots of mangroves, as well as the lower portion of the stems of salt marsh plants.

Erosion – The action of water flow or wind on a substrate surface which removes soil, rock or dissolved material from one location to another. In blue carbon ecosystems, erosion of banks by high-flow velocities or wave action leads to destabilisation of the substrate as the material is transported away from the system.

Estuarine Functional Zone – The open water area of an estuary together with the associated floodplain, incorporating estuarine habitat (such as sand and mudflats, salt marshes, rock and plant communities) and key physical and biological processes that are essential for estuarine ecological functioning.

Floodplain – The flat area of land alongside a river or estuary that gets covered by water during a flood event.

Fluvial – Found in a river. Fluvial processes are associated with rivers and streams and the deposits and landforms created by them.

Gain-Loss Method – This method estimates the difference in carbon stocks based on emissions factors for specific activities (e.g. plantings, drainage, rewetting, deforestation) derived from the scientific literature and country activity data and results in Tier 1 and 2 estimates.

Geomorphic – Relating to the form of the landscape and other natural features of the Earth's surface.

Greenhouse Gas (GHG) – Those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Besides carbon dioxide, nitrous oxide and methane, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Habitat Loss – Conversion of natural habitat in an ecosystem to a land-use or land-cover class that results in an irreversible change in the composition, structure and functional characteristics of the ecosystem concerned.

Hydrological Regime/Flow Regime – The hydrological regime (also referred to as flow regime) includes all aspects relating to the flow of water, including magnitude, frequency, duration, predictability and flashiness.

Inorganic Soil Carbon – The term 'inorganic soil carbon' refers to the carbon component of carbonates (i.e. calcium carbonate) and can be found in coastal soils in the form of shells and/or pieces of coral.

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 modelling.

Kyoto Protocol – An international treaty that operationalises the United Nations Framework Convention on Climate Change by committing industrialised countries and economies in transition to limit and reduce greenhouse gas (GHG) emissions in accordance with agreed individual targets. The Convention itself only asks those countries to adopt policies and measures on mitigation and to report periodically.

Mangrove – A tree, shrub, palm or ground fern, generally exceeding half a metre in height, which normally grows above mean sea level in the intertidal zone of marine coastal environments and estuarine margins. A mangrove is also the tidal habitat comprising such trees and shrubs.

Mitigation Measures – Measures to prevent, reduce or control adverse environmental effects of a project. In this instance, processes and practices which, if employed, would reduce GHG emissions below anticipated future levels when compared to the status quo or existing techniques normally employed.

Mitigation Opportunity – An anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases.

Mitigation Potential – The mitigation potential of a measure is the quantified amount of GHGs that can be reduced, measured against a baseline (or reference). The baseline (or reference) is any datum against which change is measured. Mitigation potential is represented in tonnes of carbon dioxide equivalent (tCO_2e).

Nationally Appropriate Mitigation Actions (NAMAs) – Any action that reduces emissions in developing countries and is prepared under the umbrella of a national governmental initiative. They can be policies directed at transformational change within an economic sector, or actions across sectors for a broader national focus.

Nationally Determined Contributions (NDCs) – National climate action plans highlighting climate actions, including climate-related targets, policies and measures governments aim to implement in response to climate change and as a contribution to global climate action. They are associated with the Paris Agreement.

Natural Climate Solutions – Solutions that involve conserving, restoring or better managing ecosystems to remove carbon dioxide from the atmosphere. Examples include allowing forests to regrow, restoring mangroves and other wetlands, and switching to restorative agricultural practices, such as cover crop rotation, that support healthy soils. These ecosystems capture carbon dioxide from the air and sequester it in plants, soils and sediments.

Paris Agreement – A legally binding international treaty on climate change. Its long-term temperature goal is to limit global average temperature to well below 2°C above pre-industrial levels, and to preferably pursue efforts that would limit warming to 1.5°C above pre-industrial levels. The Paris Agreement recognises this would substantially reduce the risks and impacts of climate change and that it must be achieved through emission reductions.

Periphyton – A mixture of organisms (algae, cyanobacteria, microbes) and detritus that is attached to submerged surfaces in aquatic environments. In blue carbon ecosystems, periphyton is found attached to the leaves of seagrasses, the aerial roots of mangroves, as well as the lower portion of the stems of salt marsh plants.

Pneumatophores – The aerial roots of mangroves which protrude above the surface of the soil. These roots are specialised for gaseous exchange.

Projection – In general usage, a projection can be regarded as any description of the future and the pathway leading to it.

Rehabilitation – The repair and replacement of essential ecosystem structures and functions which have been altered by disturbance. This is an attempt to return to a self-sustaining ecosystem.

Restoration – A return to pre-disturbance conditions. Also referred to as the process of reversing the degradation of ecosystems. This is an attempt to return an ecosystem to a former natural condition.

Salt Marsh – A tidal salt marsh is a coastal ecosystem in the upper intertidal zone between land and open salt water or brackish water that is regularly flooded by the tides. It is dominated by dense stands of salt-tolerant plants such as herbs, grasses or low shrubs.

Scenario – A coherent, internally consistent and plausible description of a possible future state of the world. It is not a forecast; rather, each scenario is one alternative image of how the future may unfold. A projection may serve as the raw material for a scenario, but scenarios often require additional information (for example, about baseline conditions).

Seagrass – Seagrasses are flowering plants belonging to four plant families, all in the order Alismatales, which grow in marine, fully saline environments. There are 12 genera with some 58 species known. In South Africa, seagrasses occur in estuaries and can tolerate brackish salinity.

Sea-Level Rise – The average long-term global rise of the ocean surface measured from the centre of the Earth (or more precisely, from the Earth reference ellipsoid), as derived from satellite observations. Global sea-level rise began in the 20th century and has accelerated due to human-caused global warming, which is driving thermal expansion of seawater and the melting of land-based ice sheets and glaciers.

- **Eustatic Sea-Level Rise** – Vertical rate of increase in local sea level, typically determined from long-term sea-level records.
- **Relative Sea-Level Rise** – The combination of eustatic sea-level rise and the local vertical land motion (subsidence or uplift).

Sediment Bulk Density – A measure of the mass to volume ratio of soil. It is an indicator of soil compaction and is dependent on the soil texture and particle size (sand, silt or clay). Bulk density generally increases with soil depth. Soils with lower bulk density tend to have higher organic carbon content.

Sediment Particle Size – Sediment particle size (or grain size) refers to the diameter of individual grains of sediment. Size ranges define sediment classes. In blue carbon ecosystems, sediment particle size ranges usually include clay (< 0.002 mm), silt (0.002–0.0063 mm) and sand (0.0063–2 mm).

Soil Organic Carbon – The carbon component of the soil organic matter. The amount of soil organic carbon depends on soil texture, climate, vegetation and historical and current land use/management.

Soil Organic Matter – The organic constituents in the soil (undecayed tissues from dead plants and animals, products produced as these decompose and the soil microbial biomass). It includes soil organic carbon.

Stratification – Technique used to divide large heterogeneous sites (which require many samples to account for variation) into smaller, more homogeneous areas (where fewer samples are needed) and is also useful when field conditions, logistical issues and resource limitations prevent dense sampling regimes.

Subsidence – The lowering of the land surface or the sinking of land. It can occur naturally or can be influenced by human activities.

Surface Elevation Change – The relative change in the surface level of the substrate. In blue carbon ecosystems, the surface elevation change is positive when vertical accretion is greater than subsidence.

Negative surface elevation change (when subsidence is greater than vertical accretion) leads to loss of blue carbon ecosystems as the position within the tidal frame is no longer suitable for the survival of the plant species.

Sustainable Development Goals – The collection of 17 interlinked global goals which are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including poverty, inequality, climate change, environmental degradation, peace and justice.

Tidal Range – The height difference between high tide and low tide. The most extreme tidal range occurs during spring tides. The mean tidal range is calculated as the difference between Mean High Water (average high tide level) and Mean Low Water (average low tide level).

Subtidal/Neritic Zone – This area is always submerged. Only seagrasses occur in this zone.

Intertidal Zone – This area is above water at low tide and underwater at high tide. Mangroves, salt marshes and seagrasses can occur in the intertidal zone.

Supratidal Zone – This area is above the spring high tide line, but it is still influenced by tidal processes. Certain mangrove and salt marsh plant species can occur in this zone.

Executive Summary

'Blue carbon' is the carbon that is naturally stored in coastal and marine ecosystems – specifically in mangroves, salt marshes and seagrasses. These ecosystems are among the most productive on Earth, and they provide numerous goods and services to people. One of the most valued ecological roles of these ecosystems is carbon storage and sequestration. Although blue carbon ecosystems cover less than 2% of the area of the global ocean, they are critical carbon sinks which capture 50% of the total carbon sequestered in ocean sediments.

Blue carbon ecosystems are a key component of the global carbon cycle. Enhancing carbon storage and sequestration from these ecosystems has been increasingly recognised as a key component for climate change mitigation over the past decade. As climate change continues to escalate, it is unlikely that emissions reductions alone will be sufficient to curb the current trends in global warming – and therefore enhancing CO_8 removals will be necessary. The oceans and associated marine ecosystems have an important role in national and global strategies for climate change mitigation in this regard.

As a signatory to the Paris Agreement, South Africa has made commitments towards reducing emissions, while still aiming

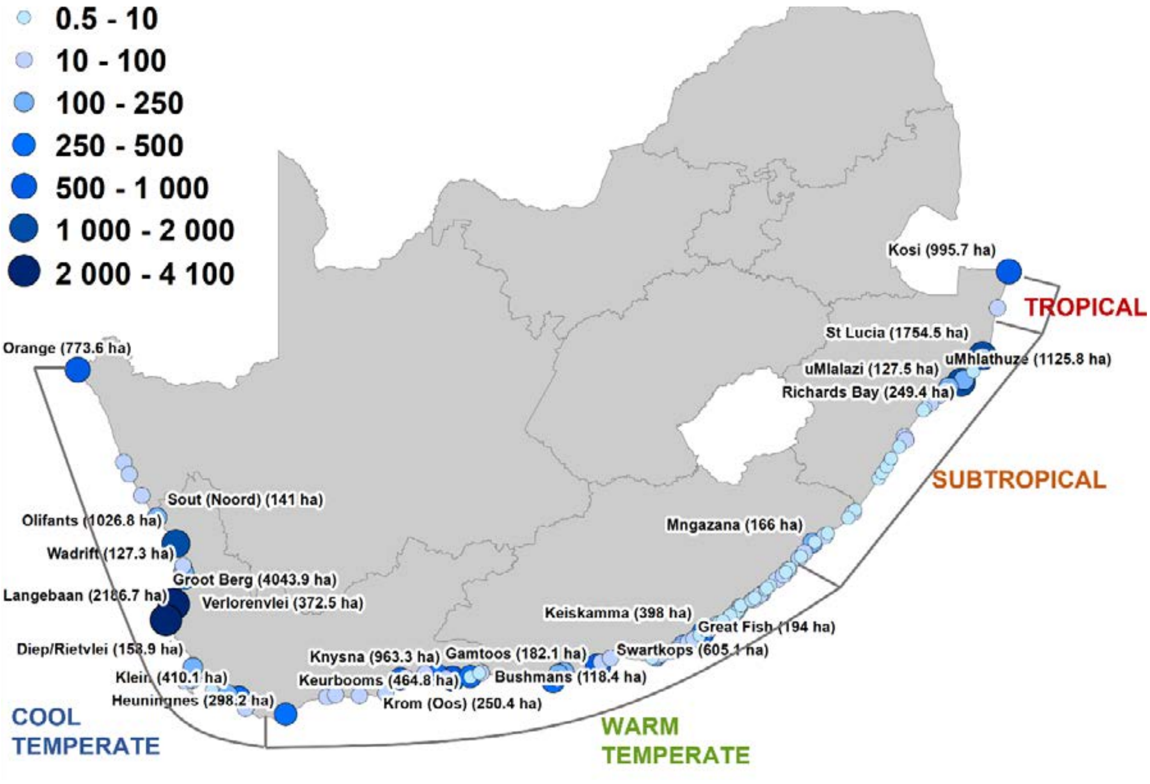
Mangroves and salt marshes are coastal vegetation types that occur at the boundary between land and sea. Within estuaries they occupy intertidal and supratidal zones. Seagrasses occur in intertidal and subtidal zones. Here mangrove trees and succulent salt marshes are shown along a tidal creek at the Nahoon Estuary (Eastern Cape).

to achieve a just transition towards a resilient, low-carbon economy. While the largest sources of CO_2 emissions in the country are from the Energy Sector, the Land Sector has the largest potential to contribute towards CO_2 removals, and this could include blue carbon ecosystems.

BLUE CARBON IN SOUTH AFRICA

Along the South African coastline blue carbon ecosystems occur within our sheltered estuaries. Mangroves are found along the tropical and subtropical coasts of KwaZulu-Natal and extend to the eastern warm-temperate coast of the Eastern Cape. Salt marshes occur more extensively along the southern warm-temperate coasts of the Eastern Cape and Western Cape, as well as along the cool-temperate west coasts of the Western Cape and Northern Cape. Seagrasses occur in estuaries across all biogeographic regions of the coastal provinces, but predominantly in those systems that maintain a permanent connection to the ocean.

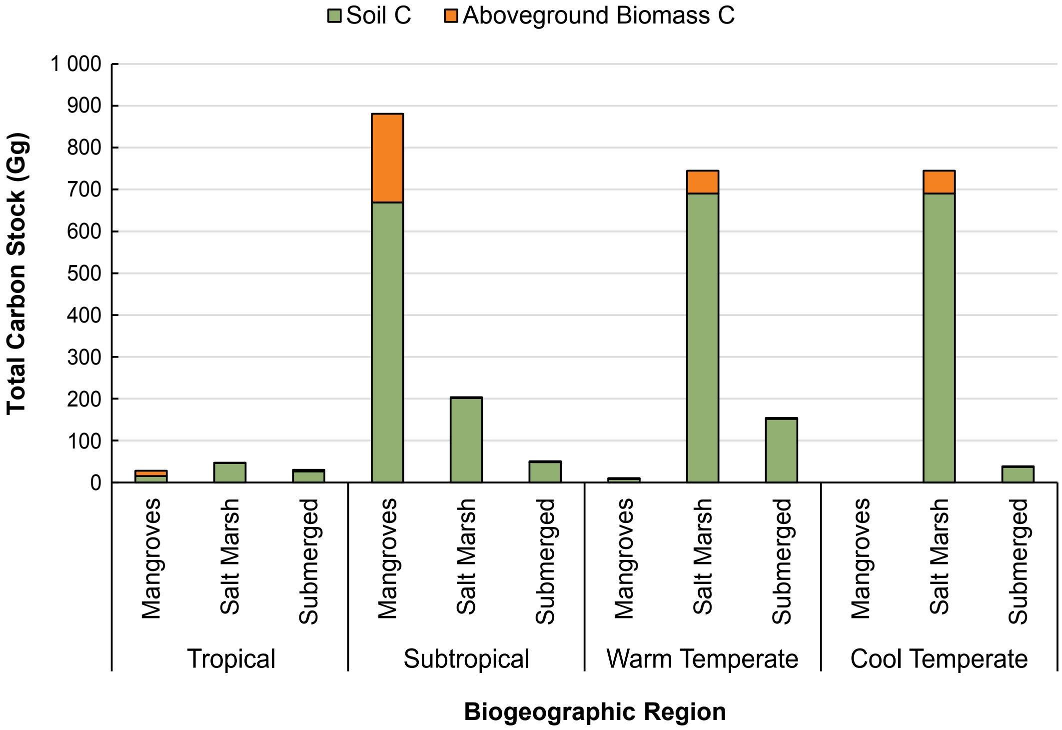
The current project – 'Scoping Study: A Blue Carbon Sinks Assessment for South Africa' – has been carried out to provide information on the carbon storage and sequestration potential of blue carbon ecosystems in the country, and thereafter identify climate change mitigation opportunities from these ecosystems. This information is needed if blue carbon ecosystems are to be included within South Africa's national greenhouse gas (GHG) inventory as part of the Agriculture, Forestry and Other Land Use (AFOLU) sectoral ambitions.



Distribution of blue carbon ecosystems along the South African coastline. Only estuaries with combined mangrove, salt marsh and submerged macrophyte area > 100 ha are labelled on the map. The biogeographic regions of the coastal provinces are indicated.

Blue carbon ecosystems in South Africa have been estimated to cover a total area of ~19 800 ha (14 713 ha of salt marshes, 3 039 ha of submerged macrophytes and 2 087 ha of mangroves). These areas have been spatially mapped and serve as an update to the national integrated coast map which was developed as part of the 2018 National Biodiversity Assessment. All blue carbon ecosystem areas are therefore available in the form of a geodatabase and a National Blue Carbon Map through the South African National Biodiversity Institute (SANBI). Blue carbon ecosystems that have been degraded are also included within the spatial dataset.

To quantify the carbon storage and sequestration potential of blue carbon ecosystems requires that in-depth measurements be taken from different carbon pools within these ecosystems using a standardised methodology provided by the International Union for Conservation of Nature (IUCN) Blue Carbon Initiative. When site-specific data are not available, it is possible to apply default values provided by the methodology. At the time of this assessment, detailed field studies had only been carried out in four estuaries (Knysna, Swartkops, Nahoon and Nxaxo-Ngqusi), but all the blue carbon ecosystem types were represented in these studies. An extrapolative model was used to estimate carbon storage for all blue carbon ecosystems in South Africa using the available data while accounting for variability across the biogeographic regions. The estimated values from the model were compared to those obtained using default values and the modelled estimates were found to be more conservative and within range to similar sites in other regions. Using this approach, it was estimated that **the current total carbon stored within South African blue carbon ecosystems is 2.9 million Mg C** (megagrams Carbon).

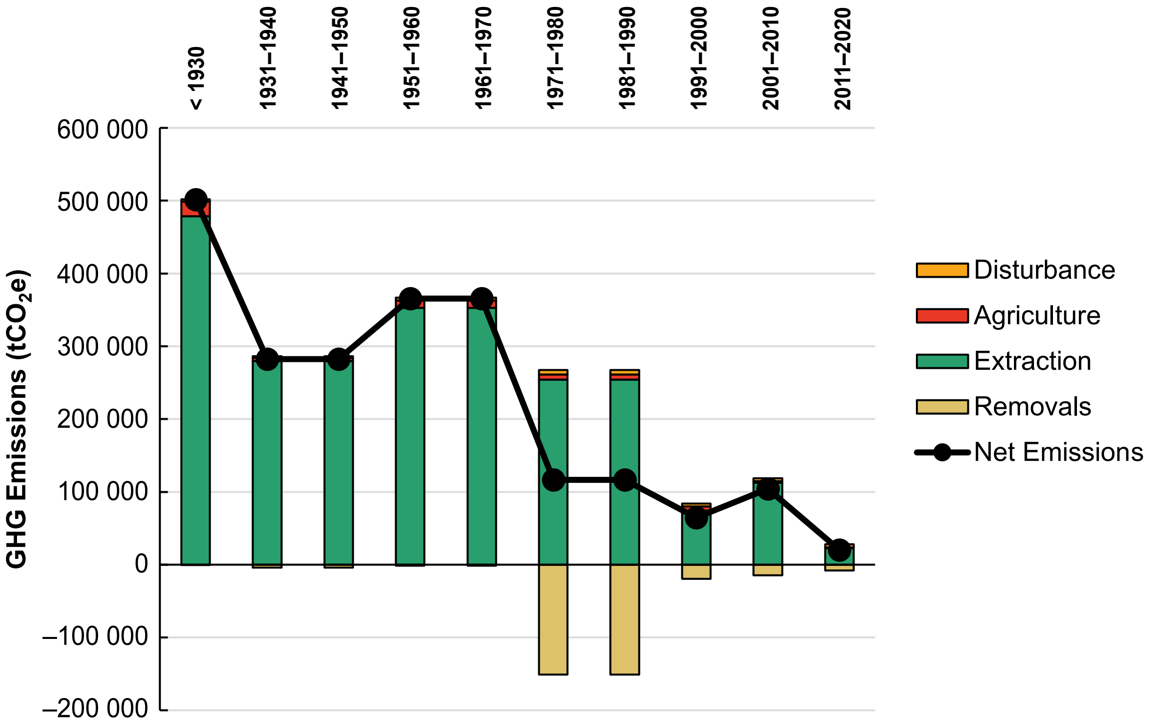


Comparison of present total carbon stocks (Gg) calculated for soil and aboveground biomass (AGB) of blue carbon ecosystems in South Africa. Stocks are compared between biogeographic regions.

HISTORICAL CO_2 EMISSIONS AND REMOVALS FROM BLUE CARBON ECOSYSTEMS

A GHG emissions baseline for South African blue carbon ecosystems was developed so that projections could be made to 2050 to be aligned with the AFOLU strategic framework. Historical GHG emissions and removals trends for blue carbon ecosystems were determined to form a trajectory along which future emissions and removals were then predicted. The methodological guidance for estimating GHG emissions and removals from blue carbon ecosystems was provided by the Intergovernmental Panel on Climate Change (IPCC) 2013 Wetlands Supplement to the 2006 Guidelines for National GHG Inventories.

Emissions and removals were estimated in relation to activities carried out in blue carbon ecosystems. Three activity types from the IPCC 2013 Guidelines were included – Extraction (the ecosystem is removed and replaced with hard infrastructure), Drainage (the ecosystem is drained for alternative land use such as agriculture or is in a degraded state and only partially intact), Rewetting (the ecosystem is restored or the ecosystem area is increased). **Overall, the total historical emissions from blue carbon ecosystems was estimated as 2 282 Gg CO_2e** (gigagram CO_2 equivalent), mostly as a result of Extraction activities (2 170 Gg CO_2e). Among the ecosystem types, the largest emissions were from salt marshes (1 532.3 Gg CO_2e). The largest CO_2 removals have occurred following the expansion of mangrove ecosystems (260 Gg CO_2e).

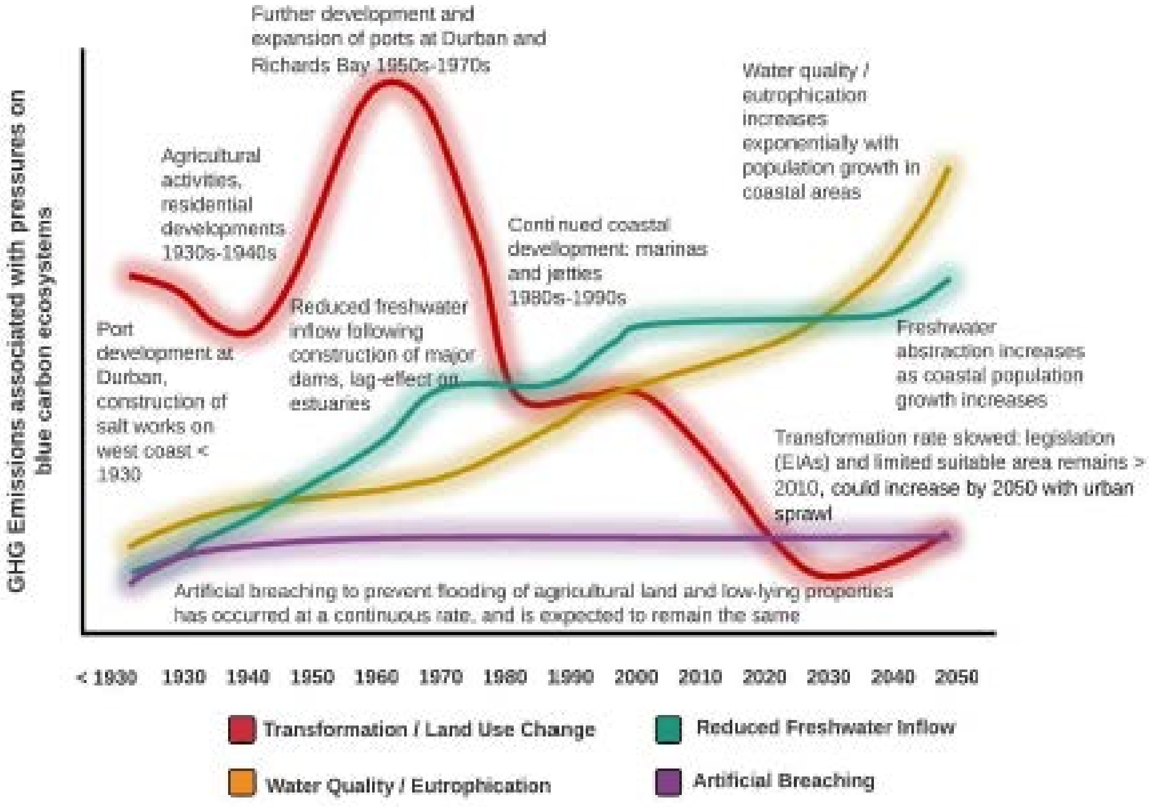


Historical trend in CO_2 emissions and removals from South African blue carbon ecosystems and the corresponding contribution of different IPCC activities to these trends. Net emissions represent the sum of all emissions and removals for a specific time period.

GHG emissions and removals were then estimated for periods from 1930 to 2020 to develop a historical baseline. Most emissions occurred prior to 1990, and particularly between 1950 and 1970. It is challenging to determine a linear trend in historical emissions, as the records for the conversion of blue carbon ecosystems are not available at regular time intervals. However, the development of policies to limit activities (such as construction of new developments) within estuarine functional zones (EFZ) means that most development activities took place before the 1990s. Additionally, specific large-scale activities that have impacted blue carbon ecosystems have been reported, so these have been captured at specific time points of change in the historical GHG emissions and removals data.

PROJECTIONS OF EMISSIONS AND REMOVALS FROM BLUE CARBON ECOSYSTEMS

Additional pressures that do not directly result in observable land cover change were also considered when developing the GHG emissions and removals baseline. Three additional abiotic pressures were considered: Reduced Freshwater Inflow/Flow Modification, Water Quality/Eutrophication, and Artificial Breaching of the estuary mouth. These pressures were highlighted as significant threats to blue carbon ecosystems, and to estuaries in general, in the 2018 National Biodiversity Assessment.



Conceptual models of the GHG emissions associated with pressures on blue carbon ecosystems in South Africa. These pressure trends were used to construct the baseline

Conceptual models of the GHG emissions associated with pressures on blue carbon ecosystems in South Africa. These pressure trends were used to construct the baseline.

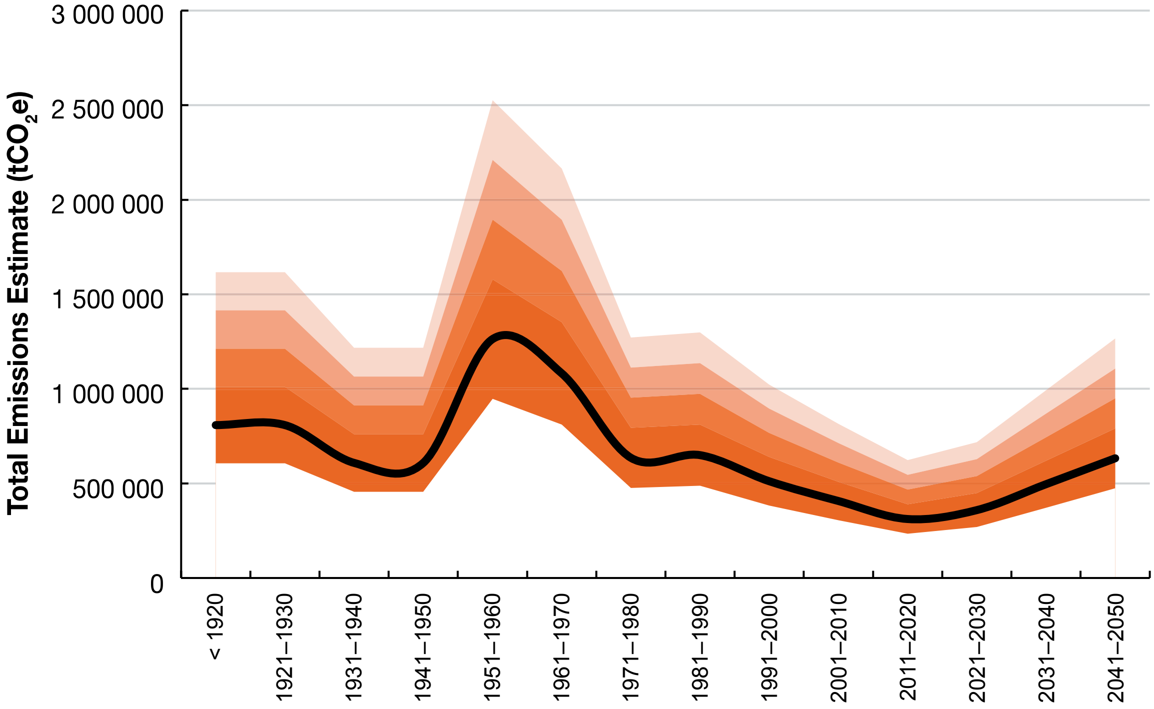
Net emissions from blue carbon ecosystems in South Africa are projected as ~359 Gg CO_2e by 2030, ~496 Gg CO_2e by 2040 and ~633 Gg CO_2e by 2050. By 2050, the largest source of emissions from blue carbon ecosystems is predicted to occur from abiotic pressures associated with Water Quality/Eutrophication (~214 Gg CO_2e).

The potential impact of climate change drivers (sea-level rise, sea storms, floods, droughts, increased CO_2, increased temperature) could have significant impacts on blue carbon ecosystems in the future. However, it was not possible to include all these drivers within the projection model due to limited data for South African estuaries.

CLIMATE CHANGE MITIGATION AND ADAPTATION OPPORTUNITIES FROM BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA

Climate-focused mitigation actions are those that will reduce climate change effects either by reducing sources of GHGs or enhancing GHG sinks. Climate-focused adaptation actions are those that will reduce the vulnerability of people and the environment to the harmful effects of climate change.

For blue carbon ecosystems, the proposed mitigation and adaptation actions are directly linked to the pressures that were identified when constructing the projected GHG emissions baseline for blue carbon ecosystems. **A total of**



GHG emissions baseline for blue carbon ecosystems based on emissions from both transformation/land-use change as well as from abiotic pressures associated with anthropogenic activities

18 actions were identified, and for each of these the recommended strategy and relevant policy/legislation are provided, as well as an overview of the current implementation or scope for the action to be carried out. Actions that can be readily carried out have been designated as 'With Existing Measures' (WEM), while those that require new policies are considered as 'With Additional Measures' (WAM).

Actions that will reduce pressure from land-use change are focused on avoiding destruction and disturbance to blue carbon ecosystems, as this leads to avoided emissions. Actions that can enhance carbon sequestration in relation to land-use change are also important, and these are represented by restoration of degraded ecosystems. This approach is aligned with the UN Decade on Ecosystem Restoration (2021–2030). Avoiding losses (including through protection) of blue carbon ecosystems and carrying out restoration are forms of climate-based mitigation as both will support GHG removals (restoration can even enhance C sequestration) and lead to a reduction in net AFOLU sector emissions. Actions that prevent clearing, disturbance and degradation of blue carbon ecosystems can largely be carried out With Existing Measures with only minor additional efforts to highlight the importance of blue carbon ecosystems within current approaches. Actions that are related to restoration will need to be carried out With Additional Measures. Legislation that can be leveraged towards these measures include the National Biodiversity Act (2004), the National

Blue carbon ecosystems face pressures from land-use change, particularly at the boundary with terrestrial ecosystems. Here residential properties occur on areas that would naturally be the salt marsh at the Knysna Estuary (Western Cape). New developments within estuarine functional zones should not be permitted to avoid emissions from removing blue carbon ecosystems (Photo: J Adams).

Reduced water quality and eutrophication in blue carbon ecosystems occurs when effluents from WWTWs, urban stormwater or agricultural runoffs flow into the estuarine environment. Artificial wetlands present a sustainable development approach to filter such inputs. Shown here is one at the Swartkops Estuary which drains runoff from the Motherwell area (Gqeberha, Eastern Cape) (Photo: J Adams).

Environmental Management Act (NEMA) Environmental Impact Assessment (EIA) Regulations (2014), and the Integrated Coastal Management Act (2008).

Actions related to pressures from reduced freshwater inflow/flow modification are focused on maintaining existing freshwater inputs to estuaries, reinstating those that are no longer received by blue carbon ecosystems, maintaining sediment transport processes, and improving riverine flow and tidal exchange. Reinstating freshwater inflow can be carried out as a restoration action to improve blue carbon ecosystem health, reverse degradation and therefore enhance C sequestration. The contribution to GHG removals through reinstating flows is highest for mangrove ecosystems. Maintaining and reinstating flows are forms of climate-based mitigation, as both will secure existing C sinks and enhance C sequestration, and thus contribute towards GHG removals. Actions that will maintain existing freshwater flows can be carried out With Existing Measures such as the freshwater flow allocations ('Reserves') and Resource Quality Objectives (RQOs) gazetted under the National Water Act (1998) by the Department of Water and Sanitation (DWS). In contrast, the reinstating of flows will need to be carried out With Additional Measures, as no monitoring or reporting structures currently exist to track progress in the implementation of environmental flow allocations, or the progress with achieving RQOs for macrophyte habitats, for example, condition and extent of salt marsh or mangrove habitats. Legislation that can be leveraged towards these measures includes the National Water Act (1998), the National Biodiversity Act (2004), the Integrated Coastal Management Act (2008), the NEMA EIA Regulations (2014) and the Mineral and Petroleum Resources Development Act (2002).

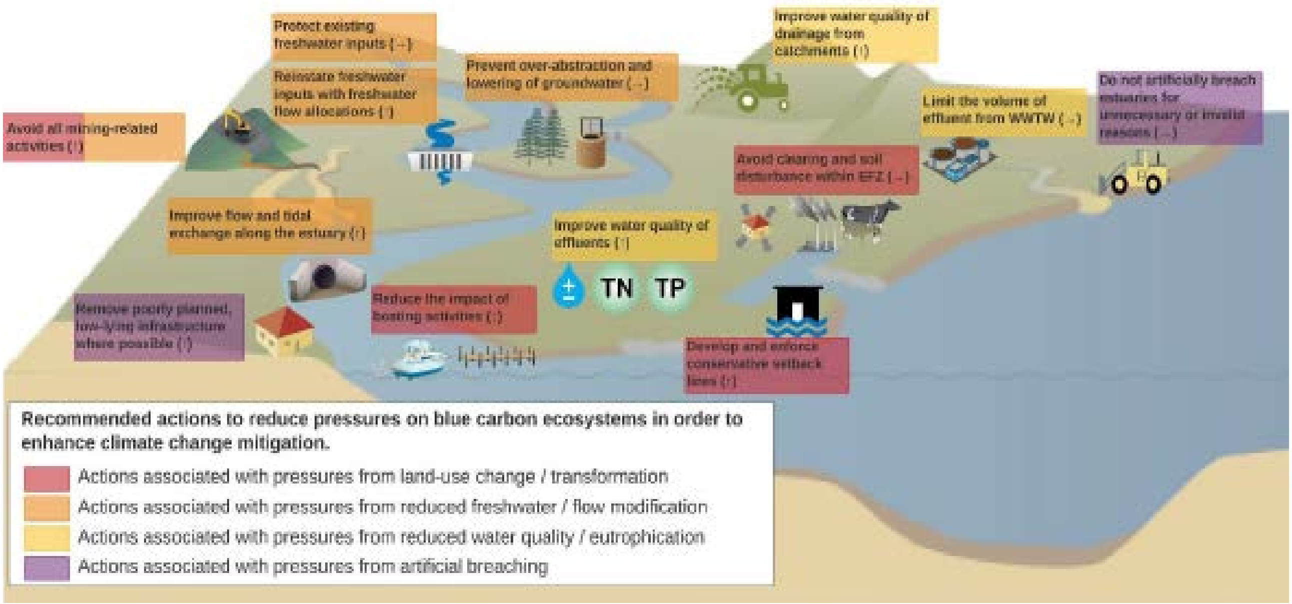
Actions related to pressure from reduced water quality and eutrophication focus on limiting and reducing the volume of wastewater treatment works (WWTW) discharges, improving the quality of return flow from agricultural land, and controlling urban stormwater runoff into estuaries. Nutrient management actions should focus on reducing loads from urban and agricultural areas in upstream catchments, and along the banks of estuaries. Because these interventions will improve estuary health it will contribute towards restoration (and enhanced C sequestration) of blue carbon ecosystems and therefore count as climate-based mitigation actions. GHG removals are estimated to be similar for mangroves and salt marshes through restoring water quality. If this pressure is alleviated, reduced shading by microalgal blooms can improve GHG removals by facilitating the growth of submerged macrophytes. A sustainable development approach can be applied to achieve this through, for example, the construction of artificial wetlands to act as filters of urban runoff. In addition, the vegetation used in the artificial wetland also has C sequestration potential and provides other ecosystem services like biodiversity maintenance. Actions to reduce and limit the volume of effluents from

Artificially breaching the mouth of an estuary is a complex process that must be carried out following a mouth-breaching protocol that has been developed for the particular estuary. Unnecessary and inappropriate breaching can have significant negative impacts on the ecological functioning, including loss of blue carbon ecosystems. Here the St Lucia Estuary (KwaZulu-Natal) is breached (Photo: C Fox).

WWTWs, as well as to improve the water quality of effluents, can be carried out With Existing Measures under the existing national policy, but there needs to be better adherence and enforcement of such legislation. Actions to improve the water quality of return flows from agricultural areas in catchments and to control urban stormwater runoff into estuaries will need to be carried out With Additional Measures. The development of a Catchment-to-Coast plan is recommended for these actions. Legislation that can be leveraged towards these measures includes the Conservation of Agricultural Resources Act (1983), the National Water Act (1998), the Integrated Coastal Management Act (2008), the Buildings Regulations and Building Standards Act (1977) and the Spatial Planning and Land Use Management Act (2013).

Actions related to pressure from artificial breaching include proper management of breaching operations to prevent unnecessary breaching, to prevent the development of new infrastructure in low-lying areas that could be subject to backflooding (and would require breaching to take place), and removal of poorly planned infrastructure in the estuarine functional zone that is repeatedly damaged by backflooding. Unnecessary breaching can cause degradation of blue carbon ecosystems, and loss of C stocks if there is erosion and scouring. Removing poorly planned, low-lying infrastructure can allow for blue carbon ecosystems to expand into these areas, therefore increasing C stocks and sequestration.

GHG removals can be obtained from salt marshes and seagrasses if these actions are carried out. Preventing unnecessary breaching and removing poorly planned low-lying infrastructure are both climate-based mitigation and transformative adaptation actions and align with actions for landward retreat. All actions for artificial breaching can be carried out With Existing Measures. Legislation that can be leveraged towards these measures includes the NEMA EIA Regulations (2014), the



Overview of actions associated with pressures (land-use change/transformation, reduced freshwater/flow modification, reduced water quality/eutrophication, and artificial breaching) on blue carbon ecosystems. Arrows indicate whether the action is predicted to increase C storage and sequestration (↑) or maintain existing C stocks (→). Image creator: J Raw.

Integrated Coastal Management Act (2008) and the Disaster Management Act (2002).

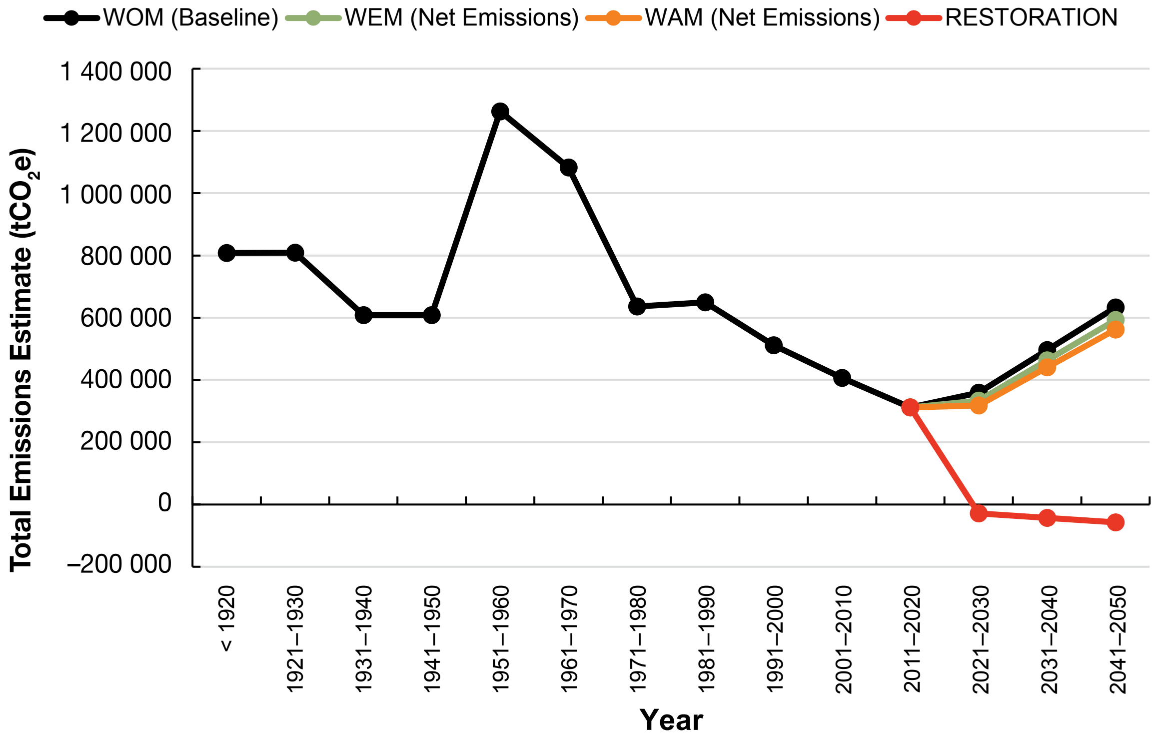
There is also scope for applying other existing tools and protocols (e.g. Natural Capital Accounting, Critical Biodiversity Mapping, and the Ecosystem Based Adaptation Strategy) to blue carbon ecosystems. The existing measures that contribute towards the protection of blue carbon ecosystems in South Africa are also outlined. As only 38.3% of blue carbon ecosystem area in South Africa is currently protected, there is significant scope for stewardship programmes to increase protection of these ecosystems. Biodiversity targets as determined by the 2018 National Biodiversity Assessment include partial protection (72 estuaries) and full protection (61 estuaries), with habitat targets ranging from 20–100% including blue carbon ecosystems.

Blue carbon ecosystems are eligible for several climate- and biodiversity-related finance mechanisms. These include convention-specific funds under 1) United Nations Framework Convention on Climate Change (UNFCCC): Reduced Emissions from Deforestation and Degradation (REDD+), Nationally Appropriate Mitigation Actions (NAMA), Clean Development Mechanism (CDM); 2) the Convention on Biological Diversity (CBD); and 3) the Ramsar Convention. Other funding opportunities such as market-based mechanisms (voluntary and regulated carbon markets, and Payments for Ecosystem Services schemes) can also be applied. Specifically, the potential for including mangroves in the national REDD+ programme that is being developed has been evaluated. In South Africa, mangroves only cover a relatively small area (~2 000 ha), but the blue carbon sink assessment can be used to inform on which mangrove estuaries are candidates for restoration projects, C stock enhancement and sustainable forest management.

REDUCING EMISSIONS AND ENHANCING REMOVALS THROUGH EXISTING AND ADDITIONAL MEASURES IN BLUE CARBON ECOSYSTEMS

The impact of the 18 identified mitigation actions on the GHG emissions and removals baseline was assessed so that projections could be made to 2050 in line with the AFOLU strategic framework. For each action it was considered whether it could be carried out With Existing Measures (WEM) or With Additional Measures (WAM). The historical effects (baseline)/Without Measures (WOM) model indicates the baseline trajectory and includes historical drivers of GHG emissions. Several actions were identified as requiring both existing and additional measures. All actions were used to inform WEM and WAM GHG emissions models that could then be compared to the WOM model.

The WEM model considered the effect of existing measures on C stocks and emissions in blue carbon ecosystems by adjusting the WOM model to reflect the expected impacts of the associated mitigation actions. Actions were grouped together in relation to the pressure which they are intended to reduce (land-use change, freshwater inflow, water quality, artificial breaching). The predicted impact on C stocks due to WEM actions was estimated per decade. Estuaries that were assigned as under high pressure have a larger potential to reduce emissions if the pressure is ameliorated or reversed by the mitigation action. The WAM model considered the effect of additional measures on C stocks and emissions in blue carbon ecosystems and shows the benefit of slowing down the rate of estuary degradation. **If all the identified existing and additional measures are implemented, GHG removals are estimated as ~70.8 Gg CO_2e by 2050.**

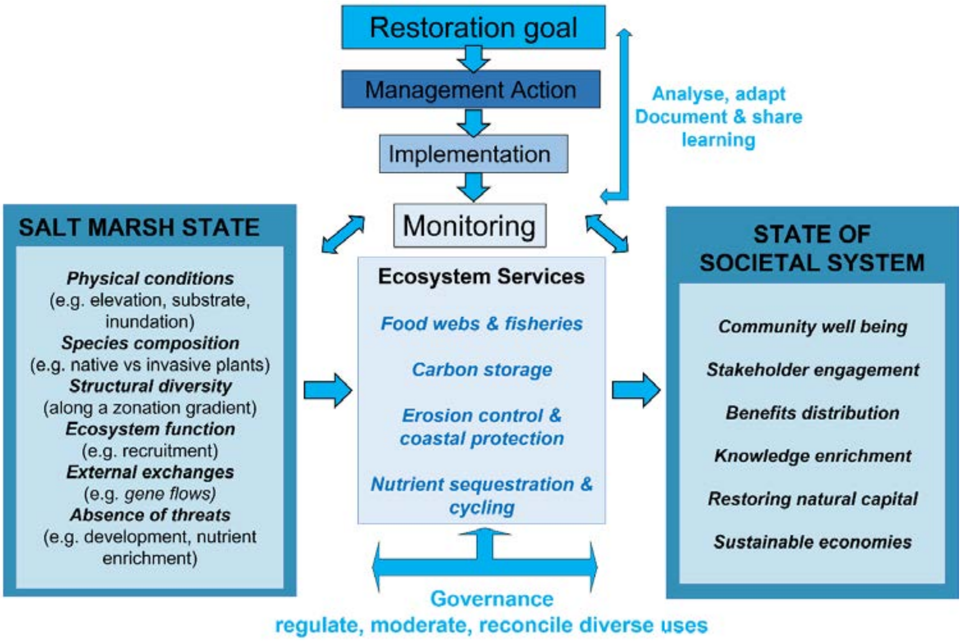


Projected GHG emissions for the Without Measures (WOM), With Existing Measures (WEM) and With Additional Measures (WAM) scenarios. Models show the net trajectory of emissions associated with all pressures. CO_2 removals associated with active restoration are also indicated.

Although all measures are predicted to contribute towards CO_2 removals, given the current level of estuary use it is acknowledged that the impacts of existing pressures cannot be completely removed. Therefore, although the WEM and WAM models show a reduction in the impacts of the pressures (e.g. ongoing flow reduction or agricultural return flow), these models also continue a trajectory of CO_2 emissions into the future. **Net emissions if all actions can be carried out with existing and additional measures are estimated as ~562 Gg CO_2e by 2050, compared to ~633 Gg CO_2e by 2050 if no actions are taken.**

Besides reducing anthropogenic pressures on blue carbon ecosystems through existing and additional measures, **there is also the need to carry out active restoration in degraded areas and this will contribute directly to CO_2 removals**. Up to 1 160 ha of blue carbon ecosystems can be restored by 2050 (100 ha of mangroves, 1 000 ha of salt marsh and 60 ha of submerged macrophytes). **By 2050, CO_2 removals associated with active restoration are estimated conservatively at ~57.2 Gg CO_2e.** Active restoration has the potential to reverse the CO_2 emissions trajectory. Actions carried out under both WEM and WAM will contribute towards restoration of these areas.

Ecological restoration has become increasingly relevant across the world's ecosystems, with this decade (2021-2030) being declared the 'UN Decade on Ecosystem Restoration' by the United Nations



Socio-ecological systems framework for blue carbon restoration (adapted from Adams et al. 2020).

General Assembly. Restoration is the process of assisting the recovery of damaged, degraded or destroyed systems. Ten guiding principles have been defined for the UN Decade on Ecosystem Restoration. All of these are applicable to blue carbon ecosystems; for example, Principle 3 refers to the continuum of restorative activities which includes reducing impacts, remediation and rehabilitation moving towards ecological restoration.

KEY RECOMMENDATIONS AND WAY FORWARD

This scoping study for a blue carbon sink assessment has served as a critical step towards ensuring blue carbon ecosystems in South Africa are secured for the critical ecosystem services that they provide, as well as for their potential to be incorporated into climate change mitigation and adaptation strategies.

Blue carbon ecosystems are recognised for their climate mitigation value by the IPCC, as these ecosystems meet the criteria as actionable for climate mitigation policy and can therefore be integrated into global climate action strategies. Some countries have already included these ecosystems within their Nationally Determined Contributions (NDCs), national GHG inventories and other climate mitigation mechanisms.

Recommendations Towards Protecting Blue Carbon Ecosystems

Conservation and restoration of blue carbon ecosystems offers an efficient pathway to avoid GHG emissions. These ecosystems also contribute towards climate adaptation and resilience by providing other ecosystem services such as coastal protection from sea-level rise and the erosion or flooding impacts associated with extreme events such as storm surges. There is therefore scope to include blue carbon ecosystems in National Adaptation Plans.

> *The establishment of more formally protected areas is a critical response to protecting blue carbon ecosystems from human activities. Stewardship also presents an important opportunity to conserve salt marsh, as supratidal areas can be located within private land.*

> *There is an urgency to better define land ownership within the national estuarine functional zone areas so that state-owned land can be proclaimed as protected, or to identify areas suitable for stewardship.*

Interventions in blue carbon ecosystems have the potential to contribute to climate mitigation, adaptation and biodiversity goals to generate a wide array of objectives for the Sustainable Development Goals, the Convention on Biological Diversity and other global targets.

Recommendations to Reduce Pressures on Blue Carbon Ecosystems

The drivers of blue carbon ecosystem loss need to be addressed so that these ecosystems can be included within climate change mitigation and adaptation actions.

> *An Integrated Estuarine Restoration Strategy/Policy needs to be developed to coordinate and direct blue carbon restoration at national, provincial or even municipal levels.*

> *Policies that support land-use planning practices for blue carbon ecosystems need to be developed. These should focus on allowing for upslope landward migration to avoid 'coastal squeeze' with sea-level rise; developing strict protocols for the setting of estuary flood/setback/management lines for inclusion in municipal Integrated Development*

Plans and Spatial Development Plans; avoiding processes that result in clearing, infilling or disturbance of estuarine habitat.

Key strategies required to reduce the impact of reduced freshwater flow modification include: reinstating freshwater inputs and flows, preventing over-abstraction and lowering of the groundwater table, and developing regional-scale sediment management plans.

Key strategies required to reduce the impact of pollution and poor water quality include: limiting the volume of effluent from existing wastewater treatment works, developing agriculture best practice guidelines, and developing strategies to encourage adaptive urban stormwater management.

Key strategies required to reduce the impact of artificial breaching include: prohibiting unnecessary breaching, prohibiting new developments in zones that are prone to flooding, and removing poorly planned low-lying infrastructure where possible.

Recommendations for Financing Blue Carbon Ecosystem Projects

Several innovative financing models have been developed for blue carbon ecosystems, and these are essential for scaling mitigation actions through the management of these ecosystems.

Market-based approaches are under development, while carbon credits for mangrove projects have been piloted in other regions and are available through the voluntary carbon market. Alternative and innovative financing approaches are needed to provide long-term, sustainable resources for the conservation of blue carbon ecosystems under different ecological, social and political conditions. For example, the Blue Carbon Accelerator Fund to support blue carbon entrepreneurs and leverage private sector finance was launched at COP26 by the International Partnership for Blue Carbon. This fund will provide readiness support for project developers, as well as implementation support for on-the-ground blue carbon ecosystem restoration.

Blue carbon ecosystems can be used to generate carbon credits, and under South Africa's Carbon Tax Act, these can be purchased by entities to meet 5–10% of their taxed liability.

Blue carbon ecosystems can be used to generate carbon credits through the Verified Carbon Standard (VCS) Methodology for Tidal Wetland and Seagrass Restoration. The VCS Program is an accredited standard under the South African tax regulation, allowing entities with tax obligations to use Verified Carbon Units to cover tax liabilities.

The national demand for offsets has been estimated as 10 Mt $CO_2e.yr^{-1}$, but it is expected that the Carbon Tax could drive investments into GHG removal activities. Blue carbon ecosystems therefore represent an important opportunity to generate carbon credits in South Africa.

Recommendations for Future Research and Monitoring

Further scientific research and capacity building is needed to expand the application of blue carbon ecosystems for climate mitigation, adaptation and resilience commitments that have been made. Globally, there is a need to expand on the capacity of policy makers and governments to assess, monitor and account for the climate mitigation and adaptation value of these ecosystems.

In South Africa, more baseline data is needed to improve and refine the estimates of carbon storage and sequestration potential of blue carbon ecosystems. The potential impacts of climate change on blue carbon ecosystems also need to be incorporated into the projected emissions and removals models.

Local communities are also essential for the effective and successful conservation and restoration of blue carbon ecosystems. Policies and actions must be inclusive and equitable.

Additional detailed studies to quantify carbon storage in South African blue carbon ecosystems are needed, with particular focus on collecting data across all four biogeographic regions.

Climate change impacts on blue carbon ecosystems need to be directly quantified. Sea-level rise will influence the distribution of blue carbon ecosystems and in some cases could allow expansion and enhancing of carbon sinks, or may put low-lying developments at risk. High-resolution digital elevation models are needed to carry out these assessments at the national scale.

A standardised approach to assess the ecological condition/degradation state of blue carbon ecosystems is needed. This information can be included in the national degradation map and should be linked to carbon sequestration potential.

The spatial data and associated data on pressures for blue carbon ecosystems should be updated every five years to reflect changes in ecosystem extent in response to any mitigation measures that are carried out as part of management practices.

Teal carbon freshwater ecosystems that are associated with estuaries – swamp forests, reeds and sedges – represent over 17 000 ha that contribute to carbon storage. However, little is known about their carbon sequestration potential and their past and present spatial extent. It is recommended that, like the blue carbon assessment, research should also be conducted on teal carbon habitats in estuaries.

Introduction and Project Objectives

One of the most valued ecological roles of vegetated coastal habitats (mangroves, salt marshes and seagrasses) is carbon (C) storage and sequestration. Although these ecosystems cover less than 2% of the area of the global ocean, they are critical carbon sinks (McLeod et al. 2011, Duarte 2017). Carbon sequestered by these ecosystems is termed 'blue carbon' (Nellemann et al. 2009) and includes C stored in the sediments, C stored in the living biomass both aboveground (leaves, stems, branches) and belowground (roots), as well as C stored in non-living biomass (leaf litter and dead wood) (McLeod et al. 2011, Howard et al. 2014). **Coastal habitats are efficient C sinks, with 50% of the total C sequestered by ocean sediments being captured by these ecosystems.** Blue carbon ecosystems are therefore one of the key components of the global C cycle (Lovelock & Duarte 2019, Spivak et al. 2019). Enhancing C storage and sequestration contributes directly towards climate change mitigation and allows these ecosystems to be incorporated into new and existing policy and market initiatives (Sutton-Grier & Moore 2016, Crooks et al. 2018b, Villa & Bernal 2018). Baselines of C stocks and sequestration rates must therefore be determined.

The South African coastline has high wave energy, and this restricts blue carbon ecosystems to occurring in sheltered estuaries (Cooper 2001, Raw et al. 2019a). **The distribution of blue carbon ecosystems follows the coastal biogeographic regions**, with mangroves along the tropical and subtropical east coast, and salt marshes occurring more extensively in estuaries along the southern warm-temperate coast as well as the cool-temperate west coast. Seagrasses and submerged macrophytes occur in larger estuaries that maintain a permanent connection to the marine environment (Adams 2016, Adams et al. 2016b, Adams 2020, Adams & Rajkaran 2021).

South Africa has an opportunity to implement targeted climate change policies for marine and coastal ecosystems. This scoping study for a national blue carbon sink assessment has been carried out to identify the principal climate change mitigation opportunities and the potential for C sequestration in these ecosystems. **Existing policies and strategies that can be leveraged towards the 2050 goal of C neutrality for South Africa are considered within this project as outlined in the Low-Emission Development Strategy** (SA-LEDS 2020). Existing commitments, including the Nationally Determined Contributions (NDCs) required by the Paris Agreement, need to be contextualised in line with the AFOLU sectoral ambitions. This assessment will be comparable and consistent to what has already been carried out for C stocks in terrestrial ecosystems by the Department of Forestry, Fisheries and the Environment (DFFE) as part of the policy directives of the Agriculture, Forestry and Other Land Use (AFOLU) sector. **The blue carbon sink spatial assessment has been built from the national integrated**

coast map which was developed as part of the 2018 National Biodiversity Assessment (NBA) (Sink et al. 2019).

This project has carried out a scoping assessment to determine the potential for coastal blue carbon ecosystems to serve as climate change mitigation opportunities in the AFOLU sector. The project objectives were:

1. To review the literature of existing best practices from other countries (developed and developing) for estimating climate change mitigation opportunities from blue carbon ecosystems and of lessons learned;
2. To map the existing distribution of blue carbon ecosystems in South Africa, and to create an associated blue carbon dataset on their C storage, sequestration and sink potential;
3. To create a GHG emissions and removals baseline for blue carbon ecosystems in South Africa;
4. To identify additional opportunities to reduce GHG emissions from sources and enhance C sinks as principal climate change mitigation actions;
5. To predict the potential effects and impacts of undertaking mitigation actions until the year 2050 to align with the AFOLU strategic framework and other long-term planning processes, including the SA-LEDS.

The research and contextualisation of each of these objectives are presented as the following sections of this report:

1. Project Context and Overview of the Literature
2. Compiling a Blue Carbon Sinks Database for South Africa
3. Developing and Modelling a GHG Emissions and Removals Baseline
4. Identification of Principal Climate Change Mitigation and Adaptation Actions
5. Mitigation Potential Analysis.

The conclusions and recommendations on measures and systems required to track blue carbon ecosystems, in addition to projects and programmes that can be scaled up to reduce GHG emissions and enhance removals from these ecosystems, are discussed.

1. Project Context and Overview of the Literature

'Blue carbon' ecosystems – mangroves, salt marshes and seagrasses (Nellemann et al. 2009), as the term suggests, contribute towards the role of the oceans within the global carbon (C) cycle. As in other vegetated ecosystems, atmospheric carbon dioxide (CO_2) is taken up during photosynthesis, and **organic C is stored within different C pools – in the soils/sediments**, in the living biomass of the plants both **aboveground (leaves, stems and branches)** and **belowground (roots)**, as well as in **non-living biomass (leaf litter and dead wood)** (McLeod et al. 2011, Howard et al. 2014). These ecosystems serve as long-term natural C sinks that will retain sequestered C in the soils for up to thousands of years (McLeod et al. 2011, Lovelock & Duarte 2019).

BOX 1: Definition of Blue Carbon Ecosystems

The term 'blue carbon' was coined in 2009 by a UNEP Rapid Response Assessment with the aim 'to highlight the critical role of the oceans and ocean ecosystems in maintaining our climate and in assisting policy makers to mainstream an oceans agenda into national and international climate change initiatives' (Nelleman et al. 2009).

This report drew attention to the **degradation of marine and coastal ecosystems** and emphasised the need for strategic restoration towards enhancing climate change mitigation, as well as other associated ecosystem services. The original description of blue carbon incorporated the organic matter captured by marine organisms, and how management of marine ecosystems could reduce GHG emissions.

It has since been established that only **mangroves, tidal marshes and seagrasses** in particular are defined as 'blue carbon ecosystems' because of their large carbon stocks, the potential for long-term carbon storage, their role in GHG emissions management, and ability to be included in other supportive adaptation policies (Mcleod et al. 2011, Lovelock & Duarte 2019).

Other marine ecosystems do not meet these key criteria for inclusion within the blue carbon framework either because there are gaps in scientific understanding of carbon stocks and fluxes, or there is limited potential for applying existing management and accounting processes for assessing carbon sequestration (Lovelock & Duarte 2019).

Ecosystems where blue carbon stocks and sequestration rates are being investigated towards their inclusion as 'blue carbon ecosystems' include: habitats of calcifying organisms (coral reefs, oyster reefs), pelagic ecosystems that include mobile organisms and phytoplankton, tidally influenced freshwater habitats, sabkhas or high intertidal salt flats, kelp and other seaweed beds (Lovelock & Duarte 2019).

Blue carbon ecosystems present an opportunity to contribute towards climate change mitigation and adaptation strategies because of their efficiency to sequester atmospheric CO_2 and the long-term storage of organic C. IPCC global projections indicate that C sequestration must be incorporated into mitigation pathways that aim to limit warming to 1.5°C above pre-industrial levels while accommodating for sustainable development (Rogelj et al. 2018). The conservation and protection of blue carbon ecosystems is therefore an easily achievable and natural solution to reduce GHG emissions (Duarte et al. 2013). However, losses of these ecosystems (either by degradation, or complete removal and conversion) in turn represent not only a loss of the natural C sink capacity, but also a contribution towards GHG emissions (Pendleton et al. 2012, Siikamäki et al. 2012). Emissions released through ecosystem conversion are recognised by the IPCC as significant sources of GHGs, with the losses of blue carbon ecosystems contributing up to **1.02 billion metric tonnes of CO_2 annually** (Pendleton et al. 2012). A global effort to quantify C stocks and sequestration rates has therefore become established, with the aim to understand the role that blue carbon ecosystems can play simultaneously in **carbon markets and conservation initiatives** (https://www.thebluecarboninitiative.org/). Specifically, there has been an increased scientific and political interest to investigate the potential of **blue carbon emissions offsets** (Macreadie et al. 2019). Many nations have already included blue carbon strategies within their initiatives to address climate change impacts (Martin et al. 2016).

South Africa is globally recognised for its marine biodiversity which provides numerous benefits to the economy as well as to society and human well-being. This includes South Africa's blue carbon ecosystems which occur in **estuaries and consist of 2 087 ha of mangroves, 14 713 ha of salt marsh and 3 040 ha of seagrass** (Van Niekerk et al. 2019b). Currently, South Africa has not yet developed explicit blue carbon strategies that could contribute towards mitigating climate change. There is an opportunity to do this, as the nation has set a goal of C neutrality by 2050 as outlined in the **Low-Emission Development Strategy 2050** (SA-LEDS 2020). Blue carbon sinks can be considered as an asset that could generate monetary benefits (through carbon offset markets), as well as additional benefits to the developing blue economy (fisheries and coastal tourism) (Steven et al. 2019). The feasibility of blue carbon offsets depends on many factors, some of which are economic, while others are related to biophysical constraints and drivers of C stocks and sequestration rates. These factors are also inextricably linked. Additionally, political consideration is also necessary, as the effectiveness of a blue carbon offset strategy depends on the **development and implementation of policies that will govern the activities**.

This literature review provides an overview and discussion of the methodologies and practices used for blue carbon sink assessments and the principal climate mitigation opportunities. This information was synthesised so that such an assessment could be carried out for South African blue carbon ecosystems as part of this project.

1.1 DRIVERS OF CARBON LOSS AND GAINS IN COASTAL ECOSYSTEMS

As in all vegetated ecosystems, the plants in blue carbon ecosystems take up CO_2 from the atmosphere and store it in the form of organic C (C_{org}) in two main pools that are either aboveground or belowground:

- **Aboveground C (AGC) Pool** – includes standing living biomass (leaves, stems, branches, tree trunks), standing dead biomass (deadwood trunks and branches), leaf litter biomass on the soil surface, and epiphytes that may colonise the surface of all of these components.

- **Belowground C (BGC) Pool** – includes the living belowground biomass (roots and rhizomes), dead belowground biomass, and the organic soil C.

Blue carbon sequestered in living plant biomass is retained for relatively short time scales (years to decades) – which is similar to terrestrial ecosystems (Howard et al. 2014). However, blue carbon sequestered in the soil C pool is much more extensive and is retained for much longer periods (centuries to millennia) in comparison to terrestrial ecosystems (McLeod et al. 2011). This is a result of efficient trapping of suspended mineral and organic matter delivered to the environment during tidal inundation. This increases the potential accumulation of soil C over and above what is stored in the aboveground standing biomass. Additionally, unlike in terrestrial ecosystems, soils in blue carbon ecosystems do not become saturated with C, because the process of vertical accretion drives the buildup of sediment over time while the ecosystem remains in good functional health (McKee et al. 2007, McLeod et al. 2011). The soil C pool therefore contains the largest proportion of the total ecosystem C stocks of blue carbon ecosystems – typically around 90% (Donato et al. 2011, Simpson et al. 2017). This makes the soil C pool of primary interest for blue carbon initiatives (Sutton-Grier & Moore 2016), but it is also the source of substantial GHG emissions if the ecosystem is degraded, destroyed or converted for other land uses (Macreadie et al. 2013, Lovelock et al. 2017a).

Although all blue carbon ecosystems occur in coastal environments, they are globally distributed and therefore consist of a wide range of plant species occurring in different water depths and tidal settings. The C stocks of blue carbon ecosystems are influenced by many factors that operate and interact across different temporal periods

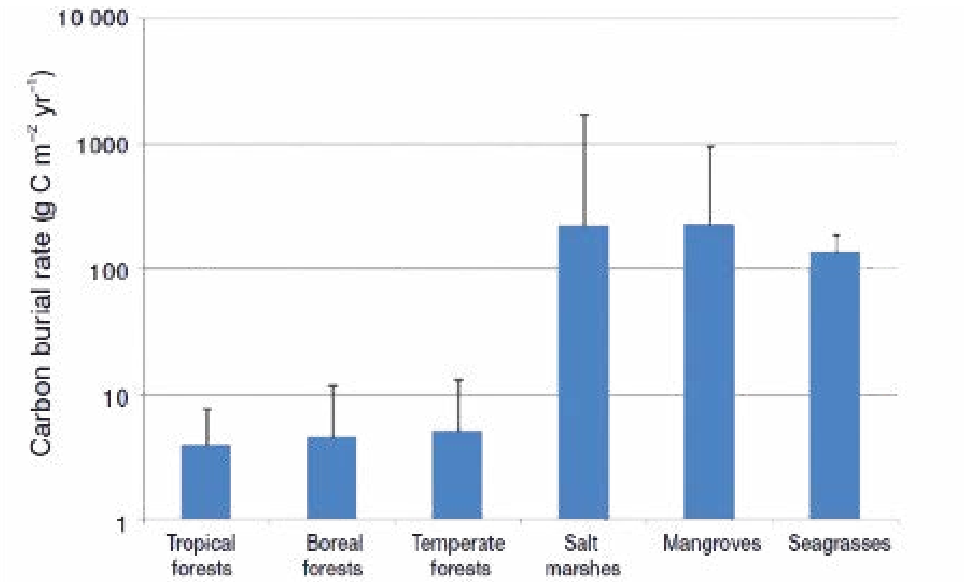


FIGURE 1.1: COMPARISON OF MEAN LONG-TERM RATES OF C SEQUESTRATION (g C m^{-2}yr^{-1}) IN SOILS OF TERRESTRIAL AND BLUE CARBON ECOSYSTEMS. ERROR BARS SHOW MAXIMUM RATES OF ACCUMULATION. SOURCED FROM MCLEOD ET AL. (2011).

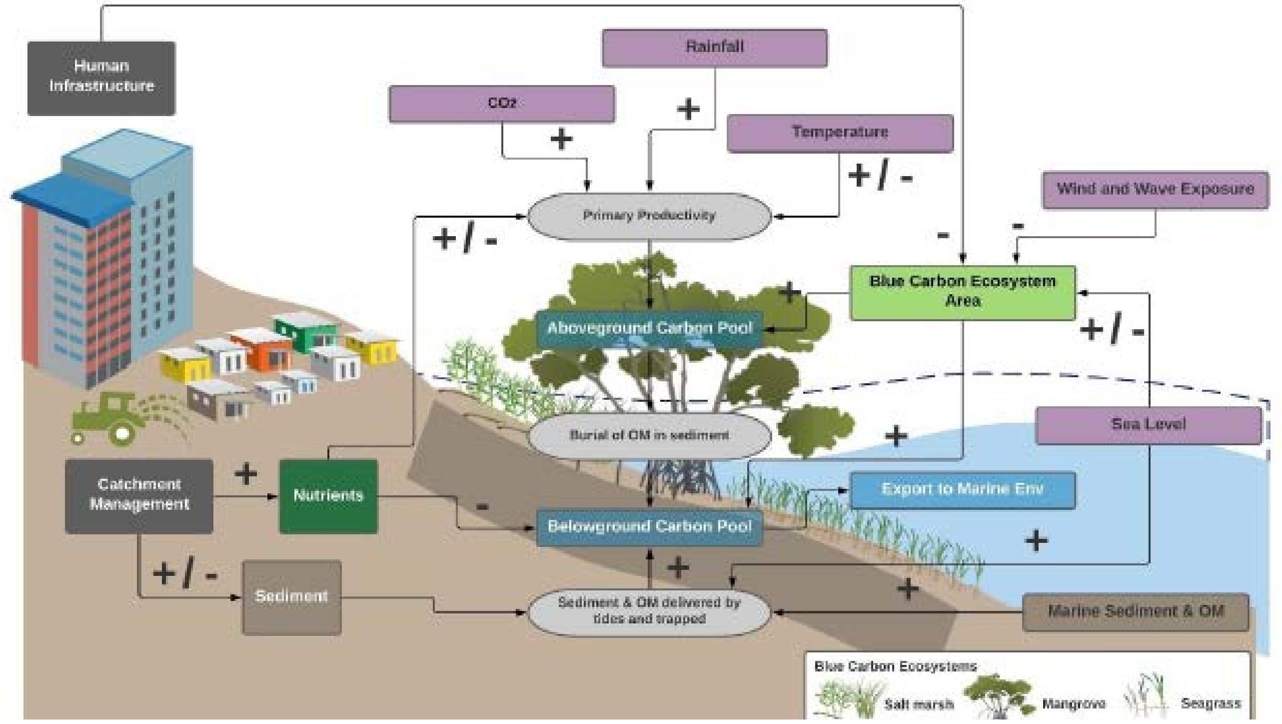


FIGURE 1.2: INTERACTING FACTORS THAT INFLUENCE C STOCKS IN BLUE CARBON ECOSYSTEMS. BLUE CARBON STOCKS (BLUE) ARE INFLUENCED BY PRIMARY PRODUCTION OF ORGANIC C, BURIAL AND EXPORT. CLIMATE CHANGE FACTORS (PURPLE) THEN INTERACT WITH THESE PROCESSES. ANTHROPOGENIC DRIVERS (GREY) ADD FURTHER IMPACTS TO BLUE CARBON ECOSYSTEMS. IMAGE ADAPTED FROM LOVELOCK & REEF (2020).

and spatial extents (Figure 1.2). The occurrence of blue carbon ecosystems in coastal environments also makes them vulnerable to anthropogenic impacts which have had a significant impact on C stocks around the world.

1.1.1 Drivers of Carbon Stocks at Global Scales

Globally, among the three blue carbon ecosystems, the largest C stocks are found within **mangrove forests** (Donato et al. 2011, Duarte 2017). The global distribution of mangroves extends from **tropical to subtropical zones**, with range limits occurring at **warm-temperate** latitudes associated with a 20°C winter isotherm for sea-surface temperature (Tomlinson 1999, Giri et al. 2011, Hamilton & Casey 2016). The most expansive mangrove forests occur in tropical zones where the climate is persistently warm, wet and humid, and there is a sufficient input of freshwater (Duke et al. 1998). Latitudinal rainfall and temperature patterns therefore directly affect mangrove distribution, growth and productivity at the global scale (Bouillon et al. 2008, Morrisey et al. 2010, Twilley et al. 2017). **Mangroves occurring in regions with higher temperatures, tidal range and riverine inputs (freshwater and nutrients) are more productive** than those occurring under harsher conditions (low temperatures, droughts, hypersalinity) (Twilley et al. 1986, Schaeffer-Novelli et al. 1990).

In mangrove forests, **net ecosystem productivity (NEP) includes primary production of the trees, seedlings and**

periphyton, and their losses due to respiration in the ecosystem (Clough 1992). However, as the respiratory losses of other components are difficult to quantify, gross primary production (GPP) and net primary productivity (NPP) are generally calculated specifically for the trees (Clough 1992, Poungparn & Komiyama 2013). Estimates of NPP can be obtained by summing net biomass accumulation in the form of wood and leaf production (aboveground) and root production (belowground) and subtracting losses of dry matter (leaf litter, flowers, propagules, branches, dead wood) from this value (Clough 1992, Komiyama et al. 2008, Ribeiro et al. 2019). **Mangrove ecosystems have been shown to produce more organic C than what is lost due to ecosystem respiration** (Twilley et al. 2017) and are therefore important for C burial and C export to the marine environment. **Global mangrove primary productivity has been estimated at ~218 ± 72 Tg C yr^{-1}.** The net ecosystem carbon budget (NECB) is a standardised approach that has been developed to account for carbon gains and losses at the ecosystem scale (Taillardat et al. 2020). Data from 63 mangrove projects (mainly in South-East Asia and the eastern USA) were used to calculate a NECB of –235 gC m^{-2} yr^{-1} for this ecosystem type, indicating an accumulation of carbon. Additionally, this study showed that **intact functional mangrove ecosystems do not have a net warming effect**. Increased growth and litterfall has been correlated with higher rainfall and thus C sequestration because of the link between mangrove productivity and both biomass and soil C stocks (Feher et al. 2017, Osland et al. 2018, Simard et al. 2019). Large productive mangrove forests in tropical zones therefore have large C sequestration and storage potential.

The global distribution of salt marshes and seagrasses is more extensive than mangroves because the plant species that form these habitats have a wider ecological tolerance range and therefore occur at higher latitudes as well as within equatorial zones (Figure 1.3).

Tropical seagrasses have been reported as significant C sinks in the Western Indian Ocean, Gulf of Mexico, Indonesia

FIGURE 1.3: GLOBAL DISTRIBUTION OF BLUE CARBON ECOSYSTEMS AS REPORTED BY THE IUCN BLUE CARBON INITIATIVE (HTTPS://WWW.THEBLUECARBONINITIATIVE.ORG/).

and Australia (Thorhaug et al. 2017, Gullström et al. 2018, Ralph et al. 2018, Wahyudi et al. 2020). In comparison, **salt marshes and seagrasses occurring in temperate latitudes have lower C storage and sequestration potential** (Mueller et al. 2019, Prentice et al. 2020).

Global variability in C storage among blue carbon ecosystems can also be explained in relation to sea-level trends that have occurred over the past ~4 000 years. Coastlines that have experienced rapid relative sea-level rise (RSLR) during the late Holocene support blue carbon ecosystems with between 1.7 to 3.7 times more soil C than those that have experienced stability in sea level over the same period (Rogers et al. 2019a). This pattern has emerged as a complex interaction between factors that drive responses of blue carbon ecosystems to sea-level rise at regional and local scales (Lovelock et al. 2015, Woodroffe et al. 2016) – see section below, 'Coastal Climate Change Impacts on Carbon Stocks and Fluxes', for details.

1.1.2 Drivers of Carbon Stocks at Regional Scales

Regional variability in blue carbon ecosystem C stocks is related to primary productivity trends that are linked to biogeographic climate gradients as well as coastal geomorphology. These trends are most notable at the latitudinal range limits for blue carbon ecosystems. In the northern hemisphere, the latitudinal range limits for mangroves are largely controlled by winter temperature minima, as the tree species are not frost-tolerant (Osland et al. 2017b, Cavanaugh et al. 2018). In contrast, **southern hemisphere range limits for mangroves are controlled by coastal geomorphology and hydrology** (Semeniuk 1983, Schaeffer-Novelli et al. 1990, Stevens et al. 2006, Raw et al. 2019a). These **range limits are transitional zones where blue carbon ecosystems shift from mangroves to salt marshes**. Regional studies across West Africa (Kauffman & Bhomia 2017), the southern United States (Simpson et al. 2017, Feagin et al. 2020) and the east coast of Australia (Rogers et al. 2019b) show that C storage and sequestration potential changes with a shift from mangroves to salt marsh. **Primary productivity of mangroves at range limits is reduced**, as these areas are not as climatically suitable in comparison to the warmer and wetter equatorial regions. Mangroves that occur at range limits are often much smaller and shrub-like (Morrisey et al. 2010), and this has implications for their C storage and sequestration potential. Most notably, at arid mangrove range limits (east-central Africa, west-central Africa, the Middle East, western Australia, western North America, western Gulf of Mexico and western South America), the potential for C storage and sequestration is lower for both mangroves and salt marshes (Schile et al. 2017, Ochoa-Gómez et al. 2019, Adame et al. 2020).

The effect of coastal geomorphology on blue carbon ecosystem C stocks is related to the wide variety of coastal landforms in which mangroves and salt marshes can occur. As these two blue carbon ecosystems are intertidal, they are found in coastal environmental settings that can be very diverse in terms of sedimentary processes, tidal regimes and wave action (Dalrymple et al. 1992, Woodroffe 1992, Cooper 2001). Different environmental settings are also associated with variability in nutrient loads and limitations and organic matter decomposition, which directly influence both aboveground carbon (AGC) and belowground carbon (BGC) pools (Twilley et al. 2018). **Higher soil C stocks have been estimated for mangrove ecosystems on carbonate coastal platforms** in comparison to those in terrigenous settings, such as deltas, estuaries and lagoons (Rovai et al. 2018, Twilley et al. 2018). The **geomorphic context is also an important driver of C stocks in salt marshes** as there is variability with depth which depends on the age of the marsh platform and the processes that influence sediment deposition (van

Ardenne et al. 2018). **Soil C stocks in fluvial and mid-estuary marshes have been reported as significantly higher** in comparison to those in marine deltas and this trend was linked to sediment grain size (Gorham et al. 2020). Large sediment grain size typically indicates high river sediment transport rates, and therefore a fast rate of deposition. However, this can lead to unstable sediment, and thus a low rate of sequestration in surface layers in these environments.

1.1.3 Drivers of Carbon Stocks at Ecosystem Scales

At ecosystem scales, **C stocks of blue carbon ecosystems are influenced by characteristics of the vegetation, hydrodynamics, sedimentary processes and the availability of allochthonous organic material**. In mangroves, the age and size structure of the forest is related to C stocks. Older forests have been recorded to have larger C stocks on account of their greater aboveground biomass and the longer time periods over which the C stocks have been able to accumulate (Kathiresan et al. 2013, Chen et al. 2018, Sahu & Kathiresan 2019). **Vegetation structure is also an important driver of C stocks in blue carbon ecosystems.** Mangrove forests with taller trees have larger total C stocks in comparison to shrub-like mangroves (Owers et al. 2016). This is because the former has larger standing biomass and deeper rooting zones, which both contribute towards accumulation in the soil C pool. In salt marshes, those consisting of taller plants (such as rushes) at higher density have larger C stocks than those with more herbaceous species (Owers et al. 2018). Similarly, C stocks in seagrasses are variable depending on the plant species that make up the habitat (Lavery et al. 2013, Sanders et al. 2019).

Hydrodynamics and sedimentary processes have a significant control on C stocks of blue carbon ecosystems, but these processes also interact with the structural characteristics of the plant species. Mangroves and salt marshes can only become established in intertidal zones that have relatively low gradients and low wave energy as these conditions promote sediment deposition (Boyd et al. 1992, Dalrymple et al. 1992) and suitable physiological conditions for the plant species (Krauss et al. 2008, Boyd et al. 2017). The area available within an intertidal zone for mangroves and salt marshes is therefore defined as 'accommodation space' where sediment deposition occurs between the surface sediment height and the upper tidal limit (Rogers et al. 2013b, Woodroffe et al. 2016). **Large, relatively flat deltas and floodplain areas therefore support larger areas of mangroves and salt marshes with greater C storage and sequestration potential.**

Tidal and fluvial hydrodynamics can influence accommodation space by causing erosion or deposition of sediment (FitzGerald 1996, Adame et al. 2010). **The accumulation of sediment in all blue carbon ecosystems is critical for maintaining and building soil C stocks** (Lovelock et al. 2014), and this gradual accretion of sediments forms the response of blue carbon ecosystems to sea-level rise (Lovelock et al. 2015, Cahoon et al. 2019). **Sediment accumulation can be facilitated by the structure of the vegetation** – such as the height and density of salt marsh and seagrass shoots and stems or mangrove pneumatophores. The plant structures can act to slow water movement to promote sedimentation, or otherwise act directly as sediment traps, thus facilitating the accretion of soil C stocks (Temmerman et al. 2005, Mudd et al. 2010).

Besides the deposition of sediment, tidal and fluvial hydrodynamics also control the deposition of allochthonous organic material. Although this organic material has originated from outside the blue carbon ecosystem, if it is deposited here, it will still contribute towards the soil C stocks. **As blue carbon ecosystems naturally occur at the interface between the marine and terrestrial realms, allochthonous material from either of these sources can be present** (Bouillon et al. 2003). Current estimates need further refinement (and research) as the **present estimates may include both sources, and this can complicate the estimation of C stocks that can be used towards offsetting for a particular site** (Saintilan et al. 2013). In some seagrass ecosystems it has been shown that soil C stocks can be comprised of ~70–90% allochthonous organic C (Ricart et al. 2020). Addressing these scientific gaps is at the forefront of global blue carbon research as the field has only developed over the past 10 years (Macreadie et al. 2019). As new information becomes available, so the recommendations for calculating C stocks will be updated, but at present **the guidelines provided by the UNFCCC and the IPCC allow coastal wetlands to be included in GHG mitigation and adaptation activities**.

1.1.4 Drivers of C Stocks at Site-Specific Scales

At the scale of specific sites within a blue carbon ecosystem, soil C stocks are influenced most significantly by the characteristics of the soil. The retention of such large quantities of organic C within the soil C pool is dependent on conditions within the soil profile remaining anoxic. Tidal inundation keeps the soils moist, and this allows the formation of a negative oxidation-reduction potential, which in turn reduces soil respiration, organic matter decomposition, and thus prevents C mineralisation – which is the conversion of organic C back to CO_2 (Alongi et al. 2001, Sasaki et al. 2009, Lewis et al. 2014). **Erosion of blue carbon habitats can therefore drive losses of C stocks, as exposure to aerobic conditions results in the C mineralisation process.**

Additional soil characteristics that can influence soil C stocks are **particle size and bulk density**. Sandy soils with larger particle size (62 μm–2 mm) do not promote organic matter retention, in contrast to silt (3.9–62 μm) and clay (0.98–3.9 μm) which allow for aggregation, resulting in a strong relationship between soil C and grain size (Kelleway et al. 2016a). **Fine particles are associated with depositional areas allowing for setting and greater sequestration, in comparison to areas that are exposed to higher flows and wave energy** (where coarser sediments are found). Fine particles also provide greater surface area for adherence. Bulk density also needs to be accounted for when measuring soil C, as it is an indicator of soil compaction.

1.1.5 Anthropogenic Drivers of Carbon Stocks

Blue carbon ecosystems are vulnerable to anthropogenic impacts because of their relatively widespread coastal distributions and historically these areas have been degraded, destroyed or converted for other land uses around the world (Alongi 2002, Gedan et al. 2009, Waycott et al. 2009). Global mangrove loss has been estimated to be as high as 35%, with deforestation rates ranging from 1–8% per year (Friess et al. 2019). Using remote sensing data, global mangrove deforestation rates have been estimated as 0.16% between 2000–2012. Salt marshes have been reclaimed and drained for agriculture and other developments globally (Gedan et al. 2009), while losses of seagrasses have been primarily attributed to reduced water quality (Waycott et al. 2009).

A study on **global mangrove C stock change between 1996 and 2016 reported a decline of 158.4 Tg attributed to land cover change**, and this decline represented a 1.8% decrease of the stock over the 20-year period (Richards et al. 2020). However, **conservation and restoration efforts, as well as natural forestation, reduced net mangrove stock losses** over this period. Over the study period, stocks along the east African coastline experienced variable net changes in carbon stocks (ranging between gains and losses) for different countries (Richards et al. 2020). At present, **no similar global assessments on carbon stock changes due to land cover change for salt marsh and seagrass ecosystems could be found**.

The loss and degradation of blue carbon ecosystems emits large quantities of CO_2 (primarily from the soil C pool) into the atmosphere, thus contributing towards global climate change (Pendleton et al. 2012). A regional study in West Papua, Indonesia, compared natural mangroves to sites that had been degraded and found **aquaculture conversion removed 60% of soil C stock and 85% of biomass C stock** (Sasmito et al. 2020). After 25 years of regeneration, **restored mangrove sites attained similar biomass and soil C stocks to undisturbed sites** (Sasmito et al. 2020). In comparison, a study carried out in Westernport Bay, Australia, assessed degraded and undisturbed salt marshes and found that land-use change resulted in a 70% loss of soil C stocks (Ewers-Lewis et al. 2019). For seagrasses, eutrophication-driven loss of the vegetation in Cockburn Sound, Australia, resulted in the loss of **up to 85% of soil C stock due to hydrodynamic erosion of the exposed sediment** (Salinas et al. 2020). In South Africa, the anthropogenic drivers causing loss of blue carbon ecosystems have been well documented and summarised in recent reports for mangroves (Adams & Rajkaran 2021), salt marshes (Adams 2020) and seagrasses (Adams 2016). However, the CO_2 emissions associated with these losses have not previously been calculated or reported before the current project.

The protection and restoration of blue carbon ecosystems therefore presents an opportunity to enhance C stocks and avoid GHG emissions. It is globally acknowledged that blue carbon research is still a developing field, and that there are scientific gaps that need to be addressed (Macreadie et al. 2019). In relation to C stocks and GHG emissions, there are assumptions that need to be tested regarding CO_2 release following different types of disturbances, and the role of allochthonous C. Despite this, it is widely accepted that reducing the ecological function of blue carbon ecosystems through removal, degradation and disturbance results in remineralisation of the stored organic C into CO_2 which is then released into the atmosphere. **Protecting and restoring blue carbon ecosystems can constitute a mechanism to offset GHG emissions** (IPCC 2014a), while also enhancing biodiversity and other essential ecosystem services provided by mangroves, salt marshes and seagrasses (Crooks et al. 2011, Sutton-Grier & Moore 2016).

1.2 COASTAL CLIMATE CHANGE IMPACTS ON CARBON STOCKS AND FLUXES

Blue carbon ecosystems and their C stocks are threatened by climate change over a range of spatial extents and temporal periods (Lovelock & Reef 2020). As all blue carbon ecosystems occur in coastal environments, **all blue carbon C stocks are exposed to sea-level rise (SLR)**, but this threat also varies regionally and temporally (Dangendorf et al. 2017). **Increased drought and storms** predicted for subtropical latitudes (Collins et al. 2013) threaten mangrove C stocks in these regions (Sippo et al. 2018). **Warmer temperatures at higher latitudes have facilitated mangrove range expansions into salt marsh** (Saintilan et al. 2014, Osland et al. 2017b, Cavanaugh et al. 2018). Although mangroves and salt marshes occur in the same intertidal zone, mangroves are limited in their latitudinal range by temperature, thus as temperatures warm, **mangroves have expanded in subtropical and warm-temperate latitudes and replaced the salt marsh in these areas**. This has had significant impacts on soil C stocks, as **mangrove ecosystems tend to capture and store greater soil organic C than salt marshes** (Doughty et al. 2016, Kelleway et al. 2016b). Additionally, increased **wave energy** associated with oceanic variability and extreme weather events can expose soil C deposits, resulting in loss of these stocks (Rogers & Woodroffe 2016).

The adaptive capacity for blue carbon ecosystems in response to climate change is defined by the following (Lovelock & Reef 2020):

1. The potential to accrete vertically to adjust to SLR;
2. The potential to maintain C stocks;
3. The potential to maintain area by expanding landwards into suitable areas;
4. The potential to maintain vegetation species that retain C stocks and promote continued sequestration.

1.2.1 Impact of Sea-Level Rise

Sea-level rise (SLR) has a fundamental role in influencing the distribution of blue carbon ecosystems as well as the accumulation of soil C stocks (Lovelock & Reef 2020). Past sea-level fluctuations in combination with coastal geomorphology have influenced the distribution of global C stocks in blue carbon ecosystems and are therefore critical drivers of future trends (Sasmito et al. 2016, Twilley et al. 2018, Rogers et al. 2019a). **The geology of the drainage basin, as well as local coastal dynamics determine whether catchment- derived sediments are retained within the intertidal region and deposited in blue carbon ecosystems.** Blue carbon ecosystems are therefore generally located on shorelines with gently sloping topography, low wave energy and high sediment supply. These conditions also favour C burial over erosion (Sanders et al. 2010, Woodroffe et al. 2016).

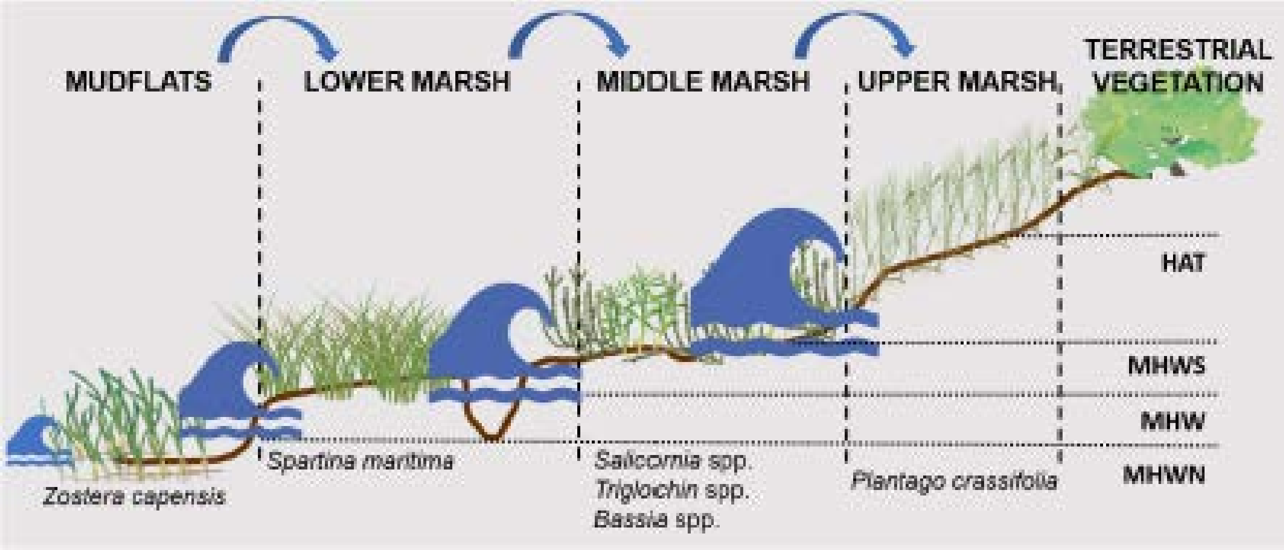


FIGURE 1.4: SCHEMATIC REPRESENTATION OF TYPICAL SPECIES ZONATION IN A SOUTH AFRICAN SALT MARSH AND HOW SEA-LEVEL RISE DRIVES A LANDWARD SHIFT IN THESE ZONES DUE TO PLANT PHYSIOLOGICAL ADAPTATIONS TO SPECIFIC SALINITY AND INUNDATION REGIMES ASSOCIATED WITH TIDAL HEIGHTS. (HAT = HIGHEST ASTRONOMICAL TIDE, MHWS = MEAN HIGH WATER SPRING, MHW = MEAN HIGH WATER, MHWN = MEAN HIGH WATER NEAP)

SLR controls sediment accommodation space, and this determines the capacity of a landscape to accumulate blue carbon stocks through **sediment deposition and landward movement of the intertidal zone** (Rogers et al. 2019a, Lovelock & Reef 2020). As a result, **mangroves and salt marshes are structured by their position in the tidal frame** (Figure 1.4). During periods of sea-level rise, areas at the lowest intertidal zones are lost first through drowning as a result of increased length and frequency of inundation as rising sea level shifts the position of the tidal frame relative to land (Grenfell et al. 2016, Spencer et al. 2016).

Mangroves and salt marshes can also be resilient against SLR and are able to respond to this threat under certain conditions which are related to positive surface elevation change and unrestricted landward migration (Di Nitto et al. 2014, Woodroffe et al. 2016, Schuerch et al. 2018, Cahoon et al. 2019). Rising sea levels may provide an opportunity for increased C burial if lost ecosystem area on the seaward side is compensated by gains on the landward side, assuming coastal squeeze is limited (Schuerch et al. 2018, Rogers et al. 2019a, Watanabe et al. 2019). **Landward migration of mangroves and salt marshes has the potential to achieve high C sequestration in both the soil and biomass C pools within the next two decades if other conditions are suitable for the vegetation to shift** (such as floodplain slope and hydrology) (Lovelock & Reef 2020, Osland et al. 2020). **Local topography and coastal development constrain the availability of areas for landward migration, but the rate of sedimentation determines the capacity of mangrove and salt marsh ecosystems to resist SLR through surface elevation gain** (Lovelock et al. 2015, Baustian & Mendelssohn 2018). Predictive models that incorporate landward migration and surface elevation processes can be used to estimate potential changes in blue carbon C stocks under different SLR scenarios (Lovelock & Reef 2020). Spatially explicit models such as these have been applied at global (Schuerch et al. 2018), regional (Lovelock et al. 2015) and local scales (Kirwan et al. 2016, Mogensen & Rogers 2018) – including two studies in South Africa at the Knysna and Swartkops estuaries (Raw et al. 2020, 2021).

Although SLR may result in gains in C stocks, several additional climate change impacts may limit such gains. These impacts include changes to wind and wave energy, extreme storms and erosion, rising temperature, and changes to rainfall and freshwater discharge patterns (Smoak et al. 2013, Ward et al. 2016). **All of these have the potential to erode sediment, thereby resulting in losses from the soil C stock.** As the mangrove or salt marsh platform is eroded away there will also be loss of biomass C as the vegetation becomes destabilised, causing dieback.

1.2.2 Impact of Wind and Wave Exposure

Wind and wave regimes are linked to processes that influence ocean C cycling as well as the ecological characteristics of blue carbon coastal ecosystems (Möller et al. 2014, Oreska et al. 2017, Walcker et al. 2018). As wind and wave regimes are predicted to be influenced by climate change (Kamranzad & Mori 2019), **blue carbon ecosystems could be impacted by direct damage to vegetation and loss of soil C stocks from erosion**. The effect of wind and wave exposure on blue carbon ecosystems under climate change will also occur in association with the increased frequency and severity of storms and cyclones (Ward et al. 2016, Saintilan et al. 2018, Adams 2020).

1.2.3 Impacts of Increasing Temperature and Changing Rainfall Patterns

Rainfall and temperature exert climatic controls on the distribution of blue carbon ecosystems (Sanders et al. 2016, Simard et al. 2019), the species composition of these ecosystems (Duke et al. 1998, Mcowen et al. 2017, McKenzie et al. 2020), their productivity (Kauffman & Bhomia 2017, Ochoa-Gómez et al. 2019), and thus on their C stocks. **Mangroves are sensitive to temperature changes as the global distribution range of this ecotype is linked to sea- surface temperature.** Rising temperatures are associated with the expansion of mangroves towards higher latitudes (polewards), described as 'tropicalisation', and several studies have reviewed these range shifts in different regions around the world (Saintilan et al. 2014, Osland et al. 2017b, Cavanaugh et al. 2018). **Mangrove expansion has often been accompanied by loss of salt marsh habitats and this can lead to ecological shifts, including changes in C stocks.** Expansions into salt marsh areas have **significantly increased soil C** stocks in New South Wales, Australia, and the Atlantic coast of Florida, USA (Doughty et al. 2016, Kelleway et al. 2016b). However, similar gains following mangrove expansion were not correlated with increased soil C at range limits in Louisiana, USA, and the Eastern Cape, South Africa (Yando et al. 2018, Raw et al. 2019b), indicating that there are additional factors controlling this relationship.

Changes to rainfall patterns will result in reduced rainfall in some regions, and this is expected to have negative impacts on blue carbon ecosystems, and particularly mangroves. **Reduced rainfall is associated with drought, hypersaline porewater and reduced sediment inputs to mangrove forests.** These conditions induce drought stress in mangrove trees by affecting physiological processes related to water uptake and water-use efficiency. Reports from recent large-scale dieback in northern and western Australia occurred under drought conditions in synergistic combination with low sea levels and low humidity (drought) as a consequence of an El Niño-Southern Oscillation (ENSO) event (Duke et al. 2017, Lovelock et al. 2017b, Asbridge et al. 2019). ENSO events drive large-scale weather patterns, including seasonal rainfall, and have not only increased in intensity over recent decades (Freund et al. 2019) but are also predicted to increase in frequency by 2100 (Sun et al. 2020). It is therefore predicted that **mangroves in mid-latitude regions that are influenced by ENSO have an increased likelihood of experiencing aridity-driven mortality events in the future under climate change** (Sippo et al. 2018).

The fate of the C stocks following aridity-driven mangrove mortality was assessed in Australia following dieback along ~1 000 km of the coast (Sippo et al. 2020). It was found that **release of CO_2 from the soil increased by 189%, and there was a 50% loss in the amount of dissolved inorganic C transported to the adjacent marine environment** (Sippo et al. 2020). This study estimated that **mangrove deforestation and dieback results in C losses of 13.7 ± 9.4 Tg C yr^{-1}**. Although aridity-driven mortality can threaten mangroves if they are suddenly exposed to these conditions, mangroves have also adapted to hot-arid climates in some regions where freshwater is obtained only from groundwater or sporadic storm events (Adame et al. 2020). However, these forests typically consist of trees with stunted growth due to the harsh conditions. Additionally, the nutrient content and C stocks in the soils are lower in comparison to mangroves from humid climates (Schile et al. 2017, Adame et al. 2020).

1.3 METHODOLOGIES AND PARAMETERS FOR BLUE CARBON SINK ASSESSMENTS

Beginning in 2017, with a Water Research Commission (WRC)-funded project (Adams et al. 2020a), the DSI/NRF Shallow Water Ecosystems Research Chair at the Nelson Mandela University, in collaboration with national research partners from the University of the Western Cape, the Council for Scientific and Industrial Research (CSIR), and the South African Environmental Observation Network (SAEON) Elwandle Coastal Node, have **advanced the understanding of the C stocks and fluxes within South African blue carbon ecosystems**. This research has been conducted following international standard protocols for quantifying C stocks and fluxes, predicting the effects of climate change on blue carbon ecosystems, and assessing the viability of a blue carbon offset mechanism for South Africa. The **Coastal Blue Carbon Manual** (Howard et al. 2014) developed by the IUCN and The Blue Carbon Initiative **provides globally recognised and accepted methodologies to allow for comparative studies and these protocols have been used for South African blue carbon research**. The information presented in this methodology section has been collated from the Blue Carbon Manual, as well as the resources generated over the past four years of research by the Working Group and is therefore comprehensive without being redundant.

This Working Group has collated existing and new data on C stocks and **calculated accumulation rates within South African blue carbon ecosystems**. This has progressed towards establishing **an inventory of C stocks for these ecosystems**. The research has also considered C fluxes following natural and anthropogenic change over time. These data provided the **baseline from which C sequestration potential** was estimated and were used to **develop predictive models of C stocks under future scenarios** as part of this project. The blue carbon spatial data, as well as the associated C stock data, can be incorporated into the South African Carbon Sinks Atlas. The data are also available for inclusion within the National GHG Inventory.

1.3.1 Methods for Assessing Blue Carbon Stocks and Fluxes

Comprehensive studies to quantify C storage in blue carbon ecosystems have been carried out globally, as this is the most important and primary step towards **using these ecosystems for climate change mitigation through policy, regulatory and finance mechanisms** (Siikamäki et al. 2013, Howard et al. 2014). The C stock in these ecosystems as well as the existing or potential emissions resulting from **natural or anthropogenic** changes must be quantified. This is referred to as creating a C inventory. There are three components that are included in a C inventory:

1. Changes in the **distribution and area coverage of blue carbon ecosystems** over time in relation to **anthropogenic impacts and land-use changes**;
2. The current C stock within these areas and the rate of C sequestration must both be quantified either through **field sampling or estimation by allometric calculations**;
3. The potential GHG emissions that could occur from **expected or potential changes** to land use.

To keep in alignment with international standards, blue carbon sink assessments should be based on the **IPCC 2013 resource: National Greenhouse Gas Inventories: Wetlands** (IPCC 2014a). These guidelines allow for C inventories to be estimated at different levels of detail, depending on the amount of the available raw data and the intended use of the final inventory product. Blue carbon sink assessments can be carried out on one of the three tiers of detail (Table 1.1).

TABLE 1.1: ADVANTAGES AND LIMITATIONS OF EACH TIER OF DETAIL FOR BLUE CARBON SINK ASSESSMENTS AS PER THE IPCC RECOMMENDATIONS.

TIER	ADVANTAGES	LIMITATIONS
1 – IPCC default factors	• IPCC default values are available for use and can be readily applied	• Default values may have large error ranges or could be unsuitable for the region
2 – Country- specific for key factors	• Increased accuracy and resolution if there are some site-specific data	• Data may be difficult to access/not easily available for application
3 – Detailed inventory of C stocks	• Can provide detailed estimates of changes, highly specific data and accuracy	• Field sampling and laboratory analysis of samples can be expensive. Requires extensive data analysis and processing.

C stock refers typically to the C_{org} that is stored within blue carbon ecosystems and is reported as Mg $C.ha^{-1}$ over a specified soil depth (usually 1 m). The C stock is the sum of all Corg within the AGC and BGC pools. National C accounting and C market projects require the quantification of four basic C pools – aboveground living biomass, aboveground dead biomass, belowground living biomass and soil carbon. If a particular C pool is small or unlikely to be affected by change then it can be excluded (Howard et al. 2014).

For South African blue carbon ecosystems, detailed Tier 3 C stock assessments have been carried out at only four estuaries – **Knysna** (34°4′57.74′ S, 23°3′41.23′ E), **Swartkops** (33°51′58.48′ S, 25°37′58.96′ E), **Nahoon** (32°59′11.18′ S, 27°57′6.13′ E), and **Nxaxo/Ngqusi** (32°35′5.03′ S, 28°31′34.53′ E). These assessments included field sampling and direct quantification of C_{org} for both AGC and BGC pools following the methodology from the Blue Carbon Manual. The Knysna and Swartkops estuaries support extensive **salt marsh** and **seagrass** areas, while the Nahoon and Nxaxo/Ngqusi estuaries support **mangroves** and **salt marsh** as well as patches of seagrass. The predominant mangrove species sampled was *Avicennia marina* (Forssk.) Vierh., the salt marsh species included *Salicornia tegetaria* S. Steffen, Mucina & G. Kadereit, *Bassia diffusa* (Thunb.) Kuntze, *Triglochin striata* Ruiz López & Pavón and *Spartina maritima* (Curtis) Fernald while seagrass was represented only by *Zostera capensis* Setchell. A summary of the soil and biomass C_{org} and total C stocks calculated from these assessments is provided in Table 1.2.

TABLE 1.2: SOIL AND BIOMASS ORGANIC CARBON (C_{org}%), TOTAL CARBON STOCKS (MG C.HA^{-1}) AND THE AREA COVER (HECTARES) OF MANGROVES, SALT MARSH AND SEAGRASS AT FOUR WARM-TEMPERATE SOUTH AFRICAN ESTUARIES (MEAN ± SE). C_{org}% WAS DETERMINED USING ELEMENTAL ANALYSIS OR DERIVED USING ORGANIC MATTER (OM%) FROM THE LOSS ON IGNITION METHOD (LOI). ADAPTED FROM BANDA ET AL. (2021).

ESTUARY	SOURCES	HABITAT TYPE	SOIL DEPTH (M)	C_{org}%		TOTAL CARBON STOCK (Mg C ha^{-1})		AREA (HA)
				Biomass	**Soil**	**Biomass**	**Soil**	
Nxaxo	Johnson et al. (2020)	Mangrove	1	40.1 ± 0.81	1.96 ± 0.31	71.45 ± 2.47	228.05 ± 27.99	9.5
	Banda et al. (2021)	Salt marsh	1	26.53 ± 0.68[1]	1.4 ± 0.29	3.96 ± 0.78	2.61± 0.19	10.91
		Seagrass	1	22.49 ± 0.75[1]	0.86 ± 0.07	1.26 ± 8.1 x 10^{-5}	1.67 ± 0.01	0.34
Nahoon	Raw et al. (2019b)	Mangrove	0.5	–	5.66 ± 0.56*	–	110.14 ± 11.02	1.62
	Adams et al. (2020a)	Salt marsh	0.5	–	6.18 ± 0.46*	–	109.62 ± 22.03	2.3
Swartkops	Els (2019)	Salt marsh	0.5	31.9 ± 1.64[1]	3.51 ± 0.34	4.28 ± 0.72	212.26 ± 43.99	547.35
	Adams et al. (2020a)		0.5	29.1 ± 0.66[1]	4.15 ± 0.41	16.27 ± 2.86	247.13 ± 47.71	
		Seagrass	0.55	27.2 ± 2.29[1]	2.85 ± 0.24	2.08 ± 0.49	224.14 ± 37.93	62
Knysna	Els (2017)W	Salt marsh	0.5	–	4.02 ± 1.47*	–	-	684.93
	Raw et al. (2020)	Seagrass	0.5	–	0.46 ± 0.09*	–	24.96 ± 6.43	447.3

SAMPLING SOIL CARBON POOLS

Belowground C pools are usually the largest pool in blue carbon ecosystems, thus it is essential that they are measured so that changes associated with **disturbance, climate change and land management** can be identified and managed accordingly. Belowground C pools account for **50–90%** of total ecosystem C stock in mangroves (Donato et al. 2011, Kauffman et al. 2011) but this takes an extremely long time to accumulate. Therefore, recently restored blue carbon ecosystems may not have significant soil C for several years after the vegetation has become successfully established (Chen et al. 2018, Sidik et al. 2019).

Soil cores are collected to accurately quantify the soil C pool. These cores are collected to a specific depth, and then subsampled so that the dry bulk density and soil organic C content (% C_{org}) can be measured. Enough **soil cores need to be extracted** so that the samples will be **representative of the habitat of interest for the project**. The device used for extracting the cores depends on the type of substrate as well as the desired sample depth (Figure 1.5) (Howard et al. 2014, Owers et al. 2018).

Soil cores were collected at a depth of 1 m at the Nxaxo Estuary and 0.5 m at the Nahoon, Swartkops and Knysna estuaries (Els 2017, 2019, Raw et al. 2019b, Johnson et al. 2020, Banda et al. 2021). Soil organic carbon (C_{org}%) was

FIGURE 1.5: FIELD SAMPLING FOR SOIL CORES AT THE NXAXO ESTUARY. A PVC PIPE CORER WITH PRE-DRILLED HOLES (A) WAS USED IN SALT MARSH AND SEAGRASS AND A SYRINGE WAS USED TO EXTRACT THE SUBSAMPLES (B). A RUSSIAN PEAT CORER WAS USED IN THE MANGROVES (C). FIGURE ADAPTED FROM BANDA ET AL. (2021).

determined using elemental analysis at Nxaxo and Swartkops estuaries, while at Nahoon and Knysna estuaries organic matter (OM%) was used as a proxy for C_{org}% and this was measured using the loss on ignition (LOI) method.

Soil depth is determined during field sampling while dry bulk density and $\%C_{org}$ are measured in the laboratory by processing the sampled cores. **Bulk density and $\%C_{org}$ can be variable with depth and location, thus requiring multiple cores to be extracted and sampled in a given area so that a better estimate of the soil C can be calculated.** Dry bulk density is calculated from the mass of a dried soil subsample, and its original volume. There are two recommended methods for measuring the soil $\%C_{org}$ – 1) using an automated elemental analyser; 2) using combustion and empirical relationships between organic C and organic matter (LOI method). An elemental analyser provides accurate quantitative measures of C content, but this equipment is specialised, making the analysis costly. In contrast, the equipment for the LOI method is relatively inexpensive, but the approach is only semi- quantitative as the $\%C_{org}$ is estimated from organic matter measurements. For the South African blue carbon assessments, a series of samples were analysed using both methodologies so that the empirical relationship between $\%C_{org}$ measured by elemental analysis and organic matter content measured by LOI could be derived for our specific habitats (Adams et al. 2020a, Johnson et al. 2020, Banda et al. 2021).

SAMPLING BIOMASS CARBON POOLS

The vegetative C pools in blue carbon ecosystems can be divided into three components: 1) **living aboveground biomass** (herbaceous and woody plant mass), which includes epiphytes and aerial roots (pneumatophores); 2) the **living belowground biomass** (roots and rhizomes); and 3) the **non-living aboveground biomass** (includes detritus, leaf litter, algae, dead and drowned wood) (Howard et al. 2014).

Ecosystem-specific techniques are used to determine biomass and $\%C_{org}$ for each C_{pool}, as there are differences depending on the vegetation structure and density. For the South African blue carbon assessments, **characteristics of the vegetation were measured during field sampling** – such as height, width, circumference and density – and these were used to determine biomass with recommended allometric equations (Els 2019, Johnson et al. 2020, Banda et al. 2021). **The C pool is then determined by multiplying the biomass by a corresponding C conversion factor to represent the fraction of vegetation that is C.** For the South African blue carbon assessments, specific C conversion factors were developed by measuring the $\%C_{org}$ in the plant material samples using elemental analysis.

For mangroves, live trees form the primary component of the aboveground C pool and these must be measured accurately. The area of interest is generally divided into sampling plots of suitable size to be representative and within each plot the species, stem diameter at 1.3 m from the ground (DBH – diameter at breast height), and height of each tree must be recorded. For shrub mangroves, the crown circumference can also be an informative metric (Owers et al. 2018). To quantify biomass directly requires destructive sampling, which is logistically difficult and not recommended; instead, allometric equations that define the relationship between biomass and tree parameters can be applied (Chave et al. 2005, Komiyama et al. 2008). There are several equations that can be applied, but it is recommended that **species-specific equations for the region are developed**. The choice of equation also depends on the available data collected during field sampling. For the South African blue carbon assessment, the equation defined by Chave et al. (2014) was applied as it allowed the calculation of aboveground biomass using **wood density, trunk diameter and tree height**, which could be measured in the field (Johnson et al. 2020). Estimates using this equation were comparable to those calculated by Steinke et al. (1995), who used destructive sampling to estimate biomass of *A. marina* mangroves in the uMngeni Estuary. Although we have not developed species-specific allometric equations for the region, we can calculate a range of biomass estimates using the different equations that are available. The major limitation is that in warm-temperate regions the trees tend to be smaller in comparison to tropical regions; however, this can be accounted for by scaling the allometric equations.

For salt marshes, a variety of species can constitute the ecosystem, and these are generally distributed across the intertidal area into specific zones depending on the physiological tolerances of the plants to inundation and salinity (Adams et al. 2016b, Veldkornet et al. 2016). The salt marsh area to be sampled is therefore divided along these zones with representative plots within each zone. In each sampling plot, the number of individual stems and their height are recorded within relatively small quadrats (30 x 30 cm) if the vegetation is dense. **Salt marshes can be more easily sampled to directly quantify biomass by harvesting the plants and this approach was used in the South African blue carbon assessments** (Els 2019, Banda et al. 2021). A species-specific allometric equation to define the biomass in relation to the plant height can then be generated.

For seagrasses, biomass can vary seasonally as well as in response to changing hydrological flows and sediment dynamics as these plants are submerged (Adams 2016). In South African estuaries, *Zostera capensis* occurs in the lower intertidal zone (exposed at low tide) and also in the subtidal zone (always submerged). For the blue carbon assessments, only intertidal *Z. capensis* has been sampled due to the difficulty of sampling subtidal sites which would require SCUBA. Biomass is sampled using a large-diameter PVC core tube that is pushed into the substrate and then extracted (Els 2017, 2019, Banda et al. 2021).

1.3.2 Methods for Assessing Blue Carbon Ecosystems Mitigation Potential, and the Role of Restoration in Managing GHG Emissions

The contribution of blue carbon ecosystems to climate change mitigation requires information on the extent of the ecosystems, the C stocks present and the rate at which C is emitted or sequestered. Direct estimates of CO_2 emissions reduction potential are complicated and require specialised equipment; therefore, alternative methods based on the conversion of total C stocks have been developed (Emmer et al. 2015b). C emissions can be measured as Mg $CO_2 \cdot ha^{-1}$ or Mg CO_2 equivalent (UNFCCC 2011), therefore **one carbon credit represents one metric tonne of CO_2 equivalent (t CO_2eq). A conversion factor of 3.67 is used to convert C stocks (Mg C.ha^{-1}) to CO_2 emissions as the C to CO_2 ratio is 44:12.**

C stock changes can be used as a proxy for CO_2 emissions and these can be quantified either directly by repeating a detailed Tier 3 assessment after a certain period of time, or by estimating the difference in C stocks based on emissions factors that have been defined for certain activities by the IPCC (such as drainage and deforestation) (Howard et al. 2014).

C sequestration potential can be calculated using stock differences for the vegetation with the aboveground biomass, the C conversion factor and the area covered by the habitat at a specific point in time (Vandebroek &

Crooks 2014). For soil C sequestration, changes due to soil accretion and erosion over time need to be accounted for and this is achieved by establishing a reference datum and measuring the change in the surface elevation of the substrate over time (Cahoon et al. 2000, 2019). C sequestration in the soil pool is calculated using the soil C density (measured during the C stock quantification), and the surface elevation change. The recommended method to accurately measure surface elevation change is with the Rod Surface Elevation Table (RSET), which has been globally standardised (Rogers et al. 2013a, Webb et al. 2013, Lovelock et al. 2014) (Figure 1.6). In South Africa, RSET stations to measure changes in surface elevation over time in mangroves and salt marshes have been established in the Knysna, Kromme, Swartkops, Nahoon and Nxaxo/Ngqusi estuaries. These stations are managed by SAEON and the data collected from these sites has been used in our blue carbon ecosystem assessments (Bornman et al. 2016, Adams et al. 2020a, Raw et al. 2020, 2021).

If it is not feasible to repeat a Tier 3 blue carbon inventory, then a gain-loss method can be used to account for changes in C stock between two points in time (Howard et al. 2014). Activities that influence C stocks include natural transfers between pools, plant growth and soil accretion,

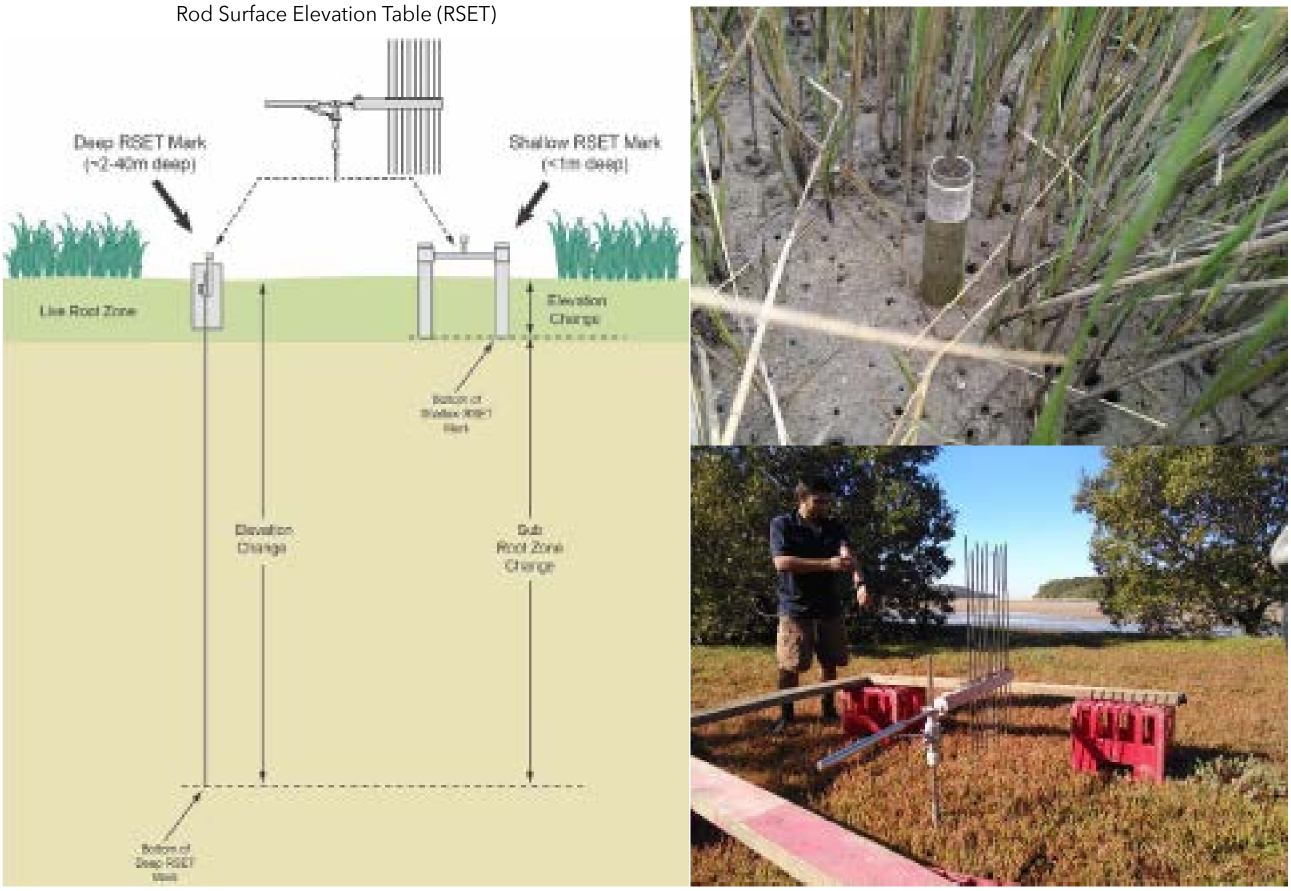


FIGURE 1.6: SCHEMATIC DIAGRAM OF RSET BENCHMARK COMPONENTS ADAPTED FROM LYNCH ET AL. (2015) (LEFT), BENCHMARK RECEIVING END IN SPARTINA MARITIMA SALT MARSH AT THE KNYSNA ESTUARY (TOP RIGHT), AND MEASUREMENTS BEING TAKEN FROM A BENCHMARK IN SALICORNIA SP. SALT MARSH AT THE NAHOON ESTUARY (BOTTOM RIGHT).

ecosystem restoration, natural disturbances and anthropogenic land-use changes. Conversion factors for activities are based on globally compiled databases from the IPCC 2013 Wetlands Supplement (IPCC 2014a).

An alternative method for determining C sequestration is to use Eddy covariance measurements of net ecosystem exchange (NEE) (Howard et al. 2014). This approach estimates a balance between C uptake through primary production and C losses through respiration and is therefore based on gaseous exchange (Saunders et al. 2007, Villa & Bernal 2018). C loss through water exports needs to be accounted for separately for C accumulation processes that occur in the soil (Waddington & Roulet 2000, Roulet et al. 2007). The use of any methodology can be subjective and is usually determined by the scope of specific projects as well as logistical and budgetary constraints. Blue carbon sink assessments can also opt to combine and compare methodologies to be more comprehensive and reduce potential errors (Villa & Bernal 2018).

Using natural ecosystems to capture and sequester C is considered the most efficient and cost-effective approach to counteract global anthropogenic GHG emissions (Duarte et al. 2013). Healthy blue carbon ecosystems also provide additional valuable ecosystem services, such as fish nursery function and coastal protection (Barbier et al. 2011, Adame et al. 2015, Sutton-Grier & Moore 2016). **The conservation and restoration of blue carbon ecosystems is therefore the most straightforward approach towards managing GHG emissions.**

Restoration projects seek to return an ecosystem to a previous state or trajectory, or to return the functionality that existed before by 1) improving the condition of degraded existing habitats; 2) creating new habitats (without replacing other natural habitats); and 3) returning impacted areas to a natural state following land-use change. Improving the condition of existing coastal wetlands to enhance C storage and sequestration involves reducing activities that contribute towards degradation, such as **overharvesting** of plant species (Rajkaran et al. 2004); trampling (Mabula et al. 2017); grazing by livestock (Nolte et al. 2013); **sediment destabilisation** caused by **bait digging** (Contessa & Bird 2004); and **pollution** (Häder et al. 2020). Decreased water quality (high nutrient input) reduces root biomass of salt marsh, which in turn decreases the accretion potential and stabilising effect of the habitat (Turner et al. 2004). However, it can be challenging to monitor whether there has been effective restoration for C storage and sequestration without a comprehensive baseline for comparison. Constructed wetlands can enhance C sequestration from a zero baseline (Were et al. 2019). However, the design and function of constructed wetlands should allow for a C sequestration rate that is equal to or greater than that of natural habitats (Madrid et al. 2012, Yang & Yuan 2019). Restoration of coastal wetlands that have been lost or modified for economic activities (such as shrimp ponds and salt extraction pans) can enhance C storage and sequestration if the areas can be **returned to a natural state** (Keller et al. 2012, Dittmann et al. 2019, Noll et al. 2019, Sidik et al. 2019).

Restoration of impacted areas has primarily focused on reinstating natural hydrology, as this promotes natural regeneration of the vegetation (Kamali & Hashim 2011, Elliott et al. 2016, Macreadie et al. 2017). Active restoration in the form of planting vegetation can help to reduce the timeframe over which the C sequestration goals are realised, and selecting species with high C capture efficiencies can increase C stocks rapidly. However, C restoration projects that also include co-benefits (such as biodiversity) need to be carried out with ecological knowledge regarding species composition, zonation and density that would be expected to **occur in a comparable reference area** (Chen et al. 2012, Dale et al. 2014, Vanderklift et al. 2020).

1.3.3 Recommended Sampling Plan Design

Blue carbon sink assessments rely on a range of input data that can be collected, collated and analysed using a variety of approaches. It is therefore critical that the goals of the project are clearly defined, as this will influence the design and execution of the project. **A clear goal should define the geographic areas that will be included, the carbon pools that will be measured, and the level of detail at which the data need to be recorded and reported** (Howard et al. 2014).

To maximise the effectiveness of the proposed blue carbon sink assessment for South Africa, the available resources need to be considered. **The ideal geographic area of interest for a national assessment would include all mangrove, salt marsh and seagrass habitats. However, it is not logistically feasible to conduct a Tier 3 assessment for every estuary.** Therefore, the recommended approach is to use the available data from the four estuaries with detailed assessments, and **scale it accordingly based on available spatial extents for a national blue carbon sink assessment**.

Following the 2018 NBA, **a total of 142 estuaries have existing spatial data, which includes the habitat area for mangroves, salt marshes and seagrasses** (Adams et al. 2019). Estuaries that support **> 5 ha of blue carbon ecosystems** but do not have spatial data were prioritised to be mapped as part of this project. Estuaries supporting large areas of **teal carbon habitats** (non-tidal freshwater habitats *sensu* Nahlik & Fennessy (2016)) were also prioritised for inclusion.

A hierarchical approach was used to map the prioritised estuaries so that separate spatial areas are defined for each blue carbon ecosystem. Initial screening and mapping was carried out by visually **examining Google Earth satellite imagery** and using expert knowledge to **differentiate between the different blue carbon ecosystems**. Older

BOX 2: Why Include the 'Teal Carbon' Ecosystems?

Teal carbon ecosystems are the freshwater, non-tidal wetlands. Research has shown that these ecosystems are equivalent to the traditional coastal blue carbon ecosystems in their capacity to regulate GHGs.

Teal carbon ecosystems are also threatened by land-use change, pollution, water extraction and landscape modification. As with blue carbon ecosystems, degradation of these ecosystems leads to the release of CO_2 and methane into the atmosphere. Teal carbon has been overlooked in comparison to other ecosystem carbon sinks (marine and terrestrial), although these ecosystems could also be incorporated into carbon offset programmes (Nahlik & Fennessy 2016).

In South African estuaries, reeds and sedges are the dominant habitat type, covering 17 500 ha in total (Van Niekerk et al. 2019). The plant species that make up this habitat type also make an important contribution to livelihoods in the form of natural resource harvesting. Protection and restoration of these ecosystems can therefore be carried out with social and ecological goals in mind.

aerial or satellite imagery, as well as historical data and maps, can be used for comparison and to examine changes in blue carbon ecosystem areas over time. However, not all estuaries have historical data, and the existing data can be patchy and at uneven intervals. It is also important to consider that these data represent a 'snapshot' in time and that there may be different states or stages that are not reflected by the available historical datasets.

Remote sensing has emerged as an important tool for determining ecosystem extent and stratification and analysing changes in land use over time and thus it has applications for C stock quantification in blue carbon ecosystems (Simard et al. 2019, Alvarez-Vanhard et al. 2020, Feagin et al. 2020). Remotely sensed data are collected at different spatial resolutions and can be used to **identify different structural characteristics of the vegetation** (Pastor- Guzman et al. 2018). Additionally, data derived from satellites are continuous over decadal time periods, which facilitates long-term and large-scale monitoring of the geographical areas of interest (Howard et al. 2014). **Remote sensing has been successfully used to measure global trends in mangrove canopy height and aboveground biomass** (Simard et al. 2019, Hu et al. 2020), to assess gross primary production in coastal wetlands over two decades in the USA (Feagin et al. 2020), to link mangrove loss to human pressures (Goldberg et al. 2020), and to quantify changes in C stocks in relation to natural and anthropogenic disturbances (Lagomasino et al. 2019, Richards et al. 2020).

Although remotely sensed data have a wide variety of applications, there are some limitations that need to be considered. Global estimates of habitat cover can over/underestimate habitat changes due to the low resolution of satellite images compared to the often-small habitat area in estuaries. In Goldberg et al. (2020), mangrove loss in South Africa was attributed to edge erosion from sea-level rise, with uMhlathuze and Kosi estuaries provided as the examples. However, **ground truthing of these two estuaries showed that uMhlathuze has increased in mangrove habitat by 740 ha and Kosi by 10.3 ha**, both due to land cover changes driving increased sedimentation into the estuaries, favouring the expansion of mangroves. For this reason, the mapping approach used in this study and the habitat areas has high confidence levels. Although tedious, manual digitising of habitats provides a much higher level of accuracy. This is particularly true in the South African environment where habitat is fragmented and often forms narrow bands. When combined with geotagged images, habitat delineation becomes easier. For this project, the area of estuarine ecosystems that has undergone land cover change will make use of the land cover change dataset from Skowno et al. (2021).

1.3.4 Scope for Monitoring Blue Carbon Ecosystems through DFFE Oceans and Coasts

The Oceans and Coasts branch of DFFE is focused on the promotion, management and strategic leadership related to ocean and coastal conservation in South Africa. This is achieved through: establishment of management frameworks and mechanisms, strengthening national science programmes for integrated ocean and coastal management, developing and contributing effective knowledge and information, and participating in and supporting international agreements that support South African priorities for the environment and sustainable development (https://www.environment.gov.za/branches/oceans).

Oceans and Coasts is therefore responsible for incorporating blue carbon ecosystems as they constitute part of the coastal zone, occurring in **sheltered estuarine**

environments. However, their integrity and biodiversity are threatened by **increasing freshwater abstraction, poor coastal development practices, declining water quality, climate change and sea-level rise**. Despite this, blue carbon ecosystems also provide services to the sector, by serving as C sinks, providing nursery habitat to commercial fish species, and through their use by people for livelihoods as well as recreational purposes. There is a need to establish a comprehensive research programme on blue carbon science that addresses current gaps while continuing to respond to immediate policy and managerial needs. Current gaps include:

- More *in situ* field data for blue carbon needs to be collected, particularly in under- represented systems such as mangrove forests of KwaZulu-Natal, and salt marshes along the arid Western Cape coastline.
- Detailed, high-resolution digital elevation models are needed for the entire coastline so that sea-level rise impacts can be appropriately assessed.
- Management guidelines that are specific to blue carbon and teal carbon ecosystems need to be developed and implemented. The importance of these ecosystems needs to be further highlighted. The formal Estuary Management Course can be used to achieve this.
- Blue carbon ecosystems need to be included as an indicator that the Oceans and Coasts can report on in Working Group 7.
- Red-listing of ecosystems needs to be applied to salt marsh ecosystems.

Oceans and Coasts is focused on management and conservation, with a purpose to integrate stakeholders and safeguard coastal environments through the application of legislation, and can therefore provide the policy support and legislative framework that is needed to incorporate blue carbon ecosystems within national climate change mitigation efforts.

1.4 BLUE CARBON ECOSYSTEMS IN RELATION TO THE PARIS AGREEMENT

Policies associated with C offsets are complex and dynamic and need to be contextualised from both national and international perspectives. It is also essential to recognise how the policy landscape is changing so that South Africa is prepared to meet our own carbon offset requirements, capitalise on international offsetting, and manage the risks around carbon abatement and emissions reductions.

1.4.1 Global Initiatives Related to Carbon Offsets and Trade

The United Nations Framework Convention on Climate Change (UNFCCC) is an international environmental treaty. It was adopted at the 1992 UN Conference on Environment and Development and came into effect in 1994 after being ratified (United Nations 1992). As of 2020, there are 197 parties that have ratified the treaty (https://treaties.un.org/). The goal of the UNFCCC is to provide a framework for international protocols and agreements with the aim to achieve stabilisation of GHG concentrations in the atmosphere to prevent anthropogenic interference with the climate system (United Nations 1992). The UNFCCC does not commit parties to limits on emissions and does not enforce any international agreements. Instead, this treaty provides a series of recommendations for international negotiations.

The Kyoto Protocol was the first international agreement to be established under the UNFCCC (United Nations 1998). Its purpose is to commit Annex I signatories to internationally binding emissions reduction targets. The level of commitment by parties is subject to economic development status. The Annex I list includes industrialised countries (members of the OECD – Organisation for Economic Co-operation and Development), as well as economies in transition from centrally planned to free markets. The Annex II list includes the OECD countries, but not countries with economies in transition. The Non-Annex I list includes developing countries, some of which are identified as being particularly vulnerable to climate change. An additional 49 countries are considered the 'least developed' and are given special consideration with regards to limited capacity to respond to climate change (https://unfccc.int/parties-observers). South Africa is listed as a Non-Annex I country, as it is still a developing economy. However, **South Africa is one of the top 20 most carbon-intensive countries in the world (currently ranked number 13)** (UNFCCC 2011, Klausbruckner et al. 2016) because of high dependence on industrial activities that rely on the burning of coal, crude oil and natural gas (Arndt et al. 2013). As **the largest CO_2 emitter in Africa, it is rated 27th in the Global Climate Risk Index**. South Africa has therefore made international and national commitments towards GHG mitigation.

There are three mechanisms under the Kyoto Protocol that allow parties to meet commitments to reduce or maintain emissions: the Clean Development Mechanism (CDM), International Emissions Trading (IET) and Joint Implementation (JI) (United Nations 1998). The CDM allows developed countries to reach targets by implementing emission reduction or removal enhancement projects that contribute to sustainable development in developing countries, while JI enables developed countries to carry out emission reduction or removal enhancement projects in other developed countries. The IET allows countries to 'sell' emissions reductions to others that would otherwise not be able to reach their reduction commitments (United Nations 1998). **These are the major global initiatives driving demand for C offsets and trade.**

The Paris Agreement expands on the IET mechanism of the Kyoto Protocol and serves as a framework for establishing a global carbon market (United Nations 2015). The Paris Agreement will replace the Kyoto Protocol once the second commitment period of the latter ends in 2021. The Paris Agreement has a central aim to keep global temperature to less than 2°C (preferably less than 1.5°C) above pre-industrial levels. Instead of focusing on stabilising emissions, as was defined in the Kyoto Protocol, the Paris Agreement calls specifically for emission reductions if the goal is to be realised. **The Paris Agreement allows parties to specify their own Nationally Determined Contributions (NDCs), which are encouraged to be ambitious** in order to achieve the goals of the Agreement (United Nations 2015). However, the NDC remains a voluntary national target that is politically encouraged, and not legally binding.

Article 6 of the Paris Agreement is focused on market-based mechanisms and provides a framework that supports international trade of C credits (United Nations 2015). Article 6 outlines three mechanisms:

1. Article 6.2: Parties shall engage in cooperative approaches that involve the use of internationally transferred mitigation outcomes towards NDC; these approaches should promote sustainable development and ensure environmental integrity and transparency. Robust accounting will be used to ensure the avoidance of double counting and consistency with the guidance adopted in the Agreement.

2. Article 6.4: A mechanism to contribute towards the mitigation of GHG emissions and support sustainable development is established under authority and guidance of the Parties to the Agreement.

3. Article 6.8: Parties recognise the importance of integrated, holistic and balanced non-market approaches being available to assist in the implementation of the NDC in the context of sustainable development and poverty eradication.

The framework encourages voluntary bilateral agreements to transfer approved units of C credits internationally to achieve NDC. Mitigation of GHG emissions through supporting sustainable development and maintaining environmental integrity in Non-Annex I countries is encouraged (United Nations 2015). It should be noted that no decision has been taken on Article 6 by the UNFCCC, so there is uncertainty regarding aspects of the proposed mechanisms.

1.4.2 Nationally Determined Contributions and Blue Carbon Ecosystems

The NDCs are compiled by countries that have ratified the Paris Agreement to outline their efforts to address climate change mitigation and adaptation, but also the financial and investment requirements. The NDCs of a country will include the actions that need to be taken to achieve their voluntary commitments to reduce GHG emissions or increase rates of C sequestration. **The NDCs serve as catalysts for action as they are politically encouraged.** Each country can develop their NDCs with mitigation and adaptation actions based on a series of measures, including nature-based solutions (Herr & Landis 2016). This includes the conservation and restoration of ecosystems.

Blue carbon ecosystems can be included explicitly within the NDCs. The UNFCCC in Article 4(1)(d) recognises the role of ecosystems, with the intent to:

> *'Promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases… including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems'*
> (United Nations 1992)

This is reiterated by Article 5 of the Paris Agreement, which highlights the importance of conservation, and enhancement of sinks and reservoirs of GHGs (United Nations 2015), as well as the IPPC Special report on Climate Change and the Oceans and Cryosphere (IPCC 2019). **Blue carbon ecosystems can be incorporated into mitigation actions because of their C storage and sequestration potential** (Taillardat et al. 2020). **They can also be included in adaptation actions** as they provide natural coastal protection from storm surges and sea-level rise (Barbier 2015, Möller 2019), as well as additional co-benefits such as nursery habitats for fish and invertebrate species, water purification and support to local livelihoods (Barbier et al. 2011, Mayrhofer & Gupta 2016).

Indian Ocean nations have emerged as global leaders on incorporating blue carbon ecosystems into their NDC, with Bangladesh, Madagascar and Sri Lanka including specific actions to restore mangroves (Vanderklift et al. 2019a). Similarly, India and Myanmar include mangroves in their adaptation strategies as natural coastal buffers against storm surges and sea-level rise. Restoration and management plans for seagrass are included in the NDCs for the Seychelles, Sri Lanka and the United Arab Emirates. As blue carbon ecosystems are widely distributed in this region (Alongi et al. 2016, Gullström et al. 2018), these nations have significant potential to contribute towards global efforts of GHG mitigation. Improving NDCs to include blue carbon ecosystems can be achieved through actions that implement IPCC guidelines. These actions should be focused on the management and restoration of coastal ecosystems to reach the required targets (Vanderklift et al. 2019b). As blue carbon ecosystems provide multiple other ecosystem services, complementary approaches such as PES (Payment for Ecosystem Services) should also be explored. Also, management actions related to land tenure and use can have a significant impact on C stocks if they prevent loss, degradation or conversion of blue carbon ecosystems. **Management actions to restore blue carbon ecosystems can enhance C sink potential as well as other ecosystem services.**

Successful restoration and management of blue carbon ecosystems can provide lessons on approaches that can be implemented in South Africa. For example, it has been widely recommended that **blue carbon projects should be structured using community-based management**, as this allows for several issues to be addressed from a bottom-up approach.

Such issues include land tenure rights, provisioning of equitable financial incentives, and inclusion of local needs and interests (Gevaña et al. 2018). Furthermore, **traditional management systems and traditional ecological knowledge need to be acknowledged and incorporated into blue carbon management** (Vierros 2017). However, **successful blue carbon projects also have high-level government support and significant donor funding** to cover the initial costs. For example, Mikoko Pamoja in Kenya is managed by three groups: 1) representatives from the Gazi and Makongeni villages; 2) the project steering group, which provides technical support and consists of unpaid volunteers from the Kenya Marine & Fisheries Research Institute, the Kenya Forest Service, the WWF, Edinburgh Napier University, the Earthwatch Institute and Bangor University; and 3) the Association for Coastal Ecosystem Services, which is a charity registered in Scotland.

South Africa's NDCs do not explicitly include blue carbon ecosystems as part of mitigation or adaptation strategies. However, wetlands are listed **as part of the adaptation section of the NDC**. There is a focus on conservation and management, protection and restoration of these ecosystems. Increasing wetland programmes is listed as an adaptation measure, with **'Working for Wetlands' identified as a key programme that could be scaled up** (Martin et al. 2016). As blue carbon ecosystems are C sinks, there is scope for South Africa to include them within climate mitigation strategies. Examples of NDC mitigation actions related to blue carbon ecosystems that have been included by other countries include the consideration of these ecosystems within Land Use, Land-Use Change and Forestry (LULUCF) commitments (particularly for mangroves) (Herr & Landis 2016). Adaptation actions can include the incorporation of coastal wetlands in protection and restoration efforts, and within specific coastal zone management for climate adaptation (Herr & Landis 2016).

1.4.3 Carbon Markets and Blue Carbon Ecosystems

C markets are based on producing C credits (CERs) through ensuring avoidance or removal of atmospheric GHGs. Emissions reduction strategies have gained popularity as GHG emissions continue to rise due to anthropogenic factors such as population growth and an increased demand for fuel and food (Sapkota & White 2020). C markets are divided into two broad categories: compliance/regulatory and voluntary markets. Voluntary C markets were created for individuals, companies or governments **that wanted to voluntarily offset their own GHG emissions** (Ullman et al. 2013). In comparison, **compliance/regulatory markets are regulated cap-and-trade schemes** established by the Kyoto Protocol to control GHG emissions by providing monetary incentives for emission reductions. The CDM is one of the most recognised examples of compliance markets. In comparison, the Reducing Emissions from Deforestation and Forest Degradation (REDD+) is a framework through which non-tradeable emissions reductions are generated, and funds are received based on the results of a specific project to stop deforestation.

Emissions trading relies on C credits that are verified by a certain 'standard', which includes the accounting, monitoring, verification and certification standards as well as the registration and enforcement systems (Wylie et al. 2016). Methodologies for certifying C credits under voluntary markets have proven to be easier to implement, as there is more flexibility in the standards and the cost of certification is lower (Vanderklift et al. 2019b). These methodologies include those from **Plan Vivo, the Verified Carbon Standard (VCS), the Gold Standard, and the Climate Community and Biodiversity Alliance (CCBA) Standard** (Herr & Pidgeon 2011, Michaelowa et al. 2019). In contrast, as REDD+ and CDM fall under UNFCCC, they must be implemented **through national government processes** (Lovell 2010). The VCS Methodology for **Tidal Wetland and Seagrass Restoration** (VM0033 V1.0) is approved by Verra (VCS – Verified Carbon Standard) as a methodology to develop a C offset project through **restoration of degraded tidal marshes, mangrove forests and seagrass meadows** (Emmer et al. 2015a). Methodologies specific to conservation of blue carbon ecosystems that are globally applicable have not as yet been implemented. However, there have been successful blue carbon projects that were verified and implemented using the above-mentioned voluntary carbon markets. Wylie et al. (2016) have compiled a brief database of such projects. In South Africa, the DFFE have been working towards the development of potential verification standards and methodologies for carbon offsets in the AFOLU sector (DEA 2015a). This research was undertaken so that other land-based mitigation options (such as grasslands and soil systems) could be considered, as the international standards and methodologies for land-based mitigation are primarily focused on forests. The project aimed to develop the framework for a South African Carbon Offsetting Standard which could be applied within the national carbon offsetting platform that was under development at the time.

There is an opportunity to develop national and/or regional blue carbon programmes that will serve towards mitigating climate change, as large areas of these ecosystems have been degraded globally, and there is a **market demand for C credits that can be obtained through the restoration of these ecosystems** (Wylie et al. 2016, Vanderklift et al. 2019b). National/regional programmes have the advantage in that they are more cost-effective, will ensure coordinated implementation, integrate effectively with existing government initiatives (e.g. Working for Water, CoastCare) and can be more effectively monitored and reported on. A database of global ongoing blue carbon projects was collated by Wylie et al. (2016) to compare the application of finance mechanisms and the contribution of the projects to climate change mitigation and adaptation. An overview of the four case studies highlighted in their paper is provided (Table 1.3).

Across all case studies, the common theme underlying their success was **the incorporation of livelihood aspects as part of the project design** (Wylie et al. 2016). Community involvement at all stages of planning and implementation was vital to success as the people were engaged from the onset and they understood the benefits of the project. It also ensures the success of the task at hand, i.e., that protecting a mangrove forest in one place does not lead to deforestation of mangroves elsewhere.

In each of the case studies, climate change mitigation was listed as one of the main objectives, but these projects are not being implemented through the UNFCCC mechanisms because the **transaction costs are too high for small project areas** (Wylie et al. 2016). Additionally, UNFCCC projects have minimum thresholds that can be difficult for coastal projects to reach, particularly as those that are community-based tend to be smaller in area. It is challenging for small projects to achieve **a compliance standard** and therefore **not possible to make a profit using these mechanisms** due to large transactional costs (Wylie et al. 2016). If a programmatic approach is taken, it could provide an opportunity to address these issues as multiple smaller projects can be bundled to reduce transactional costs.

TABLE 1.3: DESCRIPTION OF BLUE CARBON PROJECTS EXAMINED AS CASE STUDIES IN WYLIE ET AL. (2016). ALL PROJECTS ARE FOCUSED ON MANGROVE ECOSYSTEMS.

PROJECT	LOCATION	LEAD ORGANISATIONS	FUNDING ORGANISATIONS	SIZE	FINANCE MECHANISM
Mikoko Pamoja	Gazi Bay, Kenya	Association for Coastal Ecosystem Services, Kenya Marine Fisheries Institute, Napier Edinburgh University, Plan Vivo	Kenya Marine Fisheries Institute, Earthwatch Institute, Napier Edinburgh University, Plan Vivo	117 ha	Voluntary Carbon Credits – Plan Vivo
Markets and Mangroves	Mekong Delta, Vietnam	SNV Netherlands, IUCN	International Climate Initiative, German Federal Ministry for the Environment, Building and Nuclear Safety, Minh Phu	1 715 ha	Naturland Organic Shrimp Certification
India Sundarbans Mangrove Restoration	Sundarbans, India/ Bangladesh	Livelihoods, Institute of Environmental Studies and Wetland Management	Livelihoods, Danone Fund for Nature	6 000 ha	Voluntary Carbon Credits – VCS
Blue Forests Madagascar	Ambanja Bay, Ambaro Bays, Madagascar	Blue Ventures	Blue Ventures	26 000 ha	REDD+ or Plan Vivo

Instead, **voluntary markets are used as the funding mechanism, but there is potential for them to be included in the UNFCCC system through other mechanisms**. This will not be the case for all projects, and some will benefit from alternative finance mechanisms. Application of these finance mechanisms to support conservation and restoration of blue carbon ecosystems is an example of Payments for Ecosystem Services (PES), which includes payments for C storage and sequestration (Vanderklift et al. 2019b).

Other funding mechanisms for blue carbon ecosystems can be considered besides those associated with REDD+ and CDM. One such example is NAMAs (Nationally Appropriate Mitigation Actions), which is an **alternative UNFCCC mechanism** (Hermwille et al. 2017). NAMAs refer to any action that reduces emissions in developing countries and is prepared as part of national government initiatives. **NAMAs can be in the form of policies directed at transformational change within or across economic sectors.** In this way, NAMAs create flexibility in the types of projects that can be included for mitigation actions, including blue carbon ecosystems (Wylie et al. 2016). For example, the Dominican Republic has developed a NAMA for mangrove restoration (UNFCCC 2015). **The blue carbon NAMA concept is based on a capacity-building approach in support of public and private sector institutions to implement several key activities.** These include quantifying the C sink capacity, developing an inventory of C credits, facilitating a national dialogue, preserving or replanting mangroves, developing strategies to support economic development, managing finance mechanisms for key communities, and developing a tool kit that can be used by other countries in designing and implementing blue carbon NAMAs (Herr & Pidgeon 2011). **Coastal wetland-related NAMAs** have also been submitted by African countries, including Ghana and Sierra Leone (Chevallier 2012). **The Green Climate Fund (GCF) is another UNFCCC funding mechanism that is also available to be used for both adaptation and mitigation projects**, which is ideally suited for blue carbon ecosystem projects (IUCN 2015).

The review by Wylie et al. (2016) only included blue carbon projects that have been carried out in developing countries. **Examples from developed countries are less well known**, but two such projects are listed by the Blue Carbon Initiative, one in Australia (Tomago Wetland) and one in the USA (Herring River Estuary). Both of these projects are focused on restoration, and have not been carried out to generate blue carbon offset credits as yet. In the Tomago Wetland project, salt marsh was restored to a site that had been drained using an engineering approach to reinstate the tidal hydrology (https://www.wrl.unsw.edu.au/research/tomago-wetland-restoration-project). Ongoing monitoring at the site has shown **that tidal restoration reduced emissions of both CO_2 and methane** (Negandhi et al. 2019). In the Herring River Estuary project, a feasibility assessment is currently being carried out. This will **assess the market feasibility for developing a voluntary carbon offset project** at the site through the tidal restoration of salt marshes (https://nerrssciencecollaborative.org/resource/herring-river-carbon-project-feasibility-study).

A larger-scale study in Australia has been carried out to investigate **the potential for restoration of abandoned salt field operations into tidal marsh as a potential blue carbon offset project** (Dittmann et al. 2019). This project applied the VCS methodology for restoration of tidal marshes and was **able to meet the offset integrity standards** set out by the Australia Emissions Reduction Fund. This began as a conceptual project which then included an experimental component to examine how GHG emissions and removals changed over the course of the salt marsh restoration programme. The findings were then scaled to larger adjacent areas that could be restored using the same approach. The project demonstrated feasibility, but it has not as yet been implemented for blue carbon offsetting (https://www.environment.gov.au/water/wetlands/publications/wetlands-australia/national-wetlands-update-february-2020/tidal-reconnection).

1.4.4 Limitations for Blue Carbon Offset Projects

The realised potential of blue carbon offset projects can be constrained by multiple factors which are described by Vanderklift et al. (2019b):

1. Commercial considerations – reliable estimates of financial returns, risk quantification and management, supply chain demands;

2. Regulatory and legal uncertainty – complex property rights in coastal areas, policy coordination across jurisdictions, and the **dynamic policy landscape associated with blue carbon offsets**.

Besides these, there are also additional scientific limitations that will be variable between specific projects depending on available data. Kelleway et al. (2017) provided an overview of the uncertainties that remain in blue carbon science in relation to establishing emission reduction projects in Australia, but these are relevant for other regions, including South Africa:

1. Intra- and inter-ecosystem variability in C storage in blue carbon ecosystems makes it **difficult to develop robust estimates that can be scaled from local to regional and national scales**. However, the available data can be used to calculate C stocks for representative areas as long as the variability is acknowledged. In South Africa, data for C stocks are still being collected, but there are already extensive data for soil organic matter and vegetation biomass. These datasets can be used to examine the potential for variability in soil C and biomass C as these variables are closely related.

2. Spatial maps are not available for all blue carbon ecosystems and particularly for **seagrass ecosystems**. Although remote sensing tools can be used for mangroves and salt marshes, as seagrasses are subtidal the water depth and transparency influence what can be delineated from both satellite imagery and aerial photographs. In South Africa, spatial maps have been developed for all blue carbon ecosystem types using manual digitising verified with ground truthing. In this region, seagrass habitats are mostly intertidal and have been mapped.

3. Biogeochemical processes related to C cycling, fluxes of GHGs and the fate of **C_{org}** that occur in **natural and disturbed blue carbon ecosystems** require additional research so that the influence of these processes on C stocks can be fully understood. This is a rapidly developing area of blue carbon research globally. In South Africa, this area of blue carbon ecosystem research is also being developed and it is being carried out primarily by SAEON. As data from these projects become available, it can be incorporated to revise and update blue carbon sink assessments.

4. The presence of allochthonous C in blue carbon ecosystems complicates **accounting exercises** as there is the risk of **duplicating C sequestration gains** or **avoided emissions** from adjacent terrestrial ecosystems. Existing methodologies to determine the contribution of allochthonous C include both **stable isotope tracking** and **molecular genetic techniques**. This issue has been globally recognised within the

blue carbon research community and is currently an emerging research area. In South Africa, we have the capacity to undertake both stable isotope studies and molecular genetics techniques to identify the sources of C in blue carbon ecosystems. When these studies are carried out then this will inform the next steps for C stock estimations in these ecosystems.

5. The location of blue carbon ecosystems at the land-sea interface makes them vulnerable to changes that occur in the **catchment**. Connectivity between terrestrial and coastal ecosystems is complex but needs to be accounted for within **emissions reduction policies**. In South Africa, the 2018 NBA has highlighted the need for a catchment-to-coast approach to management of estuaries. This acknowledges the connectivity of these ecosystems.

6. Climate change has the potential to impact the functioning and integrity of blue carbon ecosystems, and thus influence the **C sequestration potential**. Dieback of vegetation can cause loss of C stocks and this can be exacerbated if there is also soil erosion.

The cause of dieback influences the fate of the C stored in the biomass pool. If the dead plant material remains in place, it could be incorporated into the soil C pool. However, if the vegetation is burnt or physically removed then C sequestration is completely removed. Sporadic or continuous climatic events related to global change (extreme events, reduced rainfall, higher temperatures, sea-level rise, mouth closure) are difficult to predict but need to be managed. In South African estuaries, the effects of different climate change impacts will be variable between the biogeographic regions and also between individual estuaries. Some preliminary modelling has shown that SLR could drive the expansion of salt marsh in warm-temperate estuaries that have available adjacent areas. In contrast, higher rainfall and extreme events such as sea storms are predicted to influence the subtropical east coast and these could have negative impacts on mangroves as a result of sediment scouring (floods), or closure of the estuary mouth (sea storm deposition of sediment).

1.5 SOUTH AFRICAN CONTEXT FOR BLUE CARBON MITIGATION OPPORTUNITIES

African countries have untapped potential to incorporate blue carbon into sustainable development goals and to fulfil their national and international commitments to emissions reductions as the continent supports 3.5 million hectares of mangroves, ~20% of the global total (Chevallier 2012). African mangroves occur along the western Atlantic, central Atlantic and eastern Indian Ocean coastlines of the continent. **Nigeria has the largest mangrove forests in Africa, followed by Mozambique** (Giri et al. 2011). In South Africa, mangrove **cover is less extensive and only represents ~0.05% of the African total area**; however, these ecosystems still have considerable biodiversity and socio-economic value and are therefore prioritised for conservation (Turpie et al. 2002, Adams et al. 2004, Traynor & Hill 2008, Naidoo 2016, Van Niekerk et al. 2019b). Including the area coverage of **salt marsh** and **seagrass** within **South Africa's blue carbon sink potential further increases their value**. These ecosystems therefore need to be incorporated into the national climate change **mitigation and adaptation strategies**.

1.5.1 Mitigation Opportunities from the National Terrestrial Carbon Sink Assessment

The South African National Terrestrial Carbon Sink Assessment (NTCSA) was carried out to examine terrestrial carbon stocks and fluxes at a national scale and to evaluate the climate change mitigation opportunities available to the AFOLU sector (DEA 2015b). For complementarity and to allow for direct comparisons, mitigation opportunities for blue carbon ecosystems in South Africa will **be contextualised in relation to those that have been identified for the AFOLU sector**. The NTCSA identified eight climate change mitigation opportunities, some of which had already been recommended in the National GHG Mitigation Potential Analysis report (DEA 2014). The NTCSA further used a stakeholder engagement process to assess requirements for scaling up successful interventions, and the Strategic Framework for the AFOLU sector further reinforced these mitigation opportunities.

The eight mitigation opportunities identified by the NTCSA for the AFOLU sector are:

1. Restoration of subtropical thicket, forests and woodlands;
2. Restoration and management of grasslands;
3. Commercial small-grower afforestation;
4. Biomass energy (woody biomass or bagasse);
5. Anaerobic biogas digesters;
6. Biochar production and application;
7. Reduced tillage;
8. Reduced emissions from degradation and deforestation.

The mitigation opportunities were categorised into timeframes **(short, medium and long term) over which they could be rolled out and implemented**. Additionally, the NTCSA also considered the relative social and environmental benefits of each opportunity. This was important as prioritisation of an opportunity is not driven solely by the climatic benefit, but also by the social and additional ecosystem co-benefits.

1.5.2 Applicable AFOLU Mitigation Opportunities for Blue Carbon Ecosystems

The AFOLU mitigation opportunities are not all directly transferable to blue carbon ecosystems as some attributes are unique to terrestrial agricultural ecosystems such as biomass generation, the use of biogas digesters, and the production and application of biochar. However, **AFOLU mitigation opportunities that are related to restoration, afforestation and reduced soil disturbance have the potential for application in blue carbon ecosystems**. This study has identified the mitigation actions that are relevant to blue carbon ecosystems, such as rehabilitation and restoration and avoided emissions from preventing drainage and degradation.

Restoration of blue carbon ecosystems has been shown to enhance C sequestration, although there is evidence of a lag time until soil C stocks are recovered (Negandhi et al. 2019, Sidik et al. 2019, Orth et al. 2020). **Terrestrial restoration approaches are focused on reconstruction or rehabilitation of degraded areas to restore ecosystem**

function to land that has been impacted by deforestation, land-use change and pollution (Lamb et al. 2005, Stanturf et al. 2014). However, these approaches can be challenging to adapt to restoration of coastal areas because of their complexity and connectivity with adjacent marine and terrestrial ecosystems (Waltham et al. 2019). **Offsite impacts, particularly in catchments** (such as catchment degradation, agricultural return flows and freshwater abstraction), need to be considered and incorporated into **restoration plans for coastal ecosystems** and this was highlighted in the need for a **catchment-to-coast plan** for estuaries in the recent NBA (Van Niekerk et al. 2019b).

Managing offsite impacts is not only important for the restoration of blue carbon ecosystems, but also for reducing or preventing degradation (Sheaves et al. 2014). **Nutrient management** in catchments and from urban areas should focus on reducing loads into blue carbon ecosystems, as seagrasses in particular are sensitive to **reduced water quality** (Adams 2016, Freeman et al. 2019). Water flow management is important to maintain **suitable salinity and water quality conditions** for blue carbon ecosystems and to ensure natural estuarine mouth dynamics (Whitfield et al. 2012, Van Niekerk et al. 2019a, Adams et al. 2020b). Management of sediment supply to **coastal zones** is also important for blue carbon ecosystems, as altered **flooding and associated sedimentation regimes** will directly impact these ecosystems. Excessive sedimentation can cause **dieback in seagrasses** and **mangroves** (Adams 2016, Mbense et al. 2016), but a reduced sediment supply can also lead to erosion, bank destabilisation and subsequent loss of blue carbon ecosystems and their C stocks (Marbà et al. 2015, Sapkota & White 2021). Reduced sediment supply impacts the ability of blue carbon ecosystems to respond to sea-level rise, thus decreasing their ability to serve as a **climate change adaptation measure** (Allison et al. 2017, Breithaupt et al. 2017, Schuerch et al. 2020).

Onsite mitigation activities for blue carbon ecosystems are focused on enhancing C sequestration and protecting existing C stocks from degradation. In line with AFOLU mitigation opportunities, reducing habitat loss (deforestation) and degradation can be directly applied to blue carbon ecosystems. **As the soil C is the most significant C pool, any activities that disturb the soil and sediments in blue carbon ecosystems should be avoided,** i.e., these ecosystems should not be cleared for developments. Land-use management and planning for blue carbon ecosystems and adjacent areas is therefore important for realising mitigation opportunities (Lovelock et al. 2017a, Sasmito et al. 2019). Certain land-use practices in mangrove and salt marsh ecosystems need to be altered to enhance C sequestration and avoid C stock losses. For example, **grazing by cattle reduces aboveground biomass and disturbs soil C through trampling** (Nolte et al. 2013, Hoppe-Speer & Adams 2015). Agricultural practices in these areas also directly influence soil C stocks and nutrient loads. **Land-use planning for adjacent areas is important, as these zones need to be available to allow upslope and upstream migrations of mangroves and salt marshes in response to sea-level rise** (Enwright et al. 2016, Borchert et al. 2018). The need for this has been demonstrated for South African salt marshes in the Knysna and Swartkops estuaries (Raw et al. 2020, 2021).

Small-scale afforestation was recommended as a mitigation opportunity for the AFOLU sector (DEA 2015b). **This activity can also be included in restoration plans for blue carbon ecosystems.** However, planting schemes that are not evidence-based do not result in successful restoration. For example, some mangrove restoration projects tend to prioritise short-term increases in seedling biomass over long-term establishment of functional mangrove forests with significant soil C stocks (Lee et al. 2019). It has been demonstrated that **mangrove**

ecosystems can be restored without the need for planting, and that natural regeneration will occur if natural hydrological and ecological conditions can be restored to the site (Kamali & Hashim 2011, Elliott et al. 2016). In contrast**, large-scale planting has been recommended for successful seagrass restoration projects** around the world (van Katwijk et al. 2016). Recent research therefore suggests that effective restoration of blue carbon ecosystems should incorporate the use of propagules in association with ensuring environmental conditions are suitable for establishment and long-term persistence (Vanderklift et al. 2020). **There is potential to include such approaches for mangroves within the South African REDD+ programme as it also considers the enhancement or conservation of C stocks.** The programme also allows activities to evolve over time, as long as there is still an accountable contribution towards emission reductions.

1.6 SOUTH AFRICAN CONTEXT FOR GHG EMISSIONS REDUCTIONS THROUGH EXISTING POLICIES AND MEASURES

As the application of C stocks and sequestration as climate change mitigation opportunities continues to grow, there are many stakeholders involved, including individuals, landholders, investment funds, non-governmental organisations (NGOs), large multinationals and governments (municipal, provincial, national and multinational). These stakeholders operate at different scales, and this creates a complex policy landscape which is dynamic across different jurisdictions and geopolitical boundaries. **Climate change mitigation and adaptation opportunities therefore present significant policy challenges.**

Three high-priority activities have been recommended for national governments to incorporate blue carbon priorities into climate mitigation actions (Herr & Pidgeon 2011):

1. Development of national blue carbon action plans that outline specific national circumstances, opportunities, needs and limits;
2. Conduct national scientific carbon, ecological and socio-economic assessments of blue carbon ecosystems;
3. Conduct national analyses of the costs and benefits of including blue carbon activities into national climate change mitigation strategies.

Blue carbon ecosystems can also be integrated into coastal management, climate response, biodiversity conservation and blue economy planning (PEMSEA 2017).

1.6.1 Key Policies and Measures from the National Terrestrial Carbon Sinks Assessment

To examine the existing policies and measures that may have an impact on reducing GHG emissions, enhancing climate change mitigation potential, and enhancing climate change resilience of blue carbon ecosystems in South Africa, the policy review conducted as part of the NTCSA was considered (DEA 2015b). As part of the NTCSA, 30 policies were identified as having the most influential impacts on C stocks and GHG emissions in the AFOLU sector. From these 30 policies, those identified as relevant to blue carbon ecosystems are presented in Table 1.4.

Policies focused on environmental management include the Acts and Regulations that are related to NEMA, as

well as Acts that aim to reduce negative impacts on ecosystems. Policies that are focused on undertaking prevention and mitigation for natural disasters (which could be related to climate change threats) are also relevant to blue carbon ecosystems. **Planning policies can be leveraged for potential land-use change activities**, particularly for spatial planning and to resolve competing land-use interests.

Key supporting legislation relevant to blue carbon ecosystems not identified by the NTCSA includes:

- National Water Act, 1998;
- Marine Living Resources Act, 1998;
- National Environmental Management: Integrated Coastal Management Act, 2008.

TABLE 1.4: KEY POLICIES IDENTIFIED BY THE NTCSA TO HAVE A SUBSTANTIAL IMPACT ON TERRESTRIAL C STOCKS AND FLUXES THAT ARE ALSO RELEVANT TO BLUE CARBON ECOSYSTEMS. SOURCED FROM DEA (2015B).

POLICY TYPE	POLICY NAME
White Papers	• White Paper on Disaster Management • National Climate Change Response White Paper
Acts	• Conservation of Agricultural Resources Act, 1983 • National Environmental Management Act, 1998 • National Environmental Management: Protected Areas Act, 2003 • National Environmental Management: Biodiversity Act, 2004
Regulations	• National Environmental Management: EIA Regulations • National Environmental Management: Framework Regulations
Bills	• Spatial Planning and Land-Use Management Bill
Strategies, Plans and Frameworks	• National Development Plan • Medium Term Strategic Framework • National Strategy for Sustainable Development and Action Plan • Strategic Plan for Environment Sector: 2009–2014 • National Biodiversity Framework • National Protected Areas Expansion Strategy for South Africa 2008 • Carbon Tax Policy Paper • National Disaster Management Framework

1.6.2 Carbon Tax, AFOLU Strategic Plan and Applications to Blue Carbon Ecosystems

The Carbon Tax Act 15 came into effect in June 2019. **Carbon taxes were implemented as part of South Africa's Paris Agreement pledge (NDC)**. The national emissions in 2025 and 2030 will be limited to 350–420 Mt CO_2e as per South Africa's updated NDC.

The carbon tax is expected to serve as an integral component in the national mitigation system for implementing government policy on climate change. This has been outlined in the National Climate Change Response Policy (NCCRP) and the National Development Plan (NDP). **The AFOLU 2016–2020 Strategic Plan therefore highlighted the need for a Measurement, Reporting and Verification (MRV) approach for the sector**, which was proposed to track, quantify and report on GHG emissions and impacts, as well as non-GHG impacts of emission reduction responses (DEA 2016b). The MRV is needed in the AFOLU sector so that C offsets can be quantified and utilised by entities with carbon-taxable activities in order to reduce tax liability under the carbon tax. **If blue carbon ecosystems are to be incorporated as part of an offset mechanism within the C tax, a similar approach for measuring, reporting and verifying will be required.** The MRV approach is intended to provide estimates of C sequestration and storage so that mitigation activities in the sector can be included towards the national transition towards a low-emission economy.

1.6.3 Highlights from the Low-Emission Development Strategy and Supporting Policies

South Africa's Low-Emission Development Strategy (SA-LEDS 2020) was developed in response to the Paris Agreement, with the document being submitted to the UNFCCC to **reiterate the nation's ambition towards achieving the goals of the Agreement**. The Strategy has also been designed so that **implementation will contribute both directly and indirectly towards meeting the Sustainable Development Goals** (SDGs). SA-LEDS (2020) is built from three climate-related policy documents: 1) National Development Plan (NDP), 2) National Climate Change Response Policy (NCCRP), and 3) Climate Change Bill.

The NDP has an overarching objective of eliminating poverty and reducing inequality by 2030, and it also outlines goals and actions for environmental sustainability and resilience (National Planning Commission 2012, SA-LEDS 2020). The NCCRP provides a comprehensive policy framework for climate change responses, including both adaptation and mitigation (SA-LEDS 2020). The Climate Change Bill is still forthcoming, but it is proposed to form the legislative foundation for climate change adaptation and mitigation responses (DEA 2018, SA-LEDS 2020). **The Climate Change Bill has the greatest potential to be leveraged towards mitigation opportunities** (for both the AFOLU sector and blue carbon ecosystems) as it will include determination of the national GHG emissions trajectory, sectoral emissions targets and the allocation of carbon budgets.

2. COMPILING A BLUE CARBON SINKS DATABASE FOR SOUTH AFRICA

The South African coastline has high wave energy, and this restricts blue carbon **ecosystems to occurring in sheltered estuarine areas**. The coastline is divided into **four biogeographic regions** (Figure 2.1), and these influence the distribution of blue carbon ecosystems across the country.

FIGURE 2.1: COASTAL BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA INCLUDE THE **COOL-TEMPERATE** WEST COAST, THE **WARM-TEMPERATE** SOUTH COAST AND THE **SUBTROPICAL** EAST COAST. THE 2018 NBA ADDITIONALLY RECOGNISES A **TROPICAL** REGION WHICH EXTENDS FROM CAPE VIDAL TO THE NATIONAL COASTAL BORDER WITH MOZAMBIQUE (VAN NIEKERK ET AL. 2019B).

2.1 COLLATION OF THE DATA FOR THE BLUE CARBON DATABASE

South Africa's blue carbon ecosystem spatial extent is currently hosted by the National Biodiversity Assessment (http://bgis.sanbi.org/Projects/Detail/192) (Van Niekerk et al. 2019b). The IPCC Blue Carbon Protocol (as described in Section 1) has been applied to collect data for soil and biomass C in South African blue carbon ecosystems from **four estuaries**: Knysna (34°4′57.74′S, 23°3′41.23′E), Swartkops (33°51′58.48′S, 25°37′58.96′E), Nahoon (32°59′11.18′S, 27°57′6.13′E) and Nxaxo/Ngqusi (32°35′5.03′S, 28°31′34.53′E). Estimation of national C stocks to include biogeographic variability is described in Section 3 of this report.

2.1.1 Characteristics of South African Blue Carbon Ecosystems

SEAGRASSES

Seagrasses are rooted vascular plants that are completely submerged below the water surface. **The main endemic species occurring in South Africa is *Zostera capensis*** Setchell, 1933 with the largest areas occurring in the Olifants, Langebaan, Groot Berg, Knysna, Keurbooms and Swartkops estuaries (Adams 2016). This species is adapted to growth under tidal conditions, and can tolerate periods of exposure, which enables it to occur across the lower intertidal and subtidal zones of permanently open estuaries (Adams 2016). This species has a broad salinity tolerance, ranging from 18 to 40, but it is sensitive to changes in hydrodynamics, sedimentation and water quality. The **distribution of *Z. capensis* is therefore dynamic, which creates challenges for mapping and assessing changes over time**. Entire beds can naturally be temporarily removed by flood events (Talbot et al. 1990, Adams 2016), while anthropogenic activities including bait digging and disturbance by boats cause degradation (Pillay et al. 2010).

The presence and abundance of seagrass beds signify water bodies with good water quality and rich biodiversity. *Zostera capensis* occurs along the southeast coast of Africa from South Africa to Kenya, yet despite its seemingly large global distribution the species occupies a very small area. Seagrass provides habitat in the form of substrate for epiphytes and periphyton and foraging and nursery areas for many fishes and invertebrates. Globally this seagrass is assessed as 'Vulnerable' by the IUCN, but in South Africa it qualifies as 'Endangered' based on the very small areas of occupancy, mapped to be between 11–13 km^2. It is **experiencing continued loss and degradation from extended estuary mouth closures, dredging, eutrophication, competition from invasive aquatic species and recreational disturbances**.

Other submerged plant species that occur in South African estuaries include ***Stuckenia pectinata*** (L.) Börner, 1912, and ***Ruppia cirrhosa*** (Petagna) Grande, 1918. However, these species do not tolerate salinity above 15 and are therefore found in brackish upper reaches towards the estuary head or in estuaries that close to the sea. Seagrasses and other submerged macrophytes provide a growth surface for epiphytic microalgae, which serve as a food source for invertebrates and fish (Nel et al. 2017). The beds also provide refuge habitat to small fish and benthic invertebrates such as mudprawns (Becker et al. 2012, Edworthy & Strydom 2016).

Eutrophication has been highlighted as an emerging threat to seagrasses in South African estuaries. Nutrient enrichment promotes growth of dense epiphytes and macroalgae which outcompete submerged macrophytes

(Viaroli et al. 2008). Blooms of filamentous green algae (e.g. *Cladophora* spp.) are therefore a sign of eutrophication, and these blooms have been associated with declines in *Z. capensis* area in the Groot Brak and Knysna estuaries (Nunes & Adams 2014, Human et al. 2016).

SALT MARSHES

Salt marsh ecosystems occur across all the biogeographic regions of the South African coastline. Salt marshes include herbs, grasses or low shrubs that occur from the intertidal zone to the terrestrial ecotone alongside saline water bodies (Adams 2020). Salt marshes are therefore exposed to periodic flooding from tidal or non-tidal variation in water level. In South Africa, **salt marshes are categorised based on their position within the tidal frame as: intertidal salt marsh (< 1.5 m MSL), supratidal salt marsh (1.5–2.5 m MSL) and floodplain salt marsh (> 2.5 m MSL)**. Although supratidal and floodplain marshes are seldom flooded, these areas support halophytic macrophyte communities and are therefore included as 'salt marsh' ecosystems. Floodplain salt marsh is often inhabited by terrestrial species as it forms part of the ecotone (Veldkornet et al. 2015b). Floodplain salt marsh relies on groundwater during dry months of the year to survive, but water table levels are linked to tidal rise and fall as well as the water level in the estuary. Short seasonal rainfall is important to recharge groundwater, reduce salinity and thereby allow the plants to grow and reproduce (Bornman et al. 2002).

Ecosystem mapping for South African estuaries **distinguishes between intertidal and supratidal salt marsh** as these zones support different biotic communities and respond differently to abiotic drivers (Adams et al. 2019). The **greatest salt marsh area is found in the Groot Berg Estuary, with other large areas occurring in the Langebaan, Olifants, Knysna and St Lucia estuaries**. At St Lucia, salt marsh area fluctuates in response to water level. The current (2021) high-level freshwater state has caused flooding of salt marsh and expansion of submerged macrophytes as well as reeds and sedges.

Salt marsh species with the widest distribution across South African estuaries include ***Bassia diffusa*** (Thunb.) Kuntze, ***Cotula coronopifolia*** L., ***Limonium linifolium*** (L.f.) Kuntze, ***Juncus kraussi*** Hochst., ***Phragmites australis*** (Cav.) Steud and ***Triglochin striata*** Ruiz & Pav (Adams 2020). These species occur in specific zones based on tidal inundation frequency if there is a distinct elevation gradient across the shore, otherwise they form mosaics (Figure 2.3).

Pressures in South African estuaries that impact salt marsh ecosystems include: restricted tidal exchange (O'Callaghan 1990), freshwater abstraction (Bornman et al. 2002), mining and windblown dust (Bornman et al. 2004), storm surges (Riddin & Adams 2010), estuary mouth closure and associated increase in water level (Riddin & Adams 2019), eutrophication (Nunes & Adams 2014), spread of invasive plants (Adams et al. 2012, Riddin et al. 2016), and livestock browsing and trampling (Adams 2020). **Approximately 43% of salt marsh area in South Africa has been lost due to encroaching development and agriculture since the 1930s** (Adams 2020).

MANGROVES

Mangroves are woody trees and shrubs that occur within the tidal frame at the interface between land and sea along **tropical and subtropical coasts**. The optimum air temperature for mangroves therefore ranges from 5–20°C (Duke et al. 1998, Tomlinson 1999). **In South Africa, mangroves occur at one of the southernmost locations in the world** and are found within estuaries along the tropical, subtropical and warm-temperate bioregions. The dominant species are ***Avicennia marina*** (Forssk.)

FIGURE 2.2: INTERTIDAL ZOSTERA CAPENSIS EXPOSED AT LOW TIDE ADJACENT TO SALT MARSH IN THE KNYSNA ESTUARY (TOP) AND MANGROVES IN THE MNGAZANA ESTUARY (BOTTOM). (PHOTOS: J ADAMS)

FIGURE 2.3: SALT MARSH PLANTS OCCUR IN DISTINCT ZONES ALONG A TIDAL INUNDATION GRADIENT (KNYSNA ESTUARY) (TOP), OR AS MOSAICS (LANGEBAAN ESTUARY) (BOTTOM). (PHOTOS: J RAW – TOP AND J ADAMS – BOTTOM)

FIGURE 2.4: MANGROVES ASSOCIATED WITH TIDAL CREEKS. TOP: *AVICENNIA MARINA* AT THE NXAXO ESTUARY, BOTTOM: *BRUGUIERA GYMNORRHIZA* AT THE UMLALAZI ESTUARY. (PHOTOS: J ADAMS – TOP AND J RAW – BOTTOM)

Vierh., ***Bruguiera gymnorrhiza*** (L.) Lamk., and ***Rhizophora mucronata*** Lamk. Three additional species, ***Ceriops tagal*** (Perr.) C.B. Robinson, ***Laguncularia racemosa*** (L.) C.F. Gaertn., and ***Xylocarpus granatum*** König occur in the Kosi Estuary, located in the tropical biogeographic region.

Mangroves have been recorded in **34** estuaries along the South African coastline, with the largest coverage in the uMhlathuze Estuary (Adams & Rajkaran 2021). Other large mangrove areas are found in the St Lucia and Mngazana estuaries. Pressures faced by mangrove ecosystems in South Africa include: coastal development (Bruton & Appleton 1975, Rajkaran & Adams 2011), harvesting for building material and firewood (Adams et al. 2004, Rajkaran & Adams 2010), livestock browsing and trampling (Hoppe-Speer & Adams 2015), restricted tidal exchange (Hoppe-Speer et al. 2013, Adams & Human 2016), freshwater abstraction (Mbense et al. 2016), heavy metal pollution (Naidoo et al. 2014), oil pollution (Naidoo et al. 2010) and eutrophication (Geldenhuys et al. 2016).

2.2 CONSOLIDATION OF SPATIAL DATA TO MAP THE DISTRIBUTION OF CARBON STOCKS AND FLUXES

This blue carbon sink assessment was built from the spatial extents of blue carbon ecosystems that formed part of the **2018 NBA Estuarine Realm Technical Report** (Van Niekerk et al. 2019b, 2020). This report focuses on the state of estuarine biodiversity in South Africa and forms part of the National Biodiversity Assessment (NBA). This is a collaborative effort to synthesise the best scientific information available on biodiversity in the country. The NBA includes an assessment of biodiversity status, trends, responses to management challenges, and benefits of biodiversity to society. The Estuarine Realm report included **classification of estuarine ecosystems, delineation of estuaries in alignment with national ecosystem classifications for development of coastal maps**, spatially mapping estuaries (and associated coastal habitats) and determining ecosystem threat status according to the IUCN criteria (Van Niekerk et al. 2019b).

As part of the current project, **new additional spatial data were consolidated into a 2021 GIS database**. The metadata for this database are presented in this report as Appendix I. It includes the estuary name, estuary type, macrophyte habitat, date and source of information, as well as the area (ha) of the habitats. 'Developed' and 'Degraded' land cover categories were classified into the type of development, for example agriculture (sugar cane), or residential area, where it was possible to ascertain what the development was from available data sources. **Developed areas are essentially those with hard structures** like roads, railways, residential and industry; structures unlikely to be removed in the future. **Degraded areas are where biodiversity has been lost due to an activity such as being grassed, or by gravel roads**. These often include fallow lands and old fields. **Because of the lack of hard structures, these areas represent potential restoration sites in the future.** For the 'Developed' and 'Degraded' areas, the natural ecosystem that was lost or replaced was also included. These **estimates were based on assessment of the earliest available aerial imagery** (usually 1930s and 1940s) to see what the original ecosystem was prior to development. The adjacent natural habitat (polygons) was also used as an indication of what the original natural ecosystem might have been. **Both these fields then provide an estimation of the historical extent of blue carbon ecosystems and what has been lost.**

In addition to this, the **historical areas** of the blue carbon ecosystems, the years these were mapped and their source have been collated into a database. The **present ecosystem area was checked against all published data to confirm the presence of stands/habitat extent over**

time (Adams 2016, 2020, Phair et al. 2020, Adams & Rajkaran 2021). The estuaries were also visually checked on the most recently available Google Earth imagery to verify if the habitat was still present. Mangroves, salt marsh and seagrass can be visually identified and mapped using this imagery. **Approximately one-third of all estuaries have GIS spatial data of 488 coastal rivers or streams** – estuaries (290), micro-estuaries (42) and coastal seep/outlets (156) listed in the 2018 NBA, i.e., there are 367 unmapped outlets to the coast.

2.2.1 Data Gaps and Proposed Approach to Address Them

Spatial data gaps identified from the 2018 NBA Estuarine Realm Technical Report were filtered using a three-pronged approach:

1. Blue carbon ecosystem area above 10 ha;
2. Estuaries with no spatial data but have extent data recorded in literature;
3. Estuaries with spatial data older than 10 years.

Table 2.1 lists those estuaries that were prioritised for mapping using this approach.

Many estuaries contain **teal carbon ecosystems and these should be mapped in the future as these ecosystems are important for C storage**. However, this was beyond the scope of the current project. For example, the Verlorenvlei Estuary has 683.98 ha of **reeds and sedges that form important peat wetlands** (Van Niekerk et al. 2019b, 2020). Peat wetlands are characterised by the accumulation of organic matter (or peat) derived from dead and decaying plant material under conditions of permanent water saturation (Van Vuuren 2010, Faul et al. 2016). This organic matter comes from the vast expanse of vegetation surrounding the lake, which appears to have been present since the Holocene period (Meadows & Baxter 2001).

TABLE 2.1: ESTUARIES WITH BLUE CARBON ECOSYSTEM AREA > 10 HA, WITH OLD DATA (> 10 YEARS) OR MISSING SPATIAL MAPS DATA BUT LISTED IN THE LITERATURE. THESE ESTUARIES WERE PRIORITISED FOR UPDATING THE EXISTING ESTUARINE ECOSYSTEM DATASET. ALL ESTUARIES CONTAINING MANGROVES WERE INCLUDED, REGARDLESS OF SPATIAL EXTENT.

ESTUARY NAME	OLD DATA	MISSING SPATIAL DATA
Bira (Bhirha)		X
Bot/Kleinmond	X	
Breede	X	X
Bulungula		X
Cefane		X
Cintsa		X

ESTUARY NAME	OLD DATA	MISSING SPATIAL DATA
Gamtoos	X	X
Goukou	X	
Gouritz	X	X
Gqunube		X
Great Kei		X
Groot Berg	X	
Gxulu		X
Heuningnes	X	X
Kariega	X	X
Keiskamma	X	X
Klein	X	X
Kleinmond Wes		X
Kobonqaba (Khobonqaba)	X	
Kowie	X	X
Krom (Oos)		X
Kwelera (Kwelerha)		X
Langebaan	X	
Mbashe	X	
Mdumbi		X
Mgwalana		X
Mngazana	X	X
Mngazi		X
Mntafufu	X	

ESTUARY NAME	OLD DATA	MISSING SPATIAL DATA
Mnyameni	X	
Mpekweni		X
Mtakatye	X	
Mtana	X	
Mtata	X	X
Mtati (Mthathi)		X
Mtentu	X	
Mzamba	X	
Mzimvubu	X	
Mzintlava	X	
Nqabara/Nqabarana	X	
Nxaxo/Ngqusi	X	
Qinira (Quinirha)		X
Qora (Qhorha)		?
Richards Bay	X	X
St Lucia	X	
Sundays	X	X
Tyolomnqa	X	
uMthavuna	X	
Verlorenvlei	X	
Xora	X	X

2.2.2 Fluxes in Blue Carbon Ecosystem Area Coverage

Blue carbon ecosystems experience natural variability as well as losses through human impact, which are represented as land-use cover changes. Areas denoted as 'Developed' in the geodatabase are considered transformed and are unlikely to be rehabilitated back to natural land cover as the habitat has been completely removed and replaced with hard infrastructure. Areas classified as 'Degraded' are those where revegetation or restoration to natural land cover is possible, i.e., grassed recreational areas that could be converted back to supratidal or floodplain salt marsh given the correct environmental requirements. **Separation of the 'Developed' and 'Degraded' with restoration potential is also relevant to the spatial planning of Protected Areas, Critical Biodiversity Areas and Ecological Support Areas for South Africa (planned for 2021/2022).**

The National Botanical Database (Opus at SANBI: NBA 2018: Mapped estuarine habitat in South Africa) lists historical data and the source of this information. These data have been collated from various research projects and estuarine flow requirement studies (Adams et al. 2016a, 2016b). **Within the database, very few estuaries have been mapped at multiple points in time**; this makes it difficult to compare changes over a defined temporal period. **For blue carbon ecosystems, the cause of declining area is relatively well documented.** Three recent papers summarise area change across South Africa for seagrass (Adams 2016), salt marsh (Adams 2020) and mangroves (Adams & Rajkaran 2021).

NATURAL VARIABILITY IN BLUE CARBON ECOSYSTEM AREA COVERAGE

Estuarine habitats undergo natural variability in response to mouth state, water level, floods and salinity (Whitfield et al. 2008, Riddin & Adams 2012). This is particularly evident in Estuarine Lakes and Temporarily Closed Estuaries, where ambient water level determines the extent of available habitat. **Maps of these estuaries generated at any one point in time may either under- or overestimate blue carbon ecosystem area cover.** It must be noted that the blue carbon databases therefore represent a 'snapshot' or moment-in-time of the area cover.

To illustrate how this variability in area can affect a blue carbon assessment, the Klein Estuary was mapped under various water level scenarios, where changes of up to 2.5 m can take place due to mouth state (Box 3, Figure 2.5).

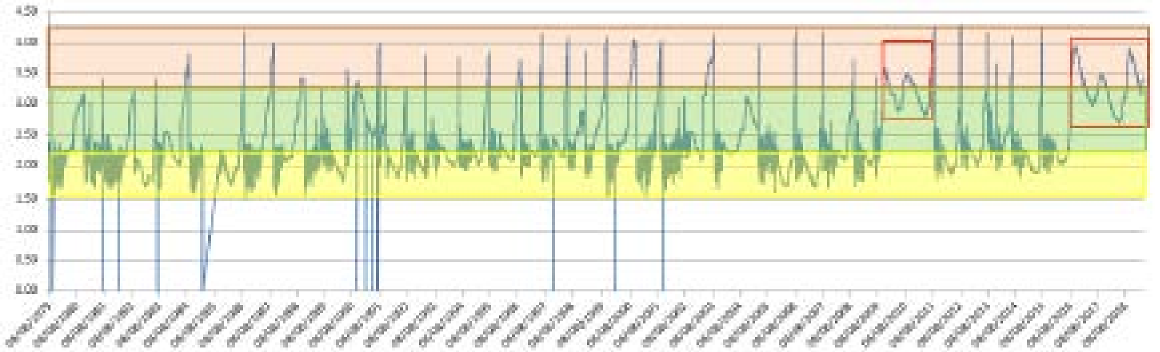
Changes in blue carbon ecosystem area occur in response to salinity and water level (Figure 2.5). In another example, at the Swartvlei Estuary in 2007**, increased salinity resulted in a 99% loss of submerged macrophytes**. In this case the mouth breached in response to a rainfall event, but this was coupled with drought conditions which further exacerbated the increase in salinity (Russell & Randall 2017). The average salinity (usually 5–12) increased to 27.6 during the 775 days over which the estuary remained open after the breach. *Zostera capensis* can therefore vary in extent from 0 to 91.42 ha depending on ambient salinity.

BOX 3: Water Level Variability Impacts Blue Carbon Ecosystems in the Klein Estuary

In the Klein Estuary, low water levels (< 2.2 m MSL) are associated with the expansion of salt marsh as previously flooded islands and deltas become exposed. Submerged macrophytes develop in the shallow areas, with reeds and sedges extending into previously flooded pans.

If the mouth remains closed, the water level increases and this leads to loss of salt marsh, while submerged macrophytes expand into newly flooded peripheral areas of the lake to reach a maximum area. Once the mouth breaches, the large beds become exposed and there is dieback of the vegetation and associated fauna. The reed *Phragmites australis* also exhibits natural winter dieback that could affect C stocks in the systems. Under prolonged mouth closure (> 2 years), submerged macrophytes as well as reeds and sedges become limited by depth as they only occur in water less than 2 m deep.

These habitat fluxes can account for a change of as much as 150 ha in blue and teal carbon ecosystems.



Historical water level readings for the Klein Estuary. Yellow = water level at which salt marsh mainly occurs, some submerged macrophytes and reeds (< 2.2 m MSL); Green = predominantly submerged macrophytes occur (2.2-3.2 m MSL); Orange = submerged macrophytes and reeds completely dominant (> 3.2 m MSL). Red boxes indicate periods of longer mouth closure due to drought.

Area of blue carbon and teal carbon ecosystems in the Klein Estuary in response to changing water levels.

	LOW (< 2.2 M MSL)	INTERMEDIATE (2.2-3.2 M MSL)	HIGH (> 3.2 M MSL)	FLUX
Submerged macrophytes	112.6	260.4	174.9	147.8
Salt marsh	163	41.9	11.5	151.5
Reeds & sedges	97.8	70.8	76.2	27
Total carbon habitat	373.6	373.1	262.6	

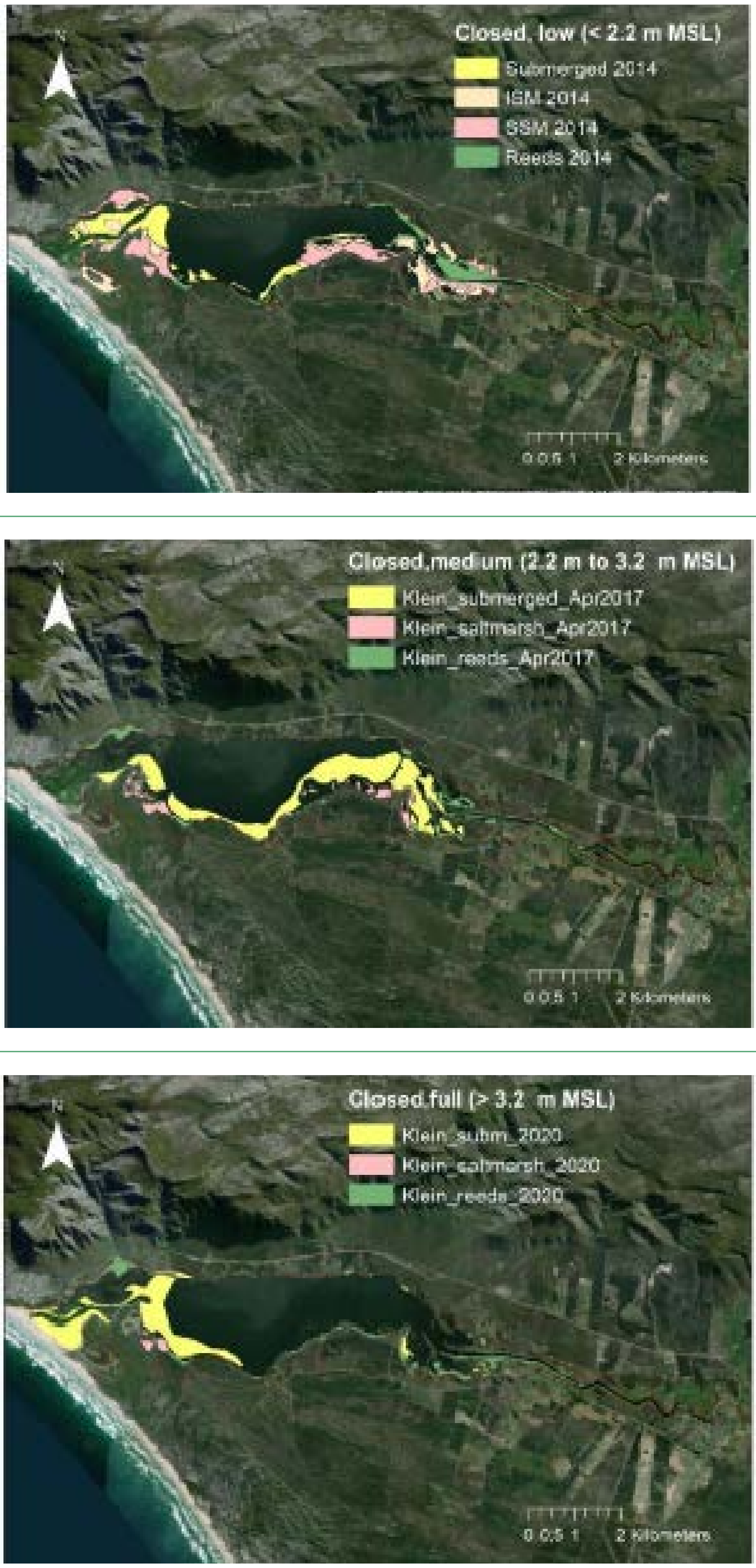


FIGURE 2.5: CHANGES IN BLUE AND TEAL CARBON ECOSYSTEM AREAS IN THE KLEIN ESTUARY IN RESPONSE TO CHANGES IN WATER LEVEL.

The St Lucia Estuarine Lake provides another example of how **large environmental changes influence the distribution and area coverage of blue and teal carbon ecosystems**. Extended mouth closure in combination with high freshwater input led to the dieback of mangroves and the expansion of the reed *P. australis* in the lower reaches of the estuary (Figure 2.6). Similarly, depending on the conditions of the mouth, the area of the seagrass *Z. capensis* has been reported to vary from 181–432 ha to being completely absent during periods of low water level, drought, and hypersalinity (Adams 2016, Lück-Vogel et al. 2016). The estuary was artificially opened to the sea in January 2021 but has remained fresh and turbid, thus restricting seagrass colonisation.

Similar to the estuarine lakes, the **temporarily closed estuaries also experience changes in the area of blue carbon ecosystems**. Salt marsh is associated with open-mouth, tidal conditions, as well as closed-mouth conditions when the water level is low. **A shift to submerged macrophytes (mainly *Ruppia cirrhosa* and *Stuckenia pectinatus*) occurs if the mouth remains closed and water level is high** (Riddin & Adams 2012). Although the salinity under these conditions is too low for the development of seagrass, the *R. cirrhosa* and *S. pectinatus* beds provide important refuge and nursery areas for juvenile fish and associated fauna (Whitfield 2017). In 2017, the West Kleinemonde Estuary breached following heavy rainfall after being closed for 25 months.


2016

2019

Mangroves healthy. St Lucia and iMfolozi with separate mouths.

Dieback of mangroves (brown).


2010/2011

2019

Little reed growth.

Extensive reed growth due to long closed-mouth period with freshwater conditions.

FIGURE 2.6: CHANGES IN BLUE CARBON ECOSYSTEMS IN THE ST LUCIA ESTUARY IN RESPONSE TO WATER LEVEL AND SALINITY VARIATIONS.

This caused a mass mortality of fish and associated fauna, which were trapped in exposed *R. cirrhosa* beds following breaching (Whitfield & Cowley 2018) (Figure 2.7). Under closed conditions, these beds can cover an area of up to 90.7 ha.

The area of blue carbon ecosystems can also change in response to floods and the associated effects of scouring and sediment deposition. In the Kariega Estuary, floods in 2012 resulted in the near-complete loss of *Z. capensis* beds (Wasserman et al. 2020). However, by the end of 2015 these beds had recovered to pre-flood extent. However, **recovery is not always to the same extent as before the flood event**, as observed in the Nahoon and Kwelera estuaries following floods in 1985. The expected return of *Z. capensis* beds 4.5 years after the floods did not occur; rather, *Halophila ovalis* colonised the lower reaches (Talbot et al. 1990). Slow post-flood recovery has also been recorded for *Z. capensis* in the Swartkops Estuary after floods in 1984 (Talbot & Bate 1987, Adams et al. 2016b). This slow or incomplete recovery is potentially related to removal of propagules with the scouring out by floods, or because of burial of propagules as sediment is brought down by floods or through deposition by sea storms. Studies have shown that **burial by as little as 1 cm/month can result in a 50% biomass loss in some *Zostera* species** (Henderson & Hacker 2015). This is because germination mostly takes place in the top 2 cm in *Zostera* species (Jørgensen et al. 2019). It can also take time for sediment substrate to re-establish in less sediment-rich catchments (decadal-scale depositional cycles observed at the Nahoon Estuary), while in sediment-rich catchment pre-flood equilibrium can be achieved in a less than a year.

Overall, macrophytes tend to respond quickly (days to weeks) to changes in driving physical factors such as salinity, water-level and flooding conditions.

LAND-USE COVER CHANGES ASSOCIATED WITH BLUE CARBON ECOSYSTEMS

The blue carbon geodatabase collated for this project includes **information on the loss of these ecosystems and the human activities that have caused these losses** – indicated by the fields 'Developed' and 'Degraded' in the database. In some cases, trends of losses or increases have been indicated through historical imagery assessment. The available historical images mostly date back to the 1930s and 1940s (used as the baseline for the National Ecosystem Account for estuaries by Van Niekerk et al. (2020)). The **distribution**

FIGURE 2.7: CHANGES IN SUBMERGED MACROPHYTE AREA FOLLOWING A BREACHING EVENT IN THE WEST KLEINEMONDE ESTUARY IN 2017. WHITE CIRCLE INDICATES RUPPIA CIRRHOSA BEDS.

of blue carbon ecosystems in historical images can then be compared to the distribution today (derived mostly from satellite imagery) and land-use change is identified where possible. Some estuaries have assessments for additional years in between the first images and the most recent ones, which are useful for examining trends (Table 2.3). **Currently, historical changes in blue carbon ecosystem area due to specific climate change drivers (such as sea-level rise) have not been incorporated** as research has focused on the projected future impacts of these, but only at the scale of individual estuaries (Yang et al. 2014, Raw et al. 2020, 2021).

For the blue carbon geodatabase, land cover change categories were defined as 'Developed' and 'Degraded'. Their alignment to the National Land Cover Classes is shown in Appendix II.

In many estuaries along the former Ciskei and Transkei coast, **agricultural incentives occurred in the floodplain salt marsh and adjacent terrestrial areas** in the 1950s and 1960s (Kirsten et al. 2007). These activities were later abandoned, leaving large sections fallow. **There is potential for these areas to be rehabilitated and restored to estuarine habitat.** For example, in the Keiskamma Estuary in the 1950s large areas of floodplain salt marsh were converted into agricultural land as part of a government land tenure programme. Colloty et al. (1999) showed a **70% loss of salt marsh for the entire Keiskamma Estuary, from 522.1 ha in 1939 to 301.6 ha in 1996**. These lands were abandoned in the 1970s and are now fallow floodplain with many invasive plants. Figure 2.8 shows the extent of agriculture in the lower reaches in 1954 compared to 2018 Google Earth imagery. The width of the water channel has also decreased over time, likely due to stabilisation of the estuary banks due to this agricultural development (Ribbink 2012). Coastal forest around the mouth of the estuary has also increased with time compared to earlier aerial photographs. Seagrass area has declined over time due to increased sedimentation associated with catchment degradation.

Similar abandoned agricultural lands are also present in the Great Fish Estuary. In 1955, extensive areas of the floodplain were used for agricultural activities, but these are now fallow lands that are mainly used for livestock (cattle, sheep and goats) ranching, while some of the low-lying floodplain areas along the banks of the river and estuary have been cultivated (mostly maize).

These abandoned agricultural fields often show partial recovery of natural land cover and thus are high-priority areas for restoration moving forward.

TABLE 2.3: ESTUARIES WITH HISTORICAL IMAGERY AND SPATIAL DATA THAT CAN BE USED TO ASSESS CHANGES IN AREA OF BLUE CARBON ECOSYSTEMS OVER TIME AND LOSSES OF THESE ECOSYSTEMS DUE TO LAND-USE CHANGE.

ESTUARY NAME	HISTORICAL AERIAL ASSESSMENTS
Orange	1937; 1997
Olifants	1942; 2003
Groot Berg	2007
Langebaan	1960; 2010
Klein	1938; 1980; 2006; 2014
Heuningnes	2007
Breede	1942; 1981; 1989; 2000
Duiwenhoks	1942; 2009
Goukou	1942; 2014

ESTUARY NAME	HISTORICAL AERIAL ASSESSMENTS
Gouritz	1942; 2014
Hartenbos	1940; 2014
Klein Brak	1940
Touw/Wilderness	1978
Knysna	1942
Noetsie	2005
Keurbooms	1936
Bloukrans	2010
Seekoei	1990
Swartkops	1939; 2000; 2008
Bushmans	1942; 1966; 1973; 1990
Kowie	1942
Great Fish	1956
Nahoon	1966; 1970; 1978; 1989; 1999; 2004; 2007; 2011
Kobonqaba	1982; 1999; 2012
Nxaxo/Ngqusi	1982; 1999; 2012; 2018
Nqabara/Nqabarana	1982; 1999; 2012

ESTUARY NAME	HISTORICAL AERIAL ASSESSMENTS
Mbashe	1982; 1999; 2012
Xora	1978; 1982; 1999; 2012
Bulungula	1978; 1982; 2000; 2012
Mtata	1982; 1999; 2012
Mdumbi	1982; 1999; 2012
Mtakatye	1982; 1999; 2012
Mngazana	1961; 1974; 1982; 1999; 2001; 2012
Mzimvubu	1982; 1999; 2012
Mntafufu	1982; 1999
Mzintlava	2008
Mtentu	1982; 2000; 2012
Mnyameni	1982; 1999; 2012
uMthavuna	1999; 2012
uMkhomazi	1982; 1999; 2012
uMvoti	1937
St Lucia	1937; 1960; 2001; 2008; 2013

FIGURE 2.8: AGRICULTURAL PRACTICES IN THE LOWER REACHES OF THE KEISKAMMA ESTUARY IN 1954 (TOP) HAVE SINCE BEEN ABANDONED, RESULTING IN DEGRADATION BY 2018 (BOTTOM).

MAPPING METHODOLOGIES INFLUENCE ECOSYSTEM EXTENT ESTIMATES

Advances in technology over time have improved the delineation and accuracy of mapping blue carbon ecosystems. **Improved resolution of satellite imagery, and imagery derived from unmanned aerial vehicles (such as drones) can result in more reliable spatial data products**. It is therefore important to note that older ecosystem maps may have larger uncertainty, particularly when the areas are relatively small or difficult to differentiate from each other. However, remote sensing is still not very accurate for habitat mapping in South African estuaries because of the small sizes of the areas covered by salt marshes, mangroves and seagrasses. Newer methods to improve the delineation of blue carbon ecosystems include the use of LiDAR data, which are unfortunately not available for the entire coastline. A 2.5 m contour for the habitat maps is needed for future mapping and better delineation of areas.

2.3 CONSOLIDATION OF EXISTING DATASETS FOR BLUE CARBON INTO A NATIONAL LAND COVER GIS FORMAT

All existing and new spatial data have been collated into a geodatabase and a corresponding numerical dataset. **A total of 138 estuaries now have spatial data for associated blue carbon ecosystems** (36 additional since the NBA 2018), although the EFZ may still have missing spatial data (e.g. for terrestrial floodplain areas). The floodplain areas typically occur above the 2.5 m above msl contour line . This was not included in earlier estuary mapping as the EFZ has only recently been extended to the 5 m contour line. Not all floodplain was mapped, only that extent where habitat was lost. **Blue carbon ecosystems cover 19 838.8 ha in South Africa** (Table 2.4, Figure 2.9), while teal carbon ecosystems (reeds and sedges) contribute an additional 17 654.9 ha (Table 2.4).

TABLE 2.4: AREA (HA) OF BLUE CARBON AND TEAL CARBON ECOSYSTEMS DISTRIBUTED OVER THE FOUR COASTAL BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA. SG = SUBMERGED MACROPHYTES; SM = SALT MARSH; MN = MANGROVES; RS = REEDS AND SEDGES.

ECOSYSTEM TYPE	COOL TEMPERATE	WARM TEMPERATE	SUBTROPICAL	TROPICAL	TOTAL
SG	667.2	1 218.9	492.9	660.3	3 039.4
SM					
(Intertidal)	2 476.5	1 418.9	217.4	58.0	4 170.8
(Supratidal)	6 611.7	2 570.3	1 131.1	229.0	10 542.0
MN	-	35.0	1 980.7	71.0	2 086.7
Total	**9 755.4**	**5 243.0**	**3 822.1**	**1 018.4**	**19 838.8**
RS	3 952.6	2 608.0	10 850.3	244.0	**17 654.9**

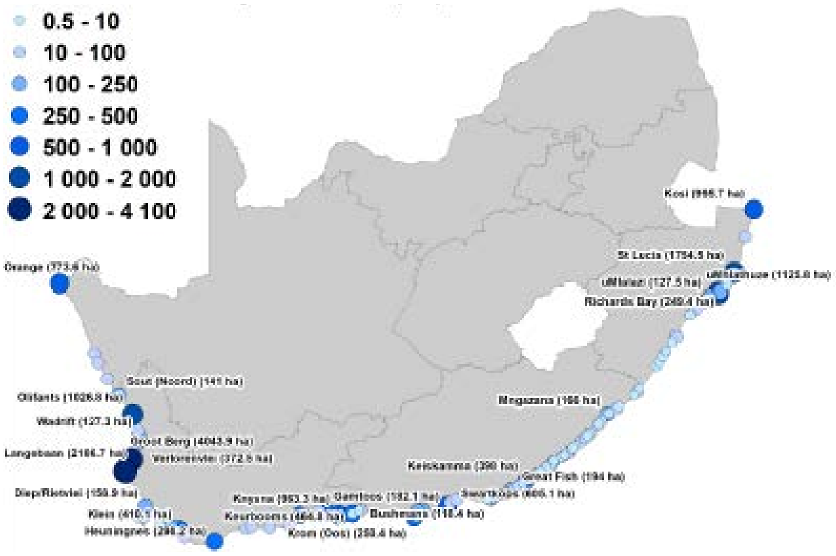


FIGURE 2.9: DISTRIBUTION OF BLUE CARBON ECOSYSTEMS ALONG THE SOUTH AFRICAN COASTLINE. ONLY ESTUARIES WITH COMBINED MANGROVE, SALT MARSH AND SUBMERGED MACROPHYTE AREA > 100 HA ARE LABELLED ON THE MAP.

Supratidal salt marsh is dominant in both the cool-temperate (6 611.7 ha) and warm- temperate biogeographic regions (2 570.3 ha) (Table 2.4). Most of the largest salt marsh areas are also found in these regions (Figure 2.10), with the exception of the St Lucia and Kosi estuaries.

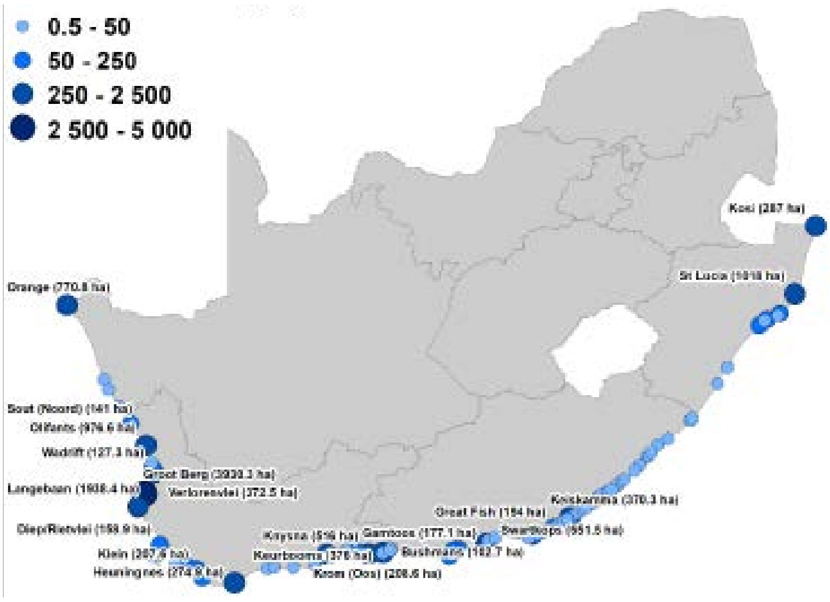


FIGURE 2.10: DISTRIBUTION AND AREA COVERAGE OF SALT MARSH IN SOUTH AFRICAN ESTUARIES. ONLY ESTUARIES WITH AREA > 100 HA ARE LABELLED ON THE MAP.

Mangroves are restricted to the subtropical region of South Africa, with a few estuaries in the warm-temperate region also supporting this ecosystem type (Figure 2.11). Present mangrove extent is 2 086.7 ha recorded for 34 estuaries in the country. uMhlathuze Estuary supports the largest mangrove area (1 087 ha), followed by St Lucia Estuary (305 ha).

FIGURE 2.11: DISTRIBUTION AND AREA COVERAGE OF MANGROVES IN SOUTH AFRICAN ESTUARIES. ONLY ESTUARIES WITH AREA > 5 HA ARE LABELLED ON THE MAP.

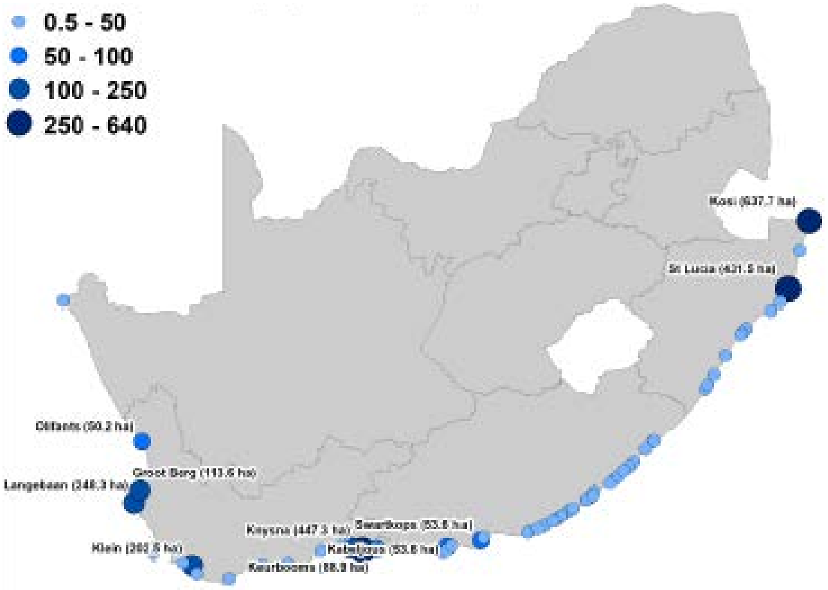


FIGURE 2.12: DISTRIBUTION AND AREA COVERAGE OF SUBMERGED MACROPHYTES IN SOUTH AFRICAN ESTUARIES. ONLY ESTUARIES WITH AREA > 50 HA ARE LABELLED ON THE MAP.

At present, only **78 estuaries support submerged aquatic vegetation** as these species are sensitive to changes to water level, turbidity, nutrients and salinity (Figure 2.12). *Zostera capensis* occurs in 37 estuaries. **Estuarine lakes provide the most suitable conditions for establishment and the largest areas are found in this scarce estuary type.** The largest area of the seagrass *Z. capensis* occurs in a 637.7 ha area in the Knysna Estuary. This seagrass has been completely lost from both the Durban Bay and St Lucia estuaries. These seagrass meadows experience extreme fluctuations in size, due to the dynamic changes in cover abundance in response to floods, droughts, sedimentation and freshwater abstraction. Recent and ongoing studies regarding the blue carbon potential of this species are improving our understanding of its dynamics and providing more detailed distribution maps.

2.4 COLLATION OF ANCILLARY DATASETS AND STRATIFICATION APPROACHES

To maximise the effectiveness of the proposed blue carbon sink assessment for South Africa, the available resources need to be considered. The **ideal geographic area of interest for a national assessment would include all mangrove, salt marsh and seagrass ecosystems**. However, it is not logistically feasible to conduct detailed field studies and C sampling for every estuary. Therefore, the **recommended approach is to use the available data from the four estuaries with detailed assessments** (Knysna, Swartkops, Nahoon, Nxaxo), and **scale it accordingly based on available spatial extents** for a national blue carbon sink assessment. Carbon stocks can be extrapolated for other areas based on biogeographic region – this has been demonstrated in similar ecosystems in Australia (Serrano et al. 2019). This approach has been documented and applied in Section 3.

A **stratification approach has been used to map the prioritised estuaries** so that separate spatial areas are defined for each blue carbon ecosystem. Stratification was carried out by visually examining Google Earth satellite imagery and using expert knowledge to differentiate between the different blue carbon ecosystems.

In line with the occurrence of blue carbon ecosystems, the **EFZ shapefiles for individual estuaries are used to delineate the ecosystem boundaries to the 5 m contour**. These shapefiles were derived from the 2018 Estuarine Ecosystem Map – Biodiversity BGIS (sanbi.org). Estuaries were mapped on an individual basis. This is because habitat is closely linked to estuary type, mouth state, elevation, estuary geomorphology and biogeographic region. Orthorectified digital imagery (50 cm resolution) was obtained from http://www.cdngiportal.co.za/cdngiportal/. The most recent images are 2015 and therefore Google Earth satellite imagery (2021) assisted with present-day extent. Manual mapping using ArcGis 10.6.1 was done on an average scale of 1:2000 and was therefore time consuming; the Groot Berg alone took over 75 hours to map. This **fine-scale mapping is preferred over the traditional supervised and unsupervised classification methods using satellite imagery because habitat is often only a few m^2 in extent**. A trained expert is also recommended as differentiation based on colour, texture and pixel density is required to identify habitat. Figure 2.13 shows how blue carbon ecosystems are identified in images for mapping.

Older satellite imagery, as well as historical data and maps, can be used for comparison and to examine changes in blue carbon ecosystem areas over time. In Figure 2.14, historical Google Earth images helped identify intertidal salt marsh in the Cefane Estuary. These

The seagrass Zostera capensis shows as black in the water body, as shown in the lower reaches near the marina in the Kromme (Oos) Estuary.

Intertidal salt marsh (orange hatch) in the lower reaches of the Swartkops Estuary. Habitat appears darker in colour due to the regular inundation with water.

Supratidal salt marsh (*Juncus kraussii*) in th uMlalazi Estuary. Appears above intertidal salt marsh and mangroves.

Mangroves appear as continuous stands in the uMlalazi Estuary. They can, however, be confused with Coastal and Swamp Forest.

Individual mangrove trees in the Great Kei Estuary.

FIGURE 2.13: EXAMPLES FOR IDENTIFICATION OF BLUE CARBON ECOSYSTEMS FROM AERIAL IMAGERY.

historical images are also important in identifying reeds and sedges, as the common reed *Phragmites australis* has a winter dieback and can often be difficult to distinguish during these dieback months. The aerial photographs obtained from the Chief Directorate: National Geo-Spatial Information (CD:NGI) also assist with historical changes as their images date back to 1934–1937.

LiDAR technology, where available, helps with the determination of salt marsh habitat versus floodplain habitat. This is because salt marsh is intrinsically linked to elevation (Adams 2020). From a digital elevation model, it was possible to determine intertidal and supratidal salt marsh versus floodplain habitat using the 2.5 m contour as the delineation (Figure 2.15). This also assisted with the estimation of the extent of development in the floodplain and the estimation of blue carbon ecosystem loss.

The geodatabase also includes **where the existing estuarine functional zone needs to be extended**. In

Low water level

Intertidal salt marsh flooded

Final intertidal salt marsh delineation

FIGURE 2.14: INTERTIDAL SALT MARSH CHANGES OVER TIME IN THE CEFANE ESTUARY AS SHOWN IN GOOGLE EARTH SATELLITE IMAGERY.

many estuaries terrestrial vegetation forms a large part of the estuarine functional zone (Figure 2.16). The South African vegetation layer was used to identify which class of terrestrial vegetation occurs. Also included in the geodatabase are columns that list the equivalent land classes under Tier 1 and Tier 2 of the South African National Land Cover that were also used in the Land and Terrestrial Ecosystem Accounts report (Stats SA 2020) (Appendix II). **It was not possible to allocate SANLCC to some of the estuarine habitat classes**, e.g., invasives, as they do not exist in the South African National Land Cover layer. Sand and mudbanks could also not be allocated to an equivalent land cover class. They would be classified as the 'Waterbody' class; however, in estuaries these areas are exposed, depending on ambient water level. Although they do fall within the defined waterbody, they represent important habitat for benthic microalgae and associated fauna, which is different to muddy or sandy bottoms that are permanently submerged. Swamp forest also falls between forested land and wetlands, with this problem being highlighted by Van Deventer et al. (2021).

From the imagery, shapefiles were generated for each blue carbon ecosystem that was evident in the image. Once the ecosystem shapefiles had been generated, they were exported and loaded into the blue carbon geodatabase.

A further challenge with using satellite images and traditional remote sensing analyses using indices and/or reflectance information is that the **spatial resolution of image datasets that are freely available is not adequate for spatial assessments of small areas, such as the blue carbon ecosystems in South African estuaries**. For this reason, the mapping approach used in this study is preferred as the estimated areas have high confidence levels. Although tedious, manual digitising of estuarine areas provides a much higher level of accuracy. This is particularly true in the South African environment where **vegetated areas are fragmented and often form**

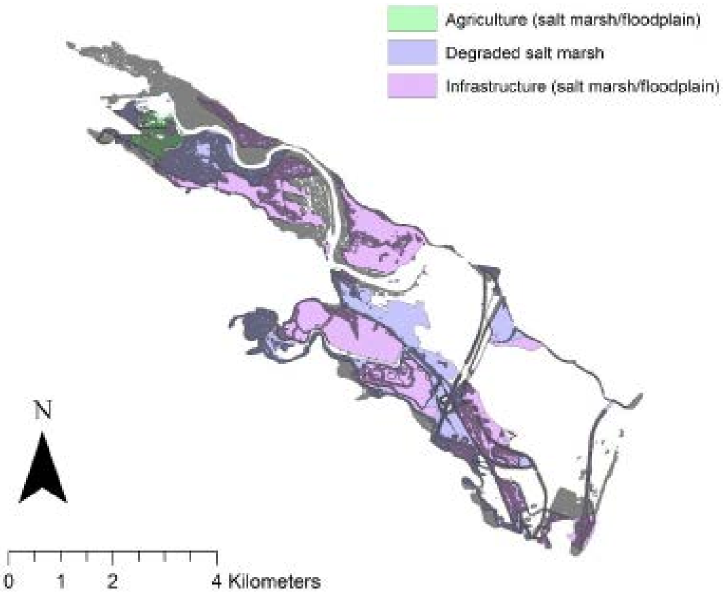


FIGURE 2.15: FLOODPLAIN HABITAT (CONTOUR LINES > 2.5 M MSL IN GREY) EXTRACTED FOR THE SWARTKOPS ESTUARY, SHOWING THE EXTENT OF DEGRADATION AS REPRESENTED BY LAND COVER AND THE CORRESPONDING NATURAL HABITAT COVER.

FIGURE 2.16: THE BOT ESTUARINE LAKE HAS 22% OF THE ESTUARINE FUNCTIONAL ZONE REPRESENTED BY TERRESTRIAL VEGETATION (SHADED IN WHITE).

narrow bands parallel to the estuary water channel. When combined with geotagged images, ecosystem delineation becomes easier. For example, the Breede Estuary is 55 km long and using geotagged notes and images in the field greatly assists with desktop digitising of ecosystem types (Figure 2.17). **Geotagged notes** are taken in the field using Avenza Maps version 3.2.3 (Avenza Systems Inc. 2017) on a digital tablet to record geotagged notes and ground control points in the field. Both the notes and the images can be exported as *.KML files and then viewed in Google Earth. These **geotagged images are also very valuable in providing visual records of historical changes**, for example in the Nxaxo/Ngqusi Estuary (Figure 2.18) where mangrove long-term monitoring has taken place since 2010 (Hoppe-Speer & Adams 2015).

Mapping of all blue carbon ecosystems in South African estuaries with a view to determining historical trends has been carried out following the same approach as used by the National Terrestrial Carbon Sink Assessment (NTCSA) (DEA 2015b). Ecosystems were mapped using the known areas based on natural variability. Where habitat has been lost, it has been described as either 'Degraded' or 'Developed'. 'Degraded' areas have potential to be restored, while 'Developed' areas have been completely transformed. LiDAR data and adjacent polygons assisted in the final determination of what ecosystem was lost. For future studies it is recommended that the 2.5 m contour be accessed to separate salt marsh versus floodplain losses.

FIGURE 2.17: GEOTAGGED IMAGES USED FOR MAPPING THE EXTENT OF BLUE CARBON ECOSYSTEMS IN THE BREEDE ESTUARY.

FIGURE 2.18: HISTORICAL GEOTAGGED IMAGES OF MANGROVES IN THE NXAXO/NGQUSI ESTUARY CAN BE USED TO COMPARE THE HABITAT BETWEEN DIFFERENT TIMES AND LOCATIONS WITHIN THE ESTUARY (LEFT = 2019 LOWER MAIN CHANNEL MANGROVES, RIGHT = 2020 MIDDLE MAIN CHANNEL MANGROVES). (PHOTOS: J ADAMS – BOTTOM LEFT AND RIGHT)

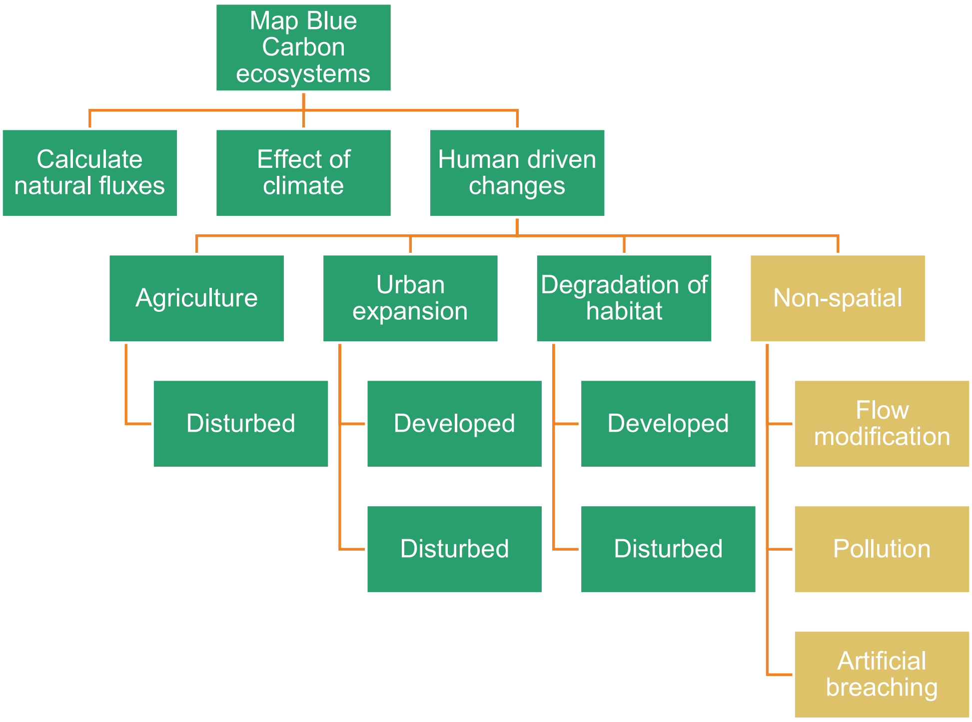


FIGURE 2.19: UNDERSTANDING THE STATUS AND FLUX OF BLUE CARBON ECOSYSTEMS IN SOUTH AFRICAN ESTUARIES. (IMAGE CREATOR: T RIDDIN)

2.5 MAPPING BLUE CARBON ECOSYSTEMS TO EXAMINE HISTORICAL TRENDS AND APPROACHES FOR ESTIMATING GHG STOCKS AND FLUXES

The following six categories of pressures on South African estuaries were identified in the 2018 NBA (Van Niekerk et al. 2019b):

1. Coastal development and habitat degradation;
2. Flow modification;
3. Pollution;
4. Exploitation of living resources;
5. Manipulation of estuary mouths;
6. Alien invasive species.

These **pressures cannot all be represented spatially, but they each have the potential to impact blue carbon ecosystems and the associated C stocks**. For this assessment, only land-use change has been systematically considered as an anthropogenic factor that influences GHG stocks and fluxes in blue carbon ecosystems, as this follows the NTCSA (DEA 2015b) and the IPCC 2013 Wetland Supplement (IPCC 2014a).

2.5.1 Estimating Land-Use Change in South African Estuaries

A previous assessment of land cover changes in South African estuaries by Veldkornet et al. (2015a) showed that many estuaries have been transformed, with **less than 30% of all estuaries, covering 7 883 ha, recorded as in a natural state**. Urban development within EFZs constituted 6 630 ha, while agriculture activities occurred over 26 855 ha (Veldkornet et al. 2015a).

For the current assessment, the area of **estuarine ecosystems that has undergone land cover change was calculated using the land cover change dataset from Skowno et al.** (2021). The dataset was sourced from: Catalog Services (saeon.ac.za). Rates and patterns of habitat loss across South Africa's vegetation biomes | South African Journal of Science (sajs.co.za). This is a 30 m resolution raster dataset that covers three time points (1990, 2014, 2018). The raster image was first clipped to the EFZ shapefile and then reclassified to extract areas defined as 'non-natural', which were categorised as: Lost pre-1990, Lost post-1990, Lost post-2014. **Shapefiles of land cover change were generated for each estuary** following this process (Figure 2.20). The land cover changes within all South African estuaries estimated from the land cover raster dataset are shown in Table 2.5. These were further divided into categories (Table 2.6). These tables are included within the blue carbon geodatabase.

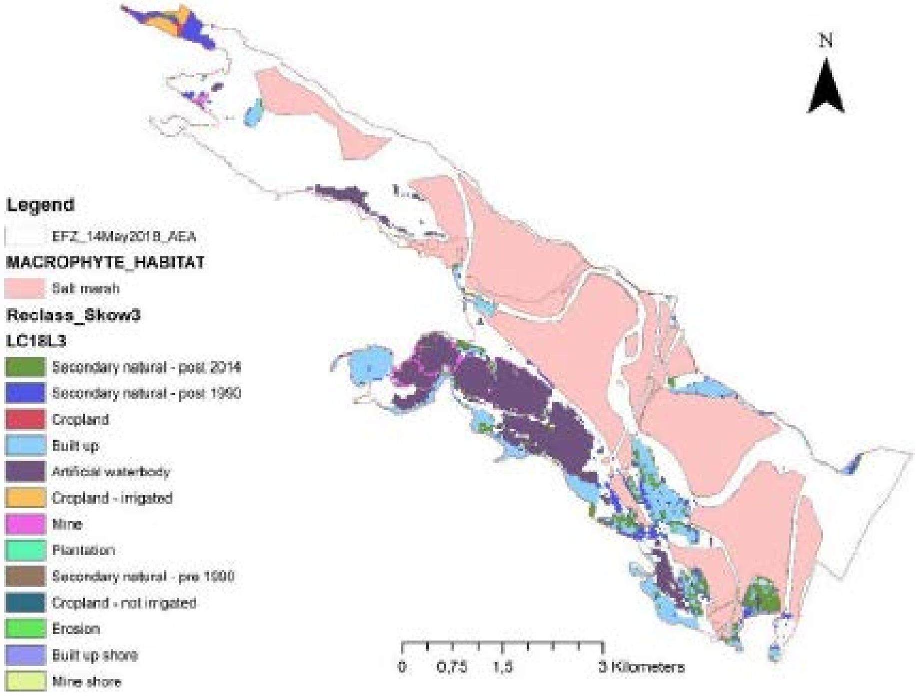


FIGURE 2.20: EXAMPLE OF LAND-USE CHANGE RASTER FROM SKOWNO ET AL. (2021) CLIPPED TO THE EFZ (INSET) AND THE SUBSEQUENT SHAPEFILE SHOWING LAND-USE CHANGE PATTERNS FOR THE SWARTKOPS ESTUARY.

TABLE 2.5: TOTAL ESTUARINE AREA THAT HAS UNDERGONE LAND COVER CHANGE AS ESTIMATED FROM THE SKOWNO ET AL. (2021) RASTER DATASET.

DATE	COUNTS (PIXEL = 30 X 30 M)	TOTAL AREA (HA)
Lost pre-1990	407 362	36 663
Lost post-1990	63 917	5 753
Lost post-2014	28 277	2 545

TABLE 2.6: LAND COVER CHANGES WITHIN THE EFZ OF ALL SOUTH AFRICAN ESTUARIES ESTIMATED OVER A 30 X 30 M PIXEL SIZE FROM THE SKOWNO ET AL. (2021) LAND COVER CHANGE RASTER DATASET.

LAND COVER CHANGE CATEGORIES	AREA (HA)
Secondary natural – post-2014	5 417
Secondary natural – post-1990	5 781
Cropland	17 624
Built up	7 626
Artificial waterbody	1 674
Cropland – irrigated	1 080
Mine	786
Plantation	1 160
Secondary natural – pre-1990	3 560
Cropland – not irrigated	10
Erosion	1
Built-up shore	221
Mine shore	20

2.5.2 Approach to Mapping Loss of Blue Carbon Ecosystems in South African Estuaries

To spatially represent losses of blue carbon ecosystems, areas that have undergone land-use change are demarcated as such and the earliest imagery available is used to determine what ecosystem type was present prior to the land-use change event. These data are collated from the EWR studies as mentioned above.

The availability of spatial data to carry out these assessments is variable between estuaries, and in some systems the entire EFZ has not been mapped. **Land-use change is therefore underestimated, as most areas that have not been mapped are within the larger floodplain area, which is also where developments are most likely to occur.** In contrast, estuaries that have been the focus of more recent research tend to have more comprehensive maps.

Loss of blue carbon ecosystems due to anthropogenic factors besides land-use change (harvesting, cattle browsing and trampling, bait digging, boat activities, eutrophication, artificial breaching, flow reduction and pollution) cannot be spatially represented. However, there are scientific literature reports of these events when they have occurred in specific estuaries.

2.5.3 Approach for Estimating GHG Stocks and Fluxes in South African Blue Carbon Ecosystems

The contribution of blue carbon ecosystems to climate change mitigation requires information on the extent of the ecosystems, the C stocks present, and the rate at which C is emitted or sequestered. Direct estimates of CO_2 emissions reduction potential are complicated and require specialised equipment, therefore alternative methods based on the conversion of total C stocks have been developed (Emmer et al. 2015b). C emissions can be measured as Mg CO_2. ha^{-1} or Mg CO_2 equivalent (UNFCCC 2011), therefore one carbon credit represents one metric tonne of CO_2 equivalent (t CO_2eq). A conversion factor of 3.67 is used to convert C stocks (Mg C.ha^{-1}) to CO_2 emissions as the C to CO_2 ratio is 44:12.

C stock changes can be used as a proxy for CO_2 emissions, and these can be quantified either directly by repeating a detailed field assessment after a certain period of time, or by **estimating the difference in C stocks based on emissions factors that have been defined for certain activities by the IPCC** (such as drainage and deforestation) (Howard et al. 2014). Activities that influence C stocks include natural transfers between pools, plant growth and soil accretion, ecosystem restoration, natural disturbances and anthropogenic land-use changes.

Conversion factors for activities are based on globally compiled databases such as the IPCC 2013 Wetlands Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2014a). This document provides guidance to report on emissions associated with land-use changes in coastal wetlands and includes conversion and degradation, as well as restoration. The Supplement increases the range of options for reducing national GHG emissions and facilitates a way to report GHG emissions in line with management actions that can in turn be related to larger-scale goals such as the Nationally Determined Contributions (NDCs). **The IPCC 2013 Wetlands Supplement was used as the technical guideline for measuring, reporting and verifying GHG emissions from blue carbon ecosystems as part of the South African blue carbon sink assessment.**

Chapter 4 of the IPCC 2013 Wetlands Supplement provides a 'road map' for accounting for GHG emissions from blue carbon ecosystems that is consistent with the 2006 Guidelines for terrestrial ecosystems (IPCC 2006, 2014a). It includes **estimates for biomass and soil C stocks in mangroves, salt marshes and seagrasses that are derived from global averages**. Tier 1 GHG emissions and removals are also provided for a range of activities. For CO_2 emissions, forest management practices are included for mangroves, while activities such as extraction (dredging or excavation), drainage (conversion to agriculture) and rewetting/revegetation (restoration) are included for all blue carbon ecosystems. Additionally, the methodology accounts for CH_4 (methane) emissions from rewetted soils.

TABLE 2.7: GHG EMISSIONS AND REMOVALS INCLUDED IN THE IPCC 2013 WETLANDS SUPPLEMENT (ADAPTED FROM LOVELOCK ET AL. (2016)).

ACTIVITY	DESCRIPTION	AFFECTED VEGETATION
Activities related to CO_2 emissions and removals		
Forest management practices	Planting, harvesting, wood removal, fuelwood removal, charcoal production	Mangrove
Extraction	Excavation to enable port, harbour and marine construction and filling or dredging to facilitate raising land elevation	Mangroves, salt marshes, seagrasses
Drainage	Agriculture, forestry, mosquito control	Mangroves, salt marshes
Rewetting, revegetation and wetland creation	Conversion from drained to saturated soils by restoring hydrology and re-establishment of vegetation Re-establishment of vegetation on undrained area	Mangroves, salt marshes Seagrasses
Activities related to non-CO_2 emissions and removals		
Aquaculture	N_2O emissions from aquaculture activities	Mangroves, salt marshes, seagrasses
Rewetted soils	CH_4 emissions from change to vegetation following modification to restore hydrology	Mangroves, salt marshes

The IPCC 2013 Wetlands Supplement provides the emission and removals factors that can be applied for Tier 1 assessments, but **it is encouraged that Tier 2 or Tier 3 approaches to determining emissions factors are used if data are available**, as this will provide better estimates. The estimation of GHG emissions and removals from blue carbon ecosystems has been described in detail in Section 3.

3. DEVELOPING AND MODELLING A GHG EMISSIONS AND REMOVALS BASELINE

A GHG emissions and removals baseline is needed so that mitigation potentials can be measured, and the effectiveness of the implementation of mitigation actions can be assessed semi-quantitatively. For the AFOLU sector, a baseline was developed so that emissions from the sector could be appropriately estimated and included within national projections. Here, a **baseline scenario is defined as the future GHG emission levels in the absence of future, additional mitigation actions and it is also referred to as the 'business as usual' scenario** (DEA 2016c).

3.1 BASE YEAR FOR BLUE CARBON ECOSYSTEM GHG EMISSIONS/ REMOVALS TRENDS

The base year is the year from which GHG emissions projections are made going forward. The most recent map is used because this is the best representation of current conditions and it includes the existing policy measures.

For the blue carbon sinks assessment, the base year will be 2000. The most recent spatial data for mangroves, salt marshes and seagrasses/submerged macrophytes has been collated as part of this project. This project updates the number of **estuaries with spatial data for these ecosystems** from the 2018 NBA (Van Niekerk et al. 2019b).

It must be noted that the 2021 map also includes spatial data captured during **previous studies, and for some estuaries,** the most recent map will be a few years old. All maps are only real-world representatives of the time for which they were generated. However, in most cases these maps are still relevant, particularly if anthropogenic pressures on an estuary are relatively stable and no significant changes have occurred since the map was generated. The South African National Estuarine Botanical Database (hosted by Nelson Mandela University) updates the spatial data for all South African estuaries when new projects are carried out and when there have been significant changes in the habitats following certain events – such as prolonged **mouth closure or breaching following extreme storm surges and floods**.

3.2 HISTORICAL DISTURBANCES/DRIVERS AND IMPACTS ON CARBON STOCKS AND BLUE CARBON ECOSYSTEMS

The historical disturbances and drivers of C stocks in blue carbon ecosystems were identified from spatial and non-spatial records of area change within the National Blue Carbon Map geodatabase and metadata. Blue carbon ecosystems experience natural variability as well as losses through human impacts, but both can be represented by the change in area coverage of the ecosystem. Areas denoted as 'Developed' in the geodatabase are considered **transformed and are unlikely to be rehabilitated back to natural land cover as the habitat has been completely removed and replaced with hard infrastructure**. Areas classified as 'Degraded' are those where revegetation or restoration to natural land cover is possible, i.e., grassed recreational areas that could be converted back to supratidal or floodplain salt marsh given the correct environmental requirements.

The National Botanical Database (Opus at SANBI: NBA 2018: Mapped estuarine habitat in South Africa) lists historical data and the source of this information. The data have been collated from various research projects and estuarine flow requirement studies (Adams et al. 2016a, b). Within the database, very few estuaries have been mapped at multiple points in time, which makes it difficult to compare changes over a continuous temporal period. For blue carbon ecosystems, the cause of the change in area is relatively well documented (Adams 2016, 2020, Adams & Rajkaran 2021). Loss of ecosystem area results in the loss of the associated C stocks, while an increase in ecosystem area is associated with C stock gain.

3.2.1 Historical Disturbances/ Drivers and Impacts on Mangroves

For mangroves (Table 3.1), large losses occurred following the development of ports at Durban and Richards Bay. However, the intentional separation of the uMhlathuze Estuary from Richards Bay during the construction of the harbour altered the hydrodynamics and increased the tidal amplitude of the system, thus facilitating a significant expansion of mangroves to form the largest stand in the country. In the St Lucia and iMfolozi estuaries, mangrove area change (both increases and decreases) has been associated with fluctuating abiotic conditions (salinity, water levels, sedimentation) that have occurred as a result of the mouth management practices that are still ongoing. For smaller estuaries, mangrove losses have occurred due to localised human impacts such as **wood harvesting** (for building material and firewood) and trampling by both people and livestock. Cattle browsing directly on mangrove trees removes biomass from the forest and impacts the growth of the trees.

TABLE 3.1: CHANGES IN MANGROVE AREAS (HA) FOR THE LARGEST FORESTS (> 10 HA) IN SOUTH AFRICA AND THE ASSOCIATED PRESSURES AND PROTECTION STATUS OF EACH ESTUARY. HABITAT TRENDS ARE INDICATED BY ARROWS (↓ DECREASING, ↑ INCREASING, → STABLE). FROM ADAMS ET AL. (2019) AND ADAMS & RAJKARAN (2021).

ESTUARY	HISTORIC AREA	PRESENT AREA	HABITAT TREND	PRESSURES/DRIVERS OF CHANGE	PROTECTION STATUS/ AUTHORITY
Kosi	60.7	71.0	↑	Harvesting of wood, construction of fish traps, cattle trampling and browsing. Mangroves increased due to sedimentation around fish traps.	iSimangaliso Wetland Park World Heritage Site
St Lucia	331.0	209.5	↓	Relinked to iMfolozi catchment, mouth closure, freshening, increased silt and water levels.	iSimangaliso Wetland Park World Heritage Site
Richards Bay	267.0	171.0	↓	Harbour construction and removal of mangroves.	Echwebeni site of conservation significance
uMhlathuze	80.0	1 087.0	↑	Expansion following separation from Richards Bay with creation of new intertidal areas. Pressures include dredging, silt and sediment deposition.	Ezemvelo KwaZulu-Natal Wildlife
uMlalazi	4.0	40.0	↑	Expansion of mangroves as estuary mouth is kept open. Pressures include sedimentation.	Ezemvelo KwaZulu-Natal Wildlife
uMngeni	20.3	33.5	↑	Sedimentation and natural expansion. Pressures include infrastructure development, reduced flows, poor water quality and mouth closure.	Beachwood Mangrove Reserve, Ezemvelo KwaZulu-Natal Wildlife
Durban Bay	451.0	13.4	↓	Harbour construction and removal of mangroves. Pressures include pollution (plastic and heavy metals).	Bayhead Natural Heritage Site
iSiphingo	12.5	4.9	↓	Removal for development. Pressures include flow reduction, tidal restriction and poor water quality.	None

ESTUARY	HISTORIC AREA	PRESENT AREA	HABITAT TREND	PRESSURES/DRIVERS OF CHANGE	PROTECTION STATUS/ AUTHORITY
Mntafufu	10.0	12.1	↑	Expansion due to sediment stability. Pressures include harvesting for wood and bark.	None
Mngazana	145.0	147.1	↓	Harvesting of wood, browsing by cattle, trampling by cattle and people, sand mining resulting in removal of habitat.	None
Mtakatye	7.7	10.7	↑	Increase in area due to sedimentation. Pressures include cattle browsing and harvesting.	None
Mtata	42.0	29.8	↓	Harvesting of wood and flow reduction.	None
Xhora	16.0	23.9	↑	Natural expansion. Pressures include cattle browsing and harvesting of wood.	None
Mbashe	12.5	10.4	↓	Cattle browsing, harvesting of wood, flow reduction.	Dwesa-Cebe Marine Protected Area
Nqabarana/ Nqabara	9.0	13.9	↑	Increase in area due to sedimentation. Pressures include cattle browsing and harvesting of wood.	None
Nxaxo/Ngqusi	14.0	16.5	↓	Cattle browsing, harvesting of wood, trampling by cattle and people.	None

3.2.2 Historical Disturbances/ Drivers and Impacts on Salt Marshes

Historical changes for intertidal (Table 3.2) and supratidal (Table 3.3) salt marsh are mostly represented by losses. For intertidal salt marsh, the largest losses have occurred at the Knysna and Groot Berg estuaries. At the Knysna Estuary, **242 ha of intertidal salt marsh** have been lost **due to development**, including the placement of infrastructure such as **marinas, jetties and roads**. The elevation of some intertidal areas was increased to allow for property development, including **residential areas which have replaced salt marsh**. At the Groot Berg Estuary, 655 ha of intertidal salt marsh have been lost following conversion of the land for agricultural use and **development (residential properties, roads, marinas and jetties)**. Other threats to intertidal salt marsh include salinisation, disturbance and grazing pressure from livestock.

For supratidal salt marsh, significant losses have occurred in several estuaries. As the supratidal marsh occurs above the high-water mark, these areas are more easily accessible to be developed, converted or transformed for alternative uses. Large losses due to agriculture have occurred at the Groot Berg (305 ha), Gouritz (212 ha) and Gamtoos (156 ha) estuaries. Similarly, development and industrial pressures have replaced large areas of supratidal salt marsh in the Knysna (459 ha) and Swartkops (284 ha) estuaries. At the Orange and Olifants estuaries, 684 ha and 1 258 ha have been lost respectively due to salinisation. The only historical increase in salt marsh area has been reported from the Langebaan Estuary (57 ha), which has occurred over recent years following the establishment of a protected area to remove the pressure of livestock grazing. Development pressure has decreased in the last decade due to the implementation of Environmental Impact Assessment (EIA) regulations that recognise the estuary functional zone (EFZ) as a development boundary. All land-use change within the EFZ is now a listed activity. This has been further supported through the Integrated Coastal Management Act that promotes the development and implementation of Estuary Management Plans as stipulated in the National Estuarine Management Protocol.

TABLE 3.2: CHANGES IN THE LARGEST INTERTIDAL SALT MARSH AREAS (HA) IN SOUTH AFRICA (WHERE THE LARGEST BLUE CARBON STOCKS ARE ESTIMATED TO OCCUR) AND THE ASSOCIATED PRESSURES AND PROTECTION STATUS OF EACH ESTUARY. HABITAT TRENDS ARE INDICATED BY ARROWS (↓ DECREASING, ↑ INCREASING, → STABLE). FROM ADAMS ET AL. (2019) AND ADAMS (2020).

ESTUARY	HISTORIC AREA	PRESENT AREA	HABITAT TREND	PRESSURES	PROTECTION STATUS
Kosi	58	58	→	Cattle browsing and grazing, trampling by people and cattle, fires.	iSimangaliso Wetland Park World Heritage Site
Great Fish	144	133	↓	Disturbance in lower reaches, flow reduction.	None
Kowie	83	27	↓	Development – houses, marina.	None
Swartkops	537	193	↓	Development – industrial, infrastructure.	None
Knysna	537	295	↓	Development – residential, infrastructure.	Partial, SANParks
Langebaan	806	806	→	Grazing pressure removed with establishment of protected area, potential for further expansion.	SANParks
Groot Berg	1 965	1 310	↓	Agriculture, flow reduction.	Partial, Cape Nature
Olifants	195	97	→	Salinisation, flow reduction.	None
Orange	154	144	→	Salinisation, flow reduction.	Ramsar

TABLE 3.3: CHANGES IN THE LARGEST SUPRATIDAL SALT MARSH AREAS (HA) IN SOUTH AFRICA (WHERE THE LARGEST BLUE CARBON STOCKS ARE ESTIMATED TO OCCUR) AND THE ASSOCIATED PRESSURES AND PROTECTION STATUS OF EACH ESTUARY. HABITAT TRENDS ARE INDICATED BY ARROWS (↓ DECREASING, ↑ INCREASING, → STABLE). FROM ADAMS ET AL. (2019) AND ADAMS (2020).

ESTUARY	HISTORIC AREA	PRESENT AREA	HABITAT TREND	PRESSURES	PROTECTION STATUS
Kosi	229	229	→	Cattle browsing, trampling by people and cattle, fires.	iSimangaliso Wetland Park World Heritage Site
Keiskamma	312	181	↓	Agriculture, cattle browsing.	None
Swartkops	643	359	↓	Development – industrial, infrastructure.	None
Gamtoos	240	84	↓	Agriculture, flow reduction.	None
Keurbooms	398	304	↓	Development.	Partial, Cape Nature
Knysna	680	221	↓	Development – residential, infrastructure.	Partial, Cape Nature
Gouritz	220	8	↓	Agriculture, flow reduction.	None
Heuningnes	500	259	↓	Agriculture, flow reduction.	Cape Nature/SANParks
Langebaan	1 075	1 132	↑	Grazing pressure removed with establishment of protected area, potential for further expansion.	SANParks
Groot Berg	2 926	2 621	↓	Agriculture, flow reduction.	Partial, Cape Nature
Olifants	1 442	183.6	↓	Development – saltworks; salinisation, flow reduction.	None
Orange	1 311	627	↓	Flow reduction and salinisation.	Ramsar

3.2.3 Historical Disturbances/ Drivers and Impacts on Seagrass

Historical trends for the seagrass (*Zostera capensis*) show increases and decreases in different estuaries (Table 3.4). Recording the change in seagrass areas is more challenging than mangroves and salt marsh as they are submerged. Past area estimates (before satellite imagery) can be difficult to obtain, or there is a measure of uncertainty that is difficult to quantify. Catchment pressures, such as degradation or erosion which leads to siltation, as well **as poor water quality and eutrophication, are associated with decreasing seagrass areas**. Seagrasses are also subject to direct disturbances from boating activities and bait digging.

3.2.4 Summary of Historical Disturbances/Drivers and Impacts on South African Blue Carbon Ecosystems

South African blue carbon ecosystems have been subjected to **numerous disturbances** over time and these can **drive changes in the area cover and ecological function**. Large areas of mangroves and salt marshes have been lost as a result of **transformation and development, including the construction of infrastructure such as roads, jetties and marinas** (Adams 2020, Adams & Rajkaran 2021). Land-use change in the form of conversion for agriculture has had the largest impact on salt marshes. Ongoing human pressures in blue carbon ecosystems are related to activities that influence environmental conditions or result in direct removal of the vegetation. In **mangrove ecosystems, the trees are harvested** directly for wood and bark and this can impact the productivity of the forest (Rajkaran et al. 2004). Both mangroves and salt marshes are impacted by **cattle grazing** on the vegetation biomass and **trampling** of the plants and sediment by both people and cattle. Seagrasses face unique pressures as these ecosystems are submerged either partially (intertidal zone) or fully (subtidal zone). **Seagrasses are most significantly impacted by boating activities** that cause direct damage and removal of the vegetation (Adams 2016). Similarly, bait-digging activities disturb the soft mud that is exposed at low tide where intertidal seagrass occurs. This can impact both soil and vegetation carbon stocks in these ecosystems.

TABLE 3.4: ESTUARIES WITH THE LARGEST SEAGRASS (*ZOSTERA CAPENSIS*) AREAS (HA) IN SOUTH AFRICA AND THE ASSOCIATED PRESSURES AND PROTECTION STATUS OF EACH ESTUARY. HABITAT TRENDS ARE INDICATED BY ARROWS(↓ DECREASING, ↑ INCREASING, → STABLE). FROM ADAMS ET AL. (2019) AND ADAMS (2016).

ESTUARY	PRESENT AREA	HABITAT TREND	PRESSURES	PROTECTION STATUS
Kosi	9.7	→	Mouth closure, disturbance.	iSimangaliso Wetland Park World Heritage Site
uMhlathuze	14.6	↓	Siltation, dredging activities.	Ezemvelo KwaZulu-Natal Wildlife
Qora	2.4	↓	Catchment degradation leading to increased siltation.	None
Keiskamma	27.7	↓	Catchment degradation leading to increased siltation.	None
Kariega	39.8	↓	Disturbance – boats, bait digging.	None
Bushmans	15.7	↓	Disturbance – boats, bait digging.	Partial, SANParks
Swartkops	53.6	↑	Eutrophication, disturbance – boats, bait digging. Recent increase due to sediment stability as drought conditions have prevented floods.	None
Kromme	41.8	↑	Disturbance – boats, bait digging.	Partial

ESTUARY	PRESENT AREA	HABITAT TREND	PRESSURES	PROTECTION STATUS
Keurbooms	88.9	↑	Disturbance – boats, bait digging. Recent increase due to sediment stability as drought conditions have prevented floods.	Partial, Cape Nature
Knysna	446.8	↑	Eutrophication – competition with macroalgae, disturbance – boats, bait digging.	Partial, SANParks
Langebaan	248.6	→	Disturbance – boats, bait digging.	SANParks
Groot Berg	113.6	→	Disturbance – boats, bait digging.	Partial, Cape Nature
Olifants	50.2	→	Disturbance – trampling in intertidal.	None

3.3 IMPACTS OF CLIMATE CHANGE ON CARBON STOCKS AND BLUE CARBON ECOSYSTEMS

This section briefly describes the main climate change pressures for South African estuaries and the response of **mangroves, salt marsh and seagrass**. The impact is quantified as the **change in habitat area** cover as a percentage by 2040 and 2050 in Tables 3.5–3.7. Rates of **plant productivity and decay rates are not directly quantified as part of these climate change impacts**. The adaptive capacity of blue carbon ecosystems to climate change is defined by the following (Lovelock & Reef 2020):

1. The potential to accrete vertically to adjust to sea-level rise (SLR);
2. The potential to maintain C stocks;
3. The potential to maintain area by expanding landwards into suitable areas;
4. The potential to maintain vegetation species that retain C stocks and promote continued sequestration.

3.3.1 Sea-Level Rise

Sea-level rise (SLR) will increase **inundation and waterlogging**, altering sediment biogeochemistry, moisture and salinity. This is the predicted scenario; however, if salt marshes and mangroves build elevation at a sufficient rate then inundation and waterlogging may not increase (Rogers et al. 2019b). **Local topography and coastal development constrain the availability of areas for landward migration, but the rate of sedimentation determines the capacity of mangrove and salt marsh ecosystems to resist SLR through surface elevation gain** (Lovelock et al. 2015, Baustian & Mendelssohn 2018). Predictive models that incorporate landward migration and surface elevation processes have been used to estimate changes in blue carbon C stocks under different SLR scenarios at the Knysna and Swartkops estuaries in South Africa (Raw et al. 2020, 2021). These studies have shown that development and coastal squeeze will limit the landward growth of salt marsh. Similar studies need to be carried out for mangroves, and at larger spatial scales, but are currently restricted by the absence of high-quality elevation data.

SLR may lead to an increase in open-mouth conditions in temporarily closed estuaries, creating favourable habitat for mangrove, salt marsh and seagrass colonisation. These positive effects may be **counteracted by drought and a reduction in freshwater inflow** that results in mouth closure, high water level flooding and dieback of mangrove and salt marsh. Nationally it is difficult to predict the future trajectory of change for the endangered seagrass *Zostera capensis*. SLR will increase salinity in estuaries and seagrass can expand upstream.

However, an increase in high-intensity rainfall events will likely remove submerged macrophyte beds (Adams 2016).

TABLE 3.5: CLIMATE CHANGE RESPONSES OF SALT MARSH IN PERMANENTLY OPEN AND TEMPORARILY CLOSED (*ITALICS*) ESTUARIES. OVERALL RESPONSE IS A DECREASE IN SALT MARSH AREA.

ABIOTIC CHANGE	ECOLOGICAL PROCESSES	HABITAT AREA
↑ Sea-level rise +1.5–2.7 mm.yr^{-1}		
Inundation & waterlogging, coastal squeeze	Salt marsh subsidence. Dieback and salt marsh loss. Changes in species composition.	Decrease in carbon storage due to salt marsh loss
↑ *Open mouth condition*	*Expansion of salt marsh on exposed sand/ mudflats.*	*Potential increase in carbon storage* *NO OVERALL CHANGE by 2040 & 2050*
↑ Sea storms & wave height		
Erosion	Loss of salt marsh.	DECREASE *3% by 2040, 4% by 2050*
↑ *Sediment deposition, constricted mouth*	*Increase in water level, flooding and dieback of salt marsh.*	
↑ Floods		
↑ Nutrient inputs & eutrophication	Macroalgal growth, smothering and loss of salt marsh.	DECREASE *3% by 2040, 4% by 2050*
Scouring of estuary, decrease in salinity	*Loss of salt marsh cover, change in species composition.*	
↑ Droughts		
↑ Salinity	Change in species and community composition. Decrease in productivity. Loss of salt marsh cover.	
↑ *Closed mouth condition*	Increase in water level, flooding and dieback of salt marsh. Loss of intertidal habitat and marine connectivity. These effects may be counteracted by artificial breaching of the mouth due to flooding of low-lying properties.	DECREASE *5% by 2040, 5.5% by 2050*
↑ CO_2		
Higher C availability	Increase in plant growth and productivity.	INCREASE *3% by 2040, 4% by 2050*

ABIOTIC CHANGE	ECOLOGICAL PROCESSES	HABITAT AREA
↑ **Temperature**		
Warming Higher aridity	Increase in plant growth and productivity; however, distributional range shifts and change in habitat diversity; mangroves replace salt marsh.	DECREASE *2% by 2040, 3% by 2050*
	Increase in invasive species. Change in salt marsh phenology and extinctions.	

3.3.2 Droughts

Mean annual runoff is variable and river flow fluctuates between floods and extremely low to zero flow. During times of low flow, the mouths of affected estuaries remain closed to the sea, making them unsuitable for the establishment of mangroves and intertidal salt marsh. At Kobonqaba Estuary, **drought, mouth closure and flooding caused dieback of the mangroves** (Mbense et al. 2016). Extended periods of mouth closure result in high water levels, inundation and dieback of salt marsh and mangroves (Riddin & Adams 2010, Tabot & Adams 2013). Under these conditions, submerged macrophytes flourish if water quality is good and turbidity is low. In permanently open estuaries, **low freshwater inflow and saline conditions increase seagrass growth**, e.g., the reduction of freshwater inflow into the Kromme Estuary due to dam construction led to an increase in *Z. capensis* biomass and area cover (Adams & Talbot 1992).

Freshwater abstraction compounds the effects of salinisation and desiccation resulting from drought. High salinity decreases salt marsh cover and productivity, particularly in the drier west coast estuaries such as Olifants and Groot Berg (Adams 2020). **Drought stress in mangrove trees affects physiological processes** related to water uptake and water use efficiency. For example, reports from recent large-scale dieback in northern and western Australia occurred under drought conditions in combination with low sea levels and low humidity as a consequence of an El Niño-Southern Oscillation (ENSO) event (Duke et al. 2017, Lovelock et al. 2017b, Asbridge et al. 2019).

3.3.3 Effects of CO_2

Enhanced productivity due to higher CO_2 levels will occur for both mangroves and salt marshes. Climate-related warming and an increase in CO_2 are positive conditions for **mangroves to expand their distribution to higher latitudes** but this will depend on propagule dispersal between estuaries and the availability of suitable habitats. Many of the small estuaries are temporarily closed to the sea for different periods of time, thus limiting recruitment.

TABLE 3.6: RESPONSE OF MANGROVES TO PREDICTED CLIMATE CHANGES. OVERALL RESPONSE IS A DECREASE IN MANGROVE AREA.

ABIOTIC CHANGE	ECOLOGICAL PROCESSES	HABITAT AREA
↑ Sea-level rise +1.5–2.7 mm.yr^{-1}		
+1.5–2.7 mm.yr^{-}1	Inundation & waterlogging	Expansion of mangroves in intertidal. Inland/landward migration of mangroves.
↑ Open mouth condition	↑ Intertidal habitat	INCREASE *3% by 2040, 4% by 2050*
↑ Sea storms & wave height		
	↑ Erosion of mangrove habitat	Loss of mangroves. Smothering, e.g. of pneumatophores.
	↑ Deposition of marine sediment and smothering of air roots	DECREASE *3% by 2040, 4% by 2050*
↑ Floods		
	↑ Bank scour	Mangrove loss due to scouring, sediment deposition & smothering.
	↑ Sediment input	DECREASE *3% by 2040, 4% by 2050*
↑ Droughts		
	↑ Salinity and aridity	Decrease in productivity. Loss of mangrove cover. Flooding and loss of mangroves.
↑ Closed mouth condition	↑ Water level & inundation, loss of intertidal habitat	DECREASE *5% by 2040, 5.5% by 2050*
↑ CO_2		
	Higher C availability	Increase in plant growth & productivity.
		INCREASE *3% by 2040, 4% by 2050*
↑ Temperature		
	Warming	Increase in plant growth & productivity. Mangroves replace salt marsh. Distributional range shifts and change in habitat diversity. INCREASE *3% by 2040, 4% by 2050*

3.3.4 Temperature

In general, South Africa will experience a warmer and drier climate in the future. **Increases in temperature and CO_2 will lead to expansion of mangroves into salt marsh habitats.** This is known as tropicalisation; rising temperatures associated with the expansion of mangroves towards higher latitudes (polewards). Range shifts have been described for different regions around the world (Saintilan et al. 2014, Osland et al. 2017a, Cavanaugh et al. 2018), including for the subtropical east coast of South Africa (Whitfield et al. 2016, Peer et al. 2018). **Successful colonisation of new sites by mangroves depends on the effectiveness of propagule dispersal between estuaries and the availability of suitable habitats** (Raw et al. 2019a, Adams & Rajkaran 2021).

Mangrove expansion and loss of salt marsh habitats can lead to **ecological shifts, including changes in C stocks**. Expansions into salt marsh areas have significantly increased soil C stocks in New South Wales, Australia, and the Atlantic coast of Florida, USA (Doughty et al. 2016, Kelleway et al. 2016b). However, similar gains following mangrove expansion were not correlated with increased soil C at range limits in Louisiana, USA, and the Eastern Cape, South Africa (Yando et al. 2018, Raw et al. 2019b), indicating that there are additional factors controlling this relationship. In both these cases the soil C was the same between salt marsh and the expanded mangrove area. **Long-term monitoring is needed in South Africa to understand these changes.**

The effect of **ocean heat waves** has not been documented in South Africa but can have severe consequences. Above-average temperatures for four months (2–4°C above average) caused 90% dieback of seagrass beds in Shark Bay, Western Australia (Strydom et al. 2020). In northern Australia the 2016 extreme El Niño event led to extensive dieback of mangroves in the Gulf of Carpentaria (Duke et al. 2017). These warming events are projected to become more common in the future.

3.3.5 Synergistic Effects

Climate change stressors can degrade coastal ecosystems and may reduce their resilience and capacity for carbon sequestration. Synergistic interactions between climate change and human impacts can only be understood from long-term studies at a local level. Without these data we have little understanding of the processes that influence the vulnerability and resilience of blue carbon habitats. For example, Adams and Rajkaran (2021) described an equal number of South African estuaries where mangrove extent has increased or decreased. The driver of change was mostly linked to **mouth condition and connection with the sea**; however, **multiple pressures made it difficult to assess the direction of change**. Multiple stressors can also **amplify negative impacts and shift ecosystems into alternative states**. Despite this uncertainty we must begin the process of adapting to climate change as major trends are often evident enough for meaningful actions to be planned and implemented (Van Niekerk et al. 2019b).

TABLE 3.7: RESPONSE OF SUBMERGED MACROPHYTES INCLUDING SEAGRASS (DOMINANT SPECIES: *ZOSTERA CAPENSIS*) TO PREDICTED CLIMATE CHANGES. THESE HABITATS ARE HIGHLY DYNAMIC WITH OVERALL LITTLE CHANGE IN HABITAT AREA PREDICTED.

ABIOTIC CHANGE	ECOLOGICAL PROCESSES	HABITAT AREA
↑ Sea-level rise +1.5–2.7 mm.yr^{-1}		
↑ Open mouth condition	Greater connectivity with sea, increase in saline conditions	Increase in intertidal seagrass.
		INCREASE *3% by 2040, 4% by 2050*
↑ Sea storms & wave height		
	Erosion	Loss of seagrass & submerged macrophytes.
	Deposition of marine sediment	DECREASE *3% by 2040, 4% by 2050*
↑ Floods		
	↑ Bank scour	Submerged macrophyte loss due to scouring, sediment deposition & smothering.
	↑ Sediment input	DECREASE *3% by 2040, 4% by 2050*
↑ Droughts		
↑ Closed mouth condition	↑ Salinity and aridity	Higher water level increases submerged macrophytes. Higher salinity increases seagrass.
	↑ Water level & inundation	INCREASE *3% by 2040, 4% by 2050*
↑ CO_2		
	Higher C availability	Increase in plant growth & productivity. INCREASE *3% by 2040, 4% by 2050*
↑ Temperature		
	Warming, increase in macroalgae and epiphytes	Displacement of submerged macrophytes by macroalgae and smothering by epiphytes. DECREASE *3% by 2040, 4% by 2050*

3.4 HISTORICAL GHG EMISSIONS AND REMOVALS TRENDS FOR BLUE CARBON ECOSYSTEMS

Guidance for setting GHG baselines is limited, and approaches and assumptions are variable between countries depending on **methodology, specific goals and targets, and the available data**. The framework for the AFOLU sector baseline was structured around the following (DEA 2016):

1. **A set timeline for emissions projections** – establish a time series of historical GHG emissions to inform emissions projections into the future and national climate change strategies.
2. **The scope of emissions sources** – consider which GHGs to include in the projection and which emitting sources should be included based on available information and the contribution towards total emissions. Use emissions inventories for guidance and ensure sector definitions are clear.
3. **Key drivers for projections** – all projections are based on assumptions about the future development/ trajectories of drivers of emissions. Analysing emissions trends will improve the credibility of the baseline. Important steps in constructing a baseline therefore include identifying the drivers of change for sectors and the assumptions on how drivers will vary over the timeframe of the baseline.

Before examining historical GHG emissions and removals trends, it was first necessary to **build an inventory of the current C stock for South Africa's blue carbon ecosystems**. Direct quantitative studies of blue carbon have only been carried out at four estuaries **(Knysna, Swartkops, Nahoon and Nxaxo/Ngqusi)**. Similarly, C sequestration (accumulation) rates have only been directly measured in these estuaries. Several estimation methods (described below) were used to obtain C stock estimates in all other estuaries with spatial data for blue carbon ecosystems. These estimates, and the underlying assumptions of each approach, were then compared so that a range of C stock values could be reported, and the appropriate approach selected.

3.4.1 Collation of Available Data and Estimation Approaches for Current Carbon Stock Assessment

The detailed South African studies on C stocks provide estimates for soil C stocks and aboveground biomass (AGB) C stocks reported as **Mg C.ha^{-1} (megagrams carbon per hectare)**. As the data from the field studies are limited to only four estuaries, it was necessary to estimate national C stocks using data obtained from other sources and to **extrapolate values for all other estuaries**. Previous studies that have been carried out in South African blue carbon ecosystems have reported on sediment organic matter or aboveground biomass. Where appropriate, these data were also incorporated in the calculation of C stocks.

Estimation Method 1: The C values from the detailed South African studies were multiplied **by the area of the habitat (hectares)** to obtain a total stock in Mg (Howard et al. 2014). The Knysna and Swartkops estuaries support extensive salt marsh and seagrass areas, while the Nahoon and Nxaxo/Ngqusi estuaries support mangroves and salt marsh as well as patches of seagrass. All of these estuaries are located within the **warm-temperate biogeographic region of the South African coastline** (Van Niekerk et al. 2019b).

C stocks in blue carbon ecosystems are known to be variable across biogeographic regions. It is therefore not recommended to conduct a simple extrapolation of the average measured at the warm-temperate estuaries across all blue carbon ecosystems along the South African coastline.

Estimation Method 2: A recent study carried out in Australia used **a modelling approach to extrapolate C stock estimates across biogeographic regions** of the continent (Serrano et al. 2019). The C values from this study were applied directly to the South African data for area cover of blue carbon ecosystems to obtain a carbon stock estimate.

Application of the Australian C values carries some assumptions, as there may be other drivers or anthropogenic activities that are different and are not being captured by this approach. Although studies have been carried out in blue carbon ecosystems on the African continent, these are typically focused on tropical mangrove and seagrass ecosystems. Salt marshes are very limited in these tropical areas as the conditions are more suitable to mangroves which develop into much larger forests than in South Africa. It is therefore necessary to capture the biogeographic variability as shown in the Australian study but using the data available from South Africa.

Estimation Method 3: The relationship between C stocks from different biogeographic regions identified in the Australian study was **applied to approximate C stocks for the other biogeographic regions in South Africa using the existing C stock measurements** from the above-mentioned South African **warm-temperate estuaries**. The C stocks measured in South African warm-temperate blue carbon ecosystems are comparable to those in **Australia as the biogeographic climatic and coastal estuarine settings are similar** (Johnson et al. 2020, Owers et al. 2020). The relationships for the extrapolations were therefore deemed appropriate to use.

Estimation Method 4: The **default values from the IPCC 2013 Wetlands Supplement** to the 2006 Guidelines for National Greenhouse Gas Inventories (IPCC 2014a) were also used as an approach to estimate C stocks. This approach was carried out to determine whether the other methods being applied resulted in a higher or lower estimate of C stocks compared to the default values. This method also serves as a sensitivity test to show how the total C stock changes based on the values that are applied.

The C stock estimation was calculated using different values for soil and AGB C (Mg C.ha^{-1}) as described (Table 3.8). The values were multiplied by the area of mangroves, salt marsh and submerged macrophytes respectively that has been reported in each estuary as part of the National Blue Carbon Map.

BOX 4: Submerged Macrophytes and Blue Carbon

For this assessment, it must be noted that areas for submerged macrophytes include the endangered seagrass Zostera capensis, as well as other species (e.g. *Stuckenia pectinata, Ruppia cirrhosa*). In South African estuaries these other species can make a large **contribution towards C stocks as their biomass and soil can be more stable than *Z. capensis***. The C stocks measured for Z. capensis are typically low, which makes the assumption of C storage in other submerged macrophyte beds conservative. A table of the largest areas of Z. capensis and submerged macrophytes is provided (Appendix V).

TABLE 3.8: AVERAGE C STOCK VALUES (Mg C.ha^{-1}) FOR SOILS AND ABOVEGROUND BIOMASS IN BLUE CARBON ECOSYSTEMS WHICH WERE USED TO ASSESS AND COMPARE ESTIMATES OF TOTAL C (ND = NO DATA, N/A = NOT APPLICABLE AS ECOSYSTEM DOES NOT OCCUR IN RESPECTIVE BIOREGION).

METHOD	DESCRIPTION				
1	**Average C stock values measured in South African warm-temperate estuaries**				
	Biogeographic Region	**Soil (Mg C.ha^{-1})**	**References**	**AGB (Mg C.ha^{-1})**	**References**
Mangrove	Warm Temperate	228	Johnson et al. (2020)	74	Johnson et al. (2020)
Salt marsh	Warm Temperate	169	Els (2019), Raw et al. (2019b)	7.12	Els (2019), Banda et al. (2021)
Seagrass	Warm Temperate	124	Els (2017, 2019)	2.08	Els (2019)
2	**Average C stock values in comparable biogeographic regions of Australia**				
	Biogeographic Region	**Soil (Mg C.ha^{-1})**	**References**	**AGB (Mg C.ha^{-1})**	**References**
Mangrove	Tropical	236	Serrano et al. (2019)	167	Serrano et al. (2019)
	Subtropical	366	Serrano et al. (2019)	101	Serrano et al. (2019)
	Temperate	247	Serrano et al. (2019)	70	Serrano et al. (2019)
	Semi-Arid	ND	-	ND	-
	Arid	ND	-	ND	-
Salt marsh	Tropical	ND	-	ND	-
	Subtropical	153	Serrano et al. (2019)	1.50	Serrano et al. (2019)
	Temperate	173	Serrano et al. (2019)	8.30	Serrano et al. (2019)
	Semi-Arid	136	Serrano et al. (2019)	1.00	Serrano et al. (2019)
	Arid	221	Serrano et al. (2019)	ND	-
Seagrass	Tropical	37	Serrano et al. (2019)	0.46	Serrano et al. (2019)
	Subtropical	90	Serrano et al. (2019)	ND	-
	Temperate	113	Serrano et al. (2019)	0.27	Serrano et al. (2019)

METHOD	DESCRIPTION				
Seagrass	Semi-Arid	Serrano et al. (2019)	Serrano et al. (2019)	ND	–
	Arid	Serrano et al. (2019)	Serrano et al. (2019)	2.5	Serrano et al. (2019)
3	**Extrapolation based on biogeographic variability with data from South Africa**				
	Biogeographic Region	**Soil (Mg C.ha^{-1})**	**References**	**AGB (Mg C.ha^{-1})**	**References**
Mangrove	Tropical	218	(Calculated)	177	(Calculated)
	Subtropical	338	(Calculated)	107	(Calculated)
	Warm Temperate	228	Johnson et al. (2020)	74	Johnson et al. (2020)
	Cool Temperate	N/A	–	N/A	–
Salt marsh	Tropical	162	(Calculated)	1.29	(Calculated)
	Subtropical	150	(Calculated)	1.29	(Calculated)
	Warm Temperate	169	Els (2019), Raw et al. (2019b)	7.12	Els (2019), Banda et al. (2021)
	Cool Temperate	76	(Calculated)	6.00	Brown & Rajkaran (2020)
Seagrass	Tropical	41	(Calculated)	4.56	Mvungi & Pillay (2019)
	Subtropical	99	(Calculated)	3.54	(Calculated)
	Warm Temperate	124	Els (2017, 2019)	2.08	Els (2019)
	Cool Temperate	56	(Calculated)	2.08	Mvungi & Pillay (2019)
4	**IPCC default values (mineral soils)**				
	Biogeographic Region	**Soil (Mg C.ha^{-1})**	**References**	**AGB (Mg C.ha^{-1})**	**References**
Mangrove	Tropical Wet	286	IPCC (2014a)	192	IPCC (2014a)
	Tropical Dry	286	IPCC (2014a)	92	IPCC (2014a)
	Subtropical	286	IPCC (2014a)	75	IPCC (2014a)
Salt marsh		226	IPCC (2014a)	ND	-
Seagrass		108	IPCC (2014a)	ND	-

The estimation methods (Table 3.8) used to calculate the total C stocks in South African blue carbon ecosystems provided a range of values (Figure 3.1). For mangroves, the total C stock estimates were similar between methods in comparison to the estimates for salt marsh. For salt marsh, the estimate using the IPCC default value (Method 4) was much higher. In comparison, for submerged macrophytes, the total C stock estimate using values from comparable bioregions in Australia (Method 2) was much lower. By comparing the different estimates, **Method 3 – Extrapolation based on biogeographic variability – was selected for all subsequent calculations**. This method included variability across all biogeographic regions and the extrapolations were based on *in situ* measurements from South African study sites.

Total C stocks for each blue carbon ecosystem were then calculated and compared between biogeographic regions (Figure 3.2). The largest C stocks are located in salt marshes, as these represent the largest blue carbon ecosystem areas in the country. Mangroves in the subtropical bioregion also make a considerable contribution towards total C stocks, as these ecosystems store the most C per unit area. Overall, submerged macrophytes make the smallest contribution across all bioregions, because these ecosystems cover the smallest area.

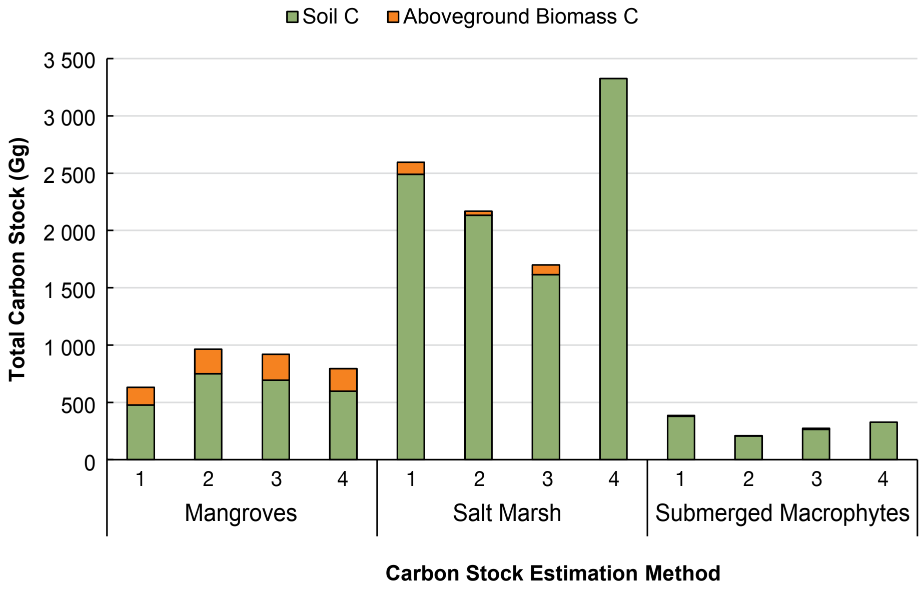


FIGURE 3.1: TOTAL CARBON STOCKS (GG) CALCULATED FOR SOIL AND ABOVEGROUND BIOMASS (AGB) OF BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA USING DIFFERENT ESTIMATION METHODS: 1) EXTRAPOLATION OF MEASURED VALUES TO ALL ESTUARIES; 2) ESTIMATES OF C STOCKS FROM COMPARABLE BIOGEOGRAPHIC REGIONS IN AUSTRALIA; 3) EXTRAPOLATION OF MEASURED VALUES INCLUDING BIOGEOGRAPHIC VARIABILITY; 4) IPCC DEFAULT VALUES FROM THE 2013 WETLANDS SUPPLEMENT (NO DEFAULTS SUPPLIED FOR AGB IN SALT MARSHES AND SEAGRASSES).

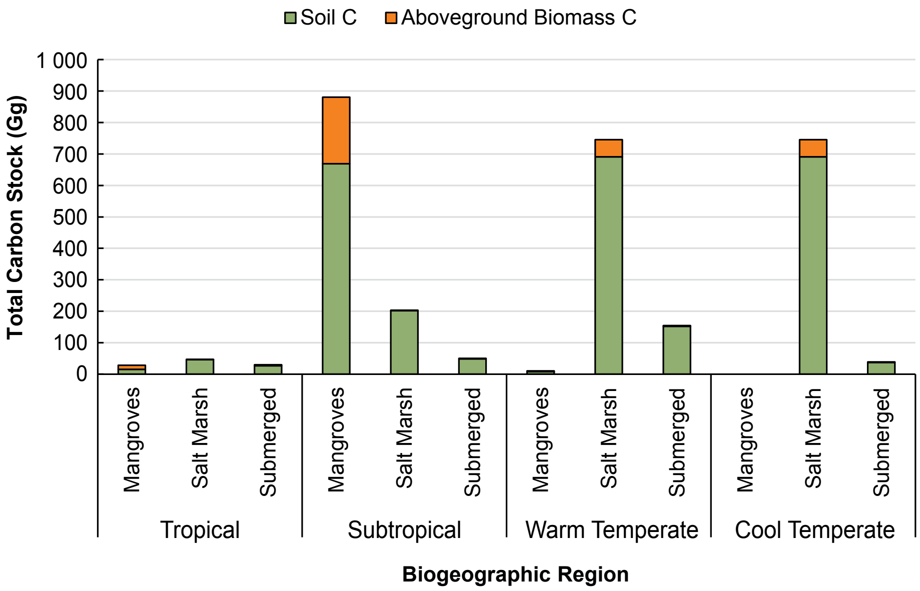


FIGURE 3.2: COMPARISON OF PRESENT TOTAL CARBON STOCKS (Gg) CALCULATED FOR SOIL AND ABOVEGROUND BIOMASS (AGB) OF BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA. STOCKS ARE COMPARED BETWEEN BIOGEOGRAPHIC REGIONS.

3.4.2 Calculating Total Historical Emissions and Removals

The historical emissions and removals trends were calculated by considering the **disturbances and drivers that have been reported to influence blue carbon ecosystems over time**. Spatial and non-spatial records of area change were incorporated from the National Blue Carbon Map geodatabase and metadata.

For each estuary where a change in blue carbon area (loss or gain) has been reported, the associated change in C stock was calculated. C stock calculations followed the same approach as described above (Method 3). **Emissions resulting from the loss or degradation of blue carbon ecosystems were calculated following the guidelines in Chapter 4 of the IPCC Wetlands Supplement** (IPCC 2014a). In these guidelines, CO_2 emissions and removals from blue carbon ecosystems can be calculated for four activities:

1. Forest management practices in mangroves;
2. Extraction (excavation, dredging, construction of ponds for aquaculture or salt production);
3. Drainage (biomass generally removed, the soil is intact but has become dry);
4. Rewetting, revegetation or creation of mangroves, salt marshes and seagrasses (rehabilitation and restoration).

Changes in the area for South African blue carbon ecosystems were assigned to one of these categories to allow for transparency in the calculations. Figure 3.3 shows how the categories were assigned (a list of categories and their corresponding National Land Cover Class is provided as part of the spatial metadata – Appendix II).

Areas classified as 'Developed' in the geodatabase are considered transformed and were therefore placed in the **'Extraction' category**, alongside areas classified as 'Dams', 'Saltworks' and 'Ponds'. Areas classified as 'Disturbed' were subdivided where possible into categories such as **'Agriculture'** and **'Grassed'**, where the soil is intact and unsaturated, but biomass has been removed. In contrast, areas classified as 'Disturbed' represented a localised impact **(such as cattle grazing, trampling, etc.)** where the soil is intact and unsaturated, but some of the biomass is still in place. All the 'Disturbed' areas were placed in the **'Drainage' category for mangroves and salt marshes**. For submerged macrophytes, areas classified as 'Disturbed' were treated separately as these are not drained, but direct anthropogenic impacts have impacted the biomass and soil. Areas where blue carbon ecosystems have expanded following anthropogenic interventions were placed in the **'Rewetting/revegetation'** category. Although mangrove harvesting is an anthropogenic activity that releases emissions, quantitative data on the annual harvesting rates

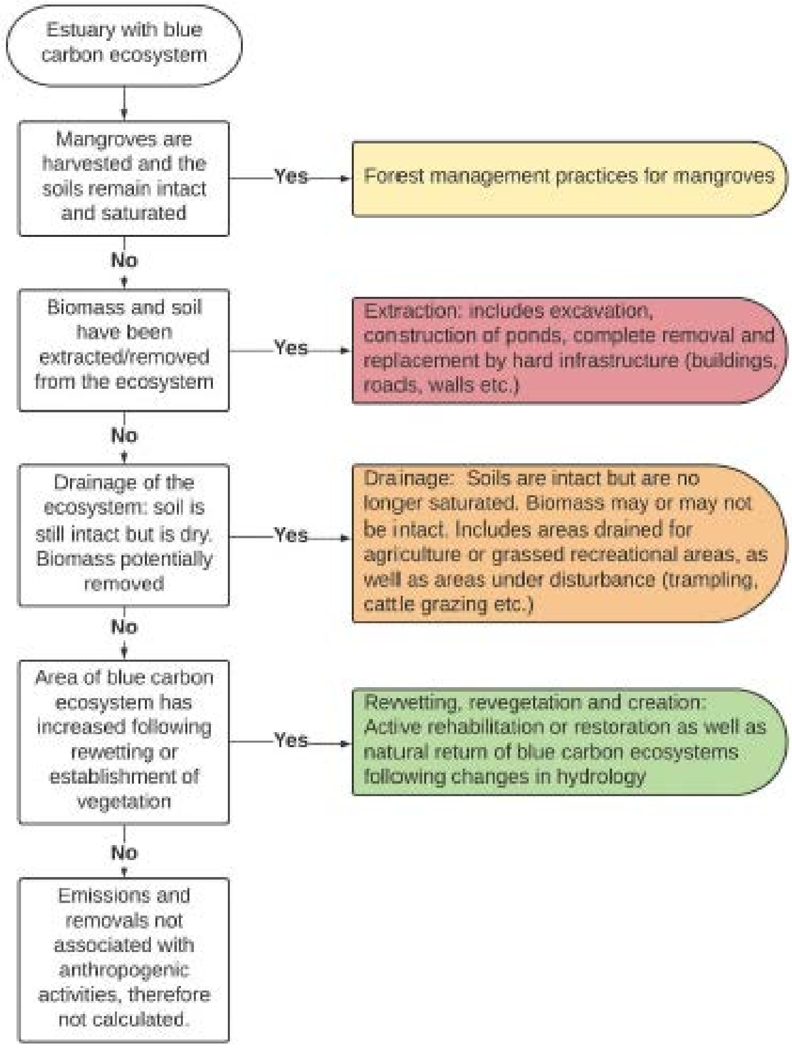


FIGURE 3.3: DECISION TREE TO ASSIGN REPORTED CHANGES IN BLUE CARBON ECOSYSTEMS TO THE EMISSIONS AND REMOVALS CATEGORIES PROVIDED BY THE IPCC 2013 WETLANDS SUPPLEMENT. ADAPTED FROM IPCC (2014).

in South Africa are limited and were therefore not included in the assessment. The IPCC Wetlands Supplement does not provide guidance to estimate CO_2 emissions and removals for areas that have not been impacted by anthropogenic activities. Blue carbon ecosystems that have not been disturbed or degraded are therefore not included.

To provide a preliminary estimate, the **total historical emissions and removals were calculated by comparing the present C stocks to the C stocks estimated from past area coverage of blue carbon ecosystems** (Figure 3.4). Past area coverage has been reported in the NBA 2018 metadata and has been derived from a collection of previous studies and reports carried out for both research and monitoring purposes by universities, research organisations and government. Overall, past C stocks were higher than present C stocks in South African blue carbon ecosystems. The largest past C stock was estimated for salt marsh in the **warm-temperate biogeographic region**, followed by **salt marsh in the cool-temperate region**, because salt marsh covers the largest area of all the blue carbon ecosystems. **Mangrove C stocks in the subtropical biogeographic region have increased** in comparison to previous records, and this is attributed to the expansion of mangroves at **uMhlathuze Estuary**. For submerged macrophytes, past and present C stocks are mostly similar across all biogeographic regions.

To calculate the total GHG emissions and removals associated with these changes in C stocks, the type of activity that occurred (Figure 3.3) was assigned to the ecosystem area change in each estuary. This information was available from the 2018 NBA metadata on estuarine ecosystem changes over time.

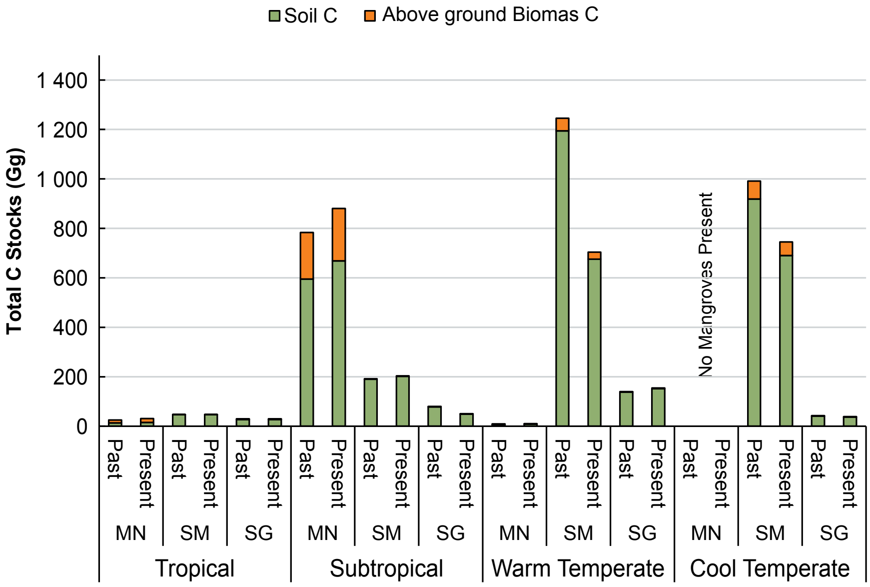


FIGURE 3.4: COMPARISON OF PAST AND PRESENT C STOCKS OF SOUTH AFRICAN BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH, SG = SUBMERGED MACROPHYTES) ACROSS DIFFERENT BIOGEOGRAPHIC REGIONS. C STOCKS WERE ESTIMATED BASED ON REPORTED AREA COVERAGE. PAST AREA COVERAGE WAS DERIVED FROM AREAS LOST DUE TO LAND-USE CHANGE SINCE THE 1930s.

TOTAL EMISSIONS FROM EXTRACTION ACTIVITIES

The change in C stocks for the biomass pool following Extraction activities (defined in Figure 3.3) was calculated from the IPCC 2013 Wetlands Supplement using Equation 4.4:

$$\Delta C_{B-CONVERSION} = \Sigma_{v,c} \{B_{AFTER} \cdot (1 + R) - B_{BEFORE} * (1 + R)\} \cdot CF \cdot A_{CONVERTED}$$

Where,

$\Delta C_{B-CONVERSION}$ = Changes in biomass carbon stock from conversion due to extraction activities; Mg C

B_{AFTER} = Carbon stock in aboveground biomass per unit of area, immediately after the conversion, by vegetation type (v), and climate (c); default value = 0

B_{BEFORE} = Carbon stock in aboveground biomass per unit of area, immediately before the conversion, by vegetation type (v), and climate (s); Mg d.m. ha^{-1}

R = Ratio of belowground to aboveground biomass by vegetation type (v) and climate (c) CF = Carbon fraction of dry matter

$A_{CONVERTED}$ = Area of conversion by vegetation type (v), and climate (c); ha

Similarly, the change in C stocks from the soil pool following 'Extraction' activities was calculated using Equation 4.6:

$$\Delta C_{SO-CONVERSION} = \Sigma_{v,s} (SO_{AFTER} - SO_{BEFORE})_{v,s} \cdot A_{CONVERTED_{v,s}}$$

Where,

$\Delta C_{SO-CONVERSION}$ = The initial change in soil carbon stock from conversion due to extraction activities by vegetation type (v), and soil type (s); Mg C

SO_{AFTER} = Soil carbon stock per unit of area, immediately after the conversion, by vegetation type (v), and soil type (s); default value = 0

SO_{BEFORE} = Soil carbon stock per unit of area, immediately before the conversion, by vegetation type (v), and soil type (s); Mg C.ha^{-1}

$A_{CONVERTED}$ = Area of conversion by vegetation type (v), and soil type (s); ha

Both equations above follow the IPCC Tier 1 methodology, which assumes that all C stocks **are completely extracted and converted to CO_2 emissions following an Extraction activity**. Once the change in C associated with the activity has been calculated, the associated CO_2 emissions are calculated as follows:

$$E_{EXTRACTION} = \text{Total}\,\Delta C_{EXTRACTION} \cdot \frac{44}{12}$$

Where,

$E_{EXTRACTION}$ = Emissions associated with extraction activities (t CO_2 equivalent)

Total $\Delta C_{EXTRACTION}$ = Total change in carbon in both biomass and soil carbon pools following extraction activities; Mg C

$\frac{44}{12}$ = Ratio of molecular weight of CO_2 to C

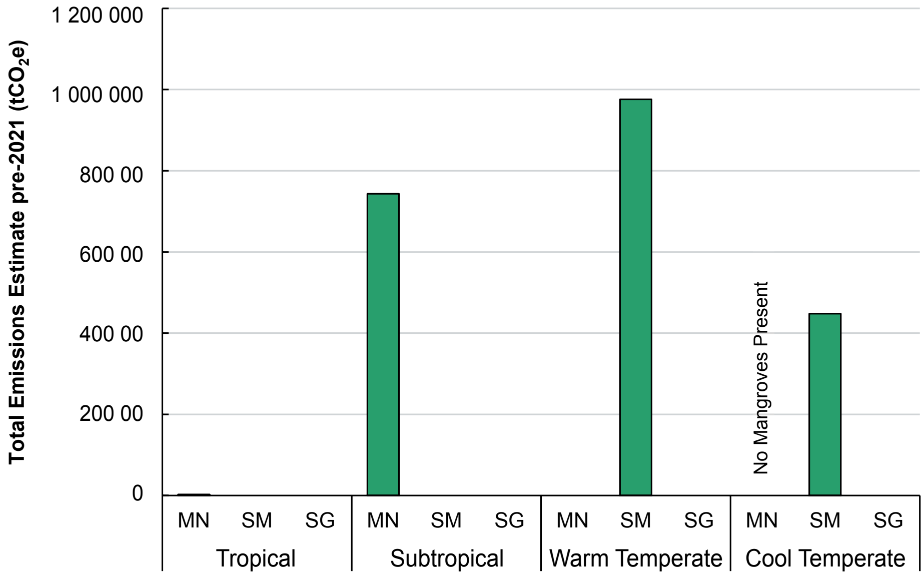


FIGURE 3.5: TOTAL CO_2 EMISSIONS FROM EXTRACTION ACTIVITIES CARRIED OUT IN BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH, SG = SUBMERGED MACROPHYTES) SINCE THE 1930s IN DIFFERENT BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA.

The total GHG emissions associated with Extraction activities were compared between blue carbon ecosystems and across the different biogeographic regions (Figure 3.5).

The largest emissions were associated with **the extraction activities that resulted in the loss/transformation of salt marsh in the warm-temperate region, followed by mangroves in the subtropical region**. Extraction activities have had a limited impact on submerged macrophytes at the national scale. However, at the scale of the individual estuaries these ecosystems can be significantly impacted by development and infrastructure, particularly marinas, jetties and slipways.

TOTAL EMISSIONS FROM DRAINAGE ACTIVITIES

When the Drainage activity was associated with **agriculture**, or conversion into grassed recreational areas, it was **assumed that 100% of the biomass C was lost**. Equation 4.4 from IPCC (2014a) was therefore used as described above for Extraction activities to calculate the change in biomass C stocks.

In comparison, if the Drainage activity was associated with **disturbance/degradation**, it was **assumed that 50% of the biomass C stock remained intact**. The change in C stocks from the biomass pool for blue carbon ecosystems that experienced disturbance was calculated from the IPCC (2006) Guidelines using Equation 2.14:

$$\Delta C_{CONVERSION} = \Sigma_i \{(B_{AFTER} - B_{BEFORE})_{v,s} \cdot \Delta A_{TO\text{–}CONVERTED}\} \cdot CF$$

Where,

$\Delta C_{CONVERSION}$ = Initial change in biomass carbon stock on land converted to another land category; Mg C

B_{AFTER} = Biomass stock immediately after the conversion, by land type (i); Mg d.m.ha^{-1}

B_{BEFORE} = Biomass stock immediately before the conversion, by land type (i); Mg d.m.ha^{-1}

$\Delta A_{TO-CONVERTED}$ = Area of land use (i) converted to another land-use category; ha

CF = Carbon fraction of dry matter

The GHG emissions from the soil C pool following Drainage activities (conversion to agriculture or grassed recreational areas, as well as areas affected by disturbance) were calculated using Equation 4.8 from IPCC (2014a):

$$CO_{2-SO-SR} = (A_{DR} \cdot EF_{DR})$$

Where,

$CO_{2-SO-SR}$ = CO_2 emissions from aggregated organic and mineral soil carbon associated with drainage; Mg C

A_{DR} = Area of land that has been impacted by the drainage activity; ha

EF_{DR} = CO_2 emissions factor associated with drainage on aggregated organic and mineral soils (7.9)

The total GHG emissions associated with Drainage activities were compared between blue carbon ecosystems and across the different biogeographic regions (Figure 3.6). **The largest emissions were associated with the drainage of salt marsh for agriculture in the warm-temperate and cool-temperate biogeographic regions.**

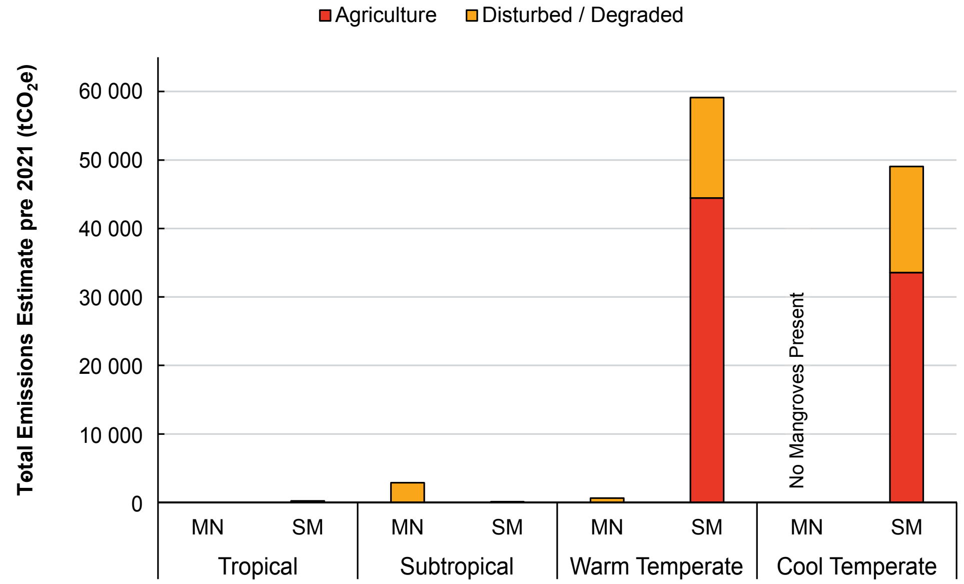


FIGURE 3.6: TOTAL CO_2 EMISSIONS FROM DRAINAGE ACTIVITIES (CONVERSION TO AGRICULTURE OR RECREATIONAL/GRASSED AREAS, AS WELL AS DISTURBANCE) CARRIED OUT IN BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH) SINCE THE 1930S IN DIFFERENT BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA.

BOX 5: Submerged Macrophytes and Drainage Activities

Emissions due to drainage are only estimated for mangroves and salt marshes (IPCC 2014), as drainage of submerged macrophytes implies an extractive activity. However, the effect of disturbance on emissions from submerged macrophytes can still be estimated in a similar way as described above.

TOTAL REMOVALS FROM REWETTING, REVEGETATION AND CREATION ACTIVITIES

In areas where blue carbon ecosystems have been **established or created** as a result of **anthropogenic interventions**, including direct management practices, GHG removals can be estimated. Rewetting activities **saturate the soil of previously drained sites**, and this is generally the first step towards the re-establishment of the lost vegetation. Revegetation can occur naturally following rewetting, or the vegetation can be re-established through planting or seeding. Blue carbon ecosystems can also be created in suitable coastal settings.

The change in biomass C stocks was calculated as follows:

$$\Delta C_B = C_{t_2} - C_{t_1}$$

Where,

ΔC_B = Change in biomass C stocks for land remaining in the same category; Mg C

C_{t_2} = Total C in biomass at time t_2; Mg C

C_{t_1} = Total C in biomass at time t_1; Mg C

For soil C changes associated with rewetting, revegetation and creation, the CO_2 emission factor is approximated as zero when resaturated soils are devoid of vegetation (IPCC 2014a). Soil organic C then accumulates when the vegetation is re-established to develop a CO_2 sink. **It is assumed that the rate of soil C accumulation is immediately equivalent to that in natural settings following the restoration/rewetting/creation activity** (IPCC 2014a).

CO_2 emissions from rewetting, revegetation and creation were calculated using Equation 4.7 from IPCC (2014a):

$$\mathrm{CO}_{2SO-RE} = \Sigma_{v,s,c}(A_{RE} \cdot EF_{RE})_{v,s,cD}\} \cdot CF$$

Where,

CO_{2SO-RE} = CO_2 emissions associated with rewetting, revegetation and creation activities by vegetation type (v), soil type (s), and climate (c); Mg C

A_{RE} = Area of soil that has been influenced by rewetting, revegetation and creation activities by vegetation type (v), soil type (s), and climate (c); ha

EF_{RE} = CO_2 emissions from aggregated mineral and organic soils that have been influenced by rewetting, revegetation and creation activities by vegetation type (*v*), soil type (*s*), and climate (*c*); (EF_{RE} = –1.62 for mangroves; –0.91 for salt marsh; –0.43 for seagrass)

CO_2 emissions associated with changes in C stocks were then calculated as described above using the ratio of molecular weight of CO_2 to C. Negative values of CO_2 emissions indicate **removals (accumulation of C)**. The total **CO_2 removals associated with rewetting, revegetation and creation activities** was then compared between blue carbon ecosystems and across the biogeographic regions of South Africa (Figure 3.7). The largest removals have occurred for **mangroves in the subtropical biogeographic region**, and this is associated with the expansion of the forest at **uMhlathuze Estuary**. Only removals associated with anthropogenic activities are measured – natural sinks are not included in the IPCC 2013 guidelines.

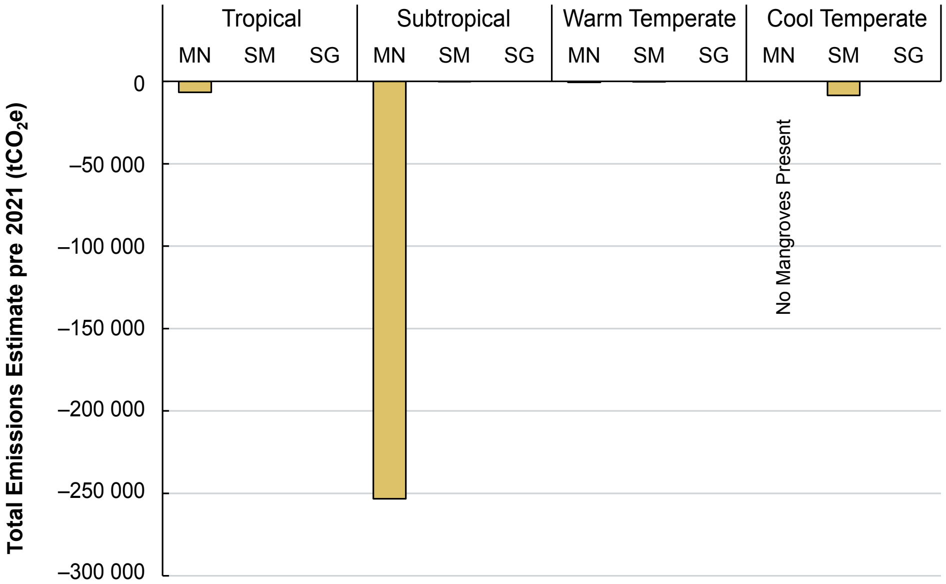


FIGURE 3.7: TOTAL CO_2 REMOVALS FROM REWETTING, REVEGETATION OR CREATION ACTIVITIES CARRIED OUT IN BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH, SG = SUBMERGED MACROPHYTES) SINCE THE 1930S IN DIFFERENT BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA.

TOTAL HISTORICAL EMISSIONS AND REMOVALS

From the above, the total emissions and removals of CO_2 from blue carbon ecosystems can be compared between different activities across all biogeographic regions (Figure 3.8). Although the **removals associated with mangroves in the subtropical region were relatively large**, these do not offset the emissions that have occurred as a result of extraction and drainage activities in salt marshes. **Extraction activities have made the largest contribution to historical emissions from blue carbon ecosystems.**

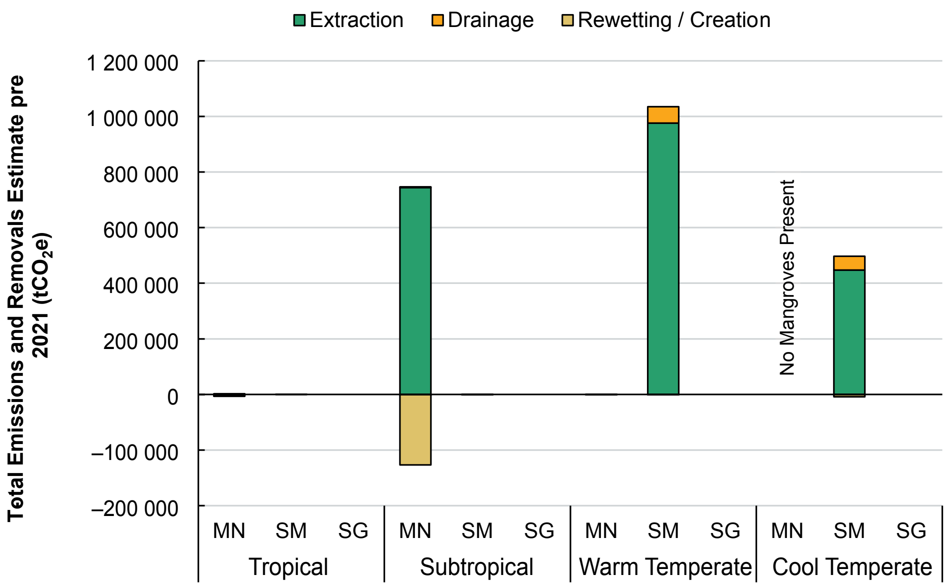


FIGURE 3.8: TOTAL CO_2 EMISSIONS AND REMOVALS FROM BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH, SG = SUBMERGED MACROPHYTES) SINCE THE 1930S IN DIFFERENT BIOGEOGRAPHIC REGIONS OF SOUTH AFRICA.

3.4.3 Calculating Total Historical Emissions and Removals Over Time

As historical data for area coverage of blue carbon ecosystems is not available for every year in every estuary, the **temporal trends in GHG emissions and removals were estimated over specific time periods**. Changes in area and the corresponding activity in different years were assigned into time periods of: < 1930, 1931–1950, 1951–1970, 1971–1990, 1991–2000, 2001–2010, 2011–2020. **Each change in area was then assigned to one of the IPCC activities** (Figure 3.3). The corresponding **change in C stocks and associated GHG emissions and removals could then be calculated for each area change associated with the specific time periods and IPCC activities** as described above for the total historical emissions and removals.

The largest source of CO_2 emissions from blue carbon ecosystems has been due to extraction activities (transformation that results in loss of the ecosystem). Net emissions have declined over time, as new activities that generate **CO_2 emissions have been limited over recent decades**. This is partially a reflection of available land in the floodplains already being utilised; however, regulatory and management practices that restrict removal or degradation of areas within the EFZ have also contributed towards this. These include the application of NEMA policies, as well as the development and implementation of estuary management plans at selected systems. The observed increase in CO_2 removals between 1971–1990 **is the result of the large mangrove expansion that occurred at the uMhlathuze Estuary**. The mangrove expansion trend (and the associated CO_2 removals) slowed in the subsequent decades as the maximum area available has become occupied.

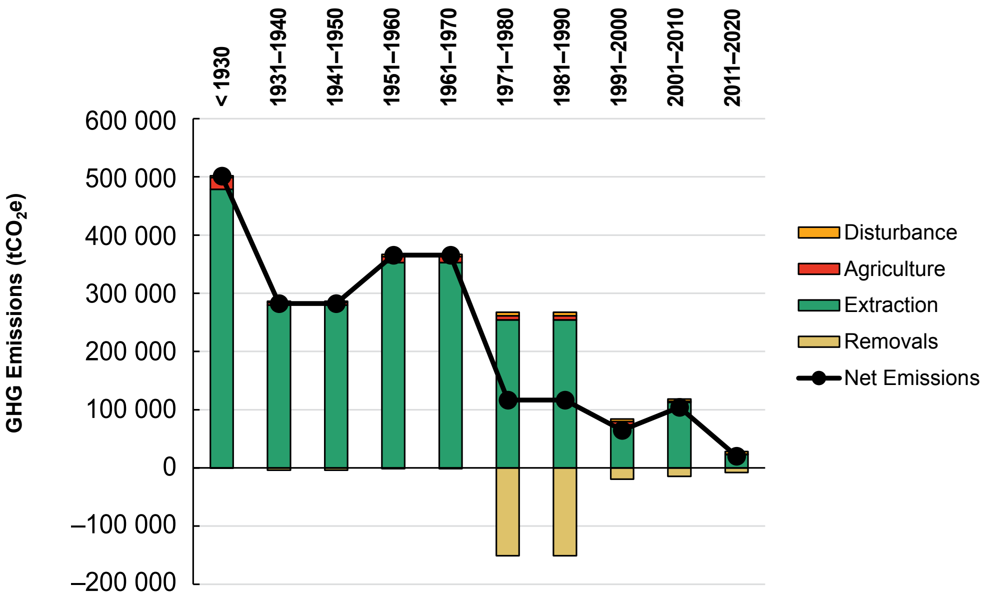


FIGURE 3.9: HISTORICAL TREND IN CO_2 EMISSIONS AND REMOVALS FROM SOUTH AFRICAN BLUE CARBON ECOSYSTEMS AND THE CORRESPONDING CONTRIBUTION OF DIFFERENT IPCC ACTIVITIES TO THESE TRENDS. NET EMISSIONS REPRESENT THE SUM OF ALL EMISSIONS AND REMOVALS FOR A SPECIFIC TIME PERIOD.

TABLE 3.9: HISTORICAL ANNUAL GHG EMISSIONS AND REMOVALS (tCO_2 E.yr^{-1}) FROM SOUTH AFRICAN BLUE CARBON ECOSYSTEMS ESTIMATED FROM CHANGE IN AREA FOLLOWING ANTHROPOGENIC ACTIVITIES. DISTURBANCE ACTIVITIES INCLUDE CATTLE GRAZING, BIOMASS HARVESTING, BAIT DIGGING, TRAMPLING BY PEOPLE AND CATTLE.

	EXTRACTION	DRAINAGE		REWETTING/ CREATION	NET EMISSIONS
		Agriculture	**Disturbance**	**Creation**	**Emissions**
1931-1950	27 973.22	461.97	208.03	-413.20	28 230.01
1951-1970	35 270.96	1 001.23	428.27	-144.11	36 556.35
1971-1990	25 404.44	734.44	598.34	-15 101.05	11 636.17
1991-2000	7 405.93	572.80	406.39	-1 939.21	6 445.90
2001-2010	11 238.35	215.84	397.80	-1 448.73	10 403.26
2011-2020	2 269.32	95.88	450.15	-786.94	2 028.41

BOX 6: The Scale of Activities and Associated Emissions

For this assessment, activities and associated emissions have been estimated at the national scale using spatial data as the primary information source. From the historical emissions trends, it appears that limited development has occurred since 1990, but this is not necessarily the case. As the area available for transformation within the EFZ is currently much smaller than in earlier decades, activities that are associated with emissions are also occurring at smaller scales. At the level of individual estuaries, building infrastructure such as **marinas, jetties and slipways** results in removal of blue carbon ecosystems. These small area changes are difficult to map in real time as they are not easily delineated from **imagery and may not be ground-truthed** if there is not ongoing research or monitoring at a particular estuary. Drainage activities can be even more challenging to assess at small scales. Recent work in the NBA has shown that land-use change and transformation ***is still occurring at a rapid pace, and particularly in coastal regions***. This needs to be accounted for in the blue carbon sink baseline scenario, even if it has not been directly recorded in the existing spatial datasets. It is expected that ecosystem conversion and disturbance will continue at rates of **2-3% per decade**.

3.5 SETTING THE GHG EMISSIONS AND REMOVALS GOALS FOR BLUE CARBON ECOSYSTEMS AND DEVELOPING THE BASELINE SCENARIO

The assessment of the historical emissions and removals trends for blue carbon ecosystems showed that **activities that result in transformation** of the ecosystem (such as for development and agriculture) **have declined over the past three decades**. The scale of disturbance-related impacts has also declined, but to a lesser degree. Considering the trajectories of these activities (Figure 3.9), it appears that all emissions associated with anthropogenic activities are expected to decline to zero along the baseline trajectory. This **decline has been associated with the implementation of policies** that reduce direct impacts on estuarine ecosystems, such as the protection of the EFZ through environmental impact assessment legislations and estuary management plans (see Box 6). However, other **anthropogenic pressures that do not result in land-use change are still expected to impact the area cover and C stocks of blue carbon ecosystems**, such as water resource development that reduces freshwater inflow to estuaries and ongoing pollution (e.g. from overloaded WWTWs and inputs of effluent to estuaries). Although these drivers cannot be directly measured using remote sensing, it would be possible to monitor changes using existing infrastructure such as estuary tidal gauges, river inflow gauges and water quality stations. About 10–15% of estuaries are currently monitored, highlighting the need for additional stations in the exiting DWS network (Van Niekerk et al. 2019a).

A conceptual model was constructed to illustrate the relative contribution of different pressures to GHG emissions from blue carbon ecosystems over time (Figure 3.10). The trajectory of emissions associated with transformation and land-use change follows the trend found from analysis of the historical data. Additional abiotic anthropogenic pressures **(freshwater flow modification, water quality changes/eutrophication, artificial breaching)** were included based on the recent assessment of pressures on South African ecosystems provided by the 2018 NBA. The trajectories of emissions associated with abiotic pressures were developed from historical reports and available records on the construction of dams and wastewater treatment works, artificial breaching activities and the rate of coastal population growth.

To build the baseline scenario for GHG emissions from blue carbon ecosystems, **the effects of pressures on C stocks were assessed**. The abiotic pressures associated with water resource development and management activities were scaled based on the potential impact they would have on blue carbon ecosystems. Flow modification (reduced freshwater inflow) was predicted to have the highest impact, followed by water quality and then artificial breaching. Additionally, the rate of projected transformation was included to capture loss of blue carbon ecosystems to **small-scale extraction and drainage activities**. The blue carbon emission baseline was developed using a modified trajectory approach. To achieve this, the historical trajectory was modified to reflect the **expected impacts of changes in the drivers**.

The predicted percentage decline in ecosystem area was estimated **per decade for each of the blue carbon ecosystems** based on the pressure score assigned to each specific estuary in the 2018 NBA. Pressure scores have been assigned as L = Low, M = Medium, H = High, VH = Very High (Van Niekerk et al. 2019b). The baseline was calculated over the available historical dataset (< 1930–2021) and projected every decade to 2050 (Table 3.10).

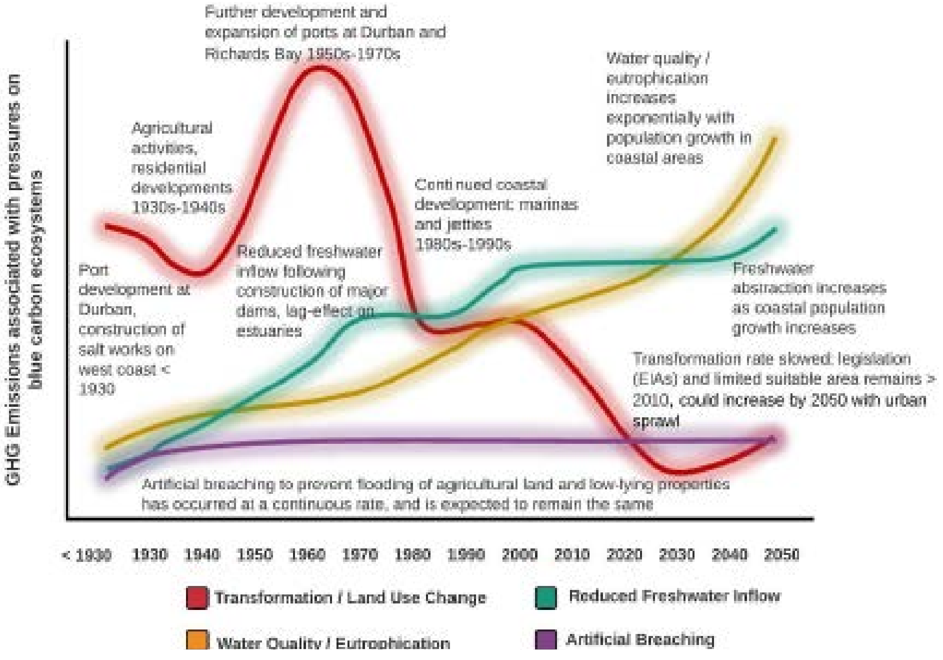


FIGURE 3.10: CONCEPTUAL MODELS OF THE GHG EMISSIONS ASSOCIATED WITH PRESSURES ON BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA. THESE PRESSURE TRENDS WERE USED TO CONSTRUCT THE BASELINE.

TABLE 3.10: PREDICTED PERCENTAGE DECLINE IN BLUE CARBON ECOSYSTEM AREA PER DECADE IN RESPONSE TO ABIOTIC PRESSURES ASSOCIATED WITH WATER RESOURCE DEVELOPMENT AND MANAGEMENT ACTIVITIES, AS WELL AS TRANSFORMATION. PERCENTAGES REPRESENT LOSS RELATIVE TO 2021 AREA COVER AND ARE SCALED RELATIVE TO THE ASSIGNED PRESSURE SCORE (L = LOW, M = MEDIUM, H = HIGH, VH = VERY HIGH).

PRESSURE: **REDUCED FRESHWATER INFLOW/FLOW MODIFICATION** (NO PROJECTED DIRECT IMPACT ON SUBMERGED MACROPHYTES AS THESE ARE LESS DEPENDENT ON FRESHWATER; SALT MARSHES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

		Predicted percentage decline in area relative to 2021 by the end of the decade		
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	4.00	5.00	6.00
	H	3.00	3.75	4.50
	M	2.00	2.50	3.00
	L	1.00	1.25	1.50
Salt Marsh	VH	5.00	7.00	9.00
	H	3.75	5.25	6.75
	M	2.50	3.50	4.50
	L	1.25	1.75	2.25

PRESSURE: **WATER QUALITY CHANGES/EUTROPHICATION** (SALT MARSHES AND SUBMERGED MACROPHYTES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

		Predicted percentage decline in area relative to 2021 by the end of the decade		
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	1.00	2.00	3.00
	H	0.75	1.50	2.25
	M	0.50	1.00	1.50
	L	0.25	0.50	0.75
Salt Marsh and Submerged Macrophytes	VH	3.00	5.00	7.00
	H	2.25	3.75	3.75
	M	1.50	2.50	2.50
	L	0.75	1.25	1.25

PRESSURE: **ARTIFICIAL BREACHING** (NO PROJECTED IMPACT ON MANGROVES AS THESE ECOSYSTEMS OCCUR IN SYSTEMS THAT ARE PREDOMINANTLY OPEN TO THE OCEAN; PRESSURE PREDICTED TO REMAIN CONSTANT)

		Predicted percentage decline in area relative to 2021 by the end of the decade		
	Estuary Score	2021–2030	2031–2040	2041–2050
Salt Marsh and Submerged Macrophytes	VH	6	6	6
	H	5	5	5
	M	4	4	4
	L	1	1	1

PRESSURE: **TRANSFORMATION** (NO PROJECTED IMPACT ON SUBMERGED MACROPHYTES AS THIS ECOSYSTEM IS GENERALLY NOT SUBJECTED TO LAND-USE CHANGE DUE TO BEING SUBMERGED)

		Predicted percentage decline in area relative to 2021 by the end of the decade		
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	(N/A)	0.5	0.75	1
		No pressure score assigned for transformation. The same% values are applied across all estuaries with mangroves.		
Salt Marsh	Intertidal	0.50	0.75	1.00
	Supratidal	0.50	1.00	2.00
		No pressure score assigned for transformation. The same% values are applied across all estuaries with intertidal and supratidal salt marsh.		

At the end of each decade, the difference in area in comparison to the current (2021) coverage was calculated and used to estimate the corresponding loss of C stocks and therefore GHG emissions. The GHG emissions were calculated using the same equations and approach as described above for the **historical emissions**. The GHG emissions baseline is represented separately as emissions due to transformation/land-use change (Figure 3.11) and emissions due to the three abiotic pressures associated with water resource development and management activities (Figure 3.12). A composite baseline which includes GHG emissions from all pressures is also included (Figure 3.13).

To demonstrate the sensitivity of the projected GHG emissions baseline model to the pressures, the predicted responses of the blue carbon ecosystems to each pressure were varied. This was achieved by developing a series

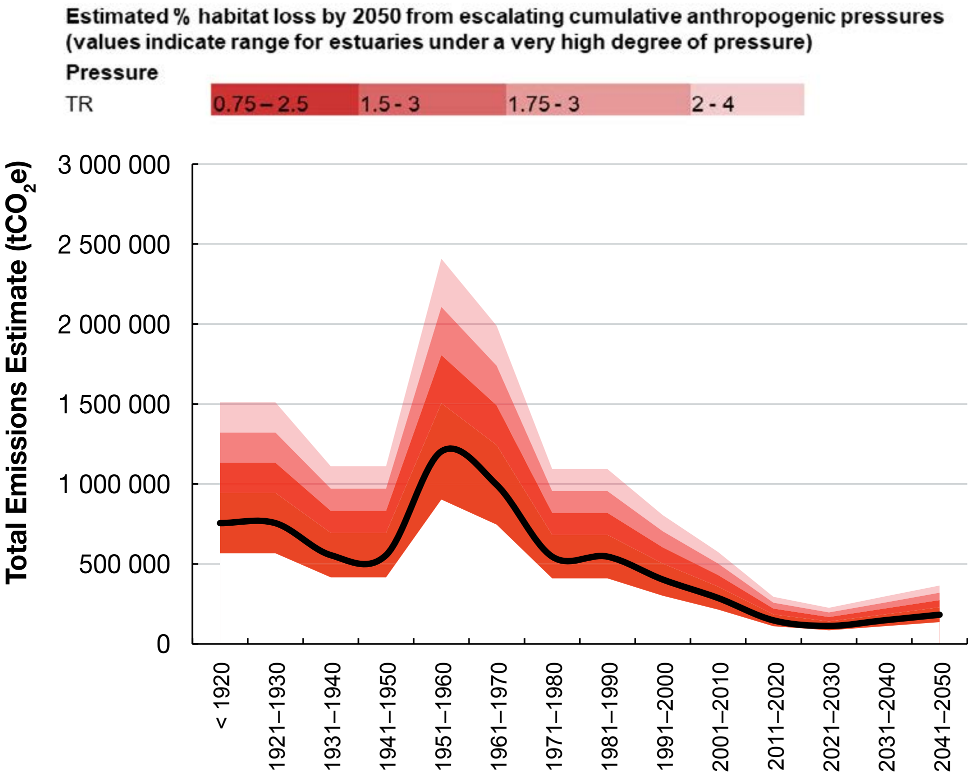
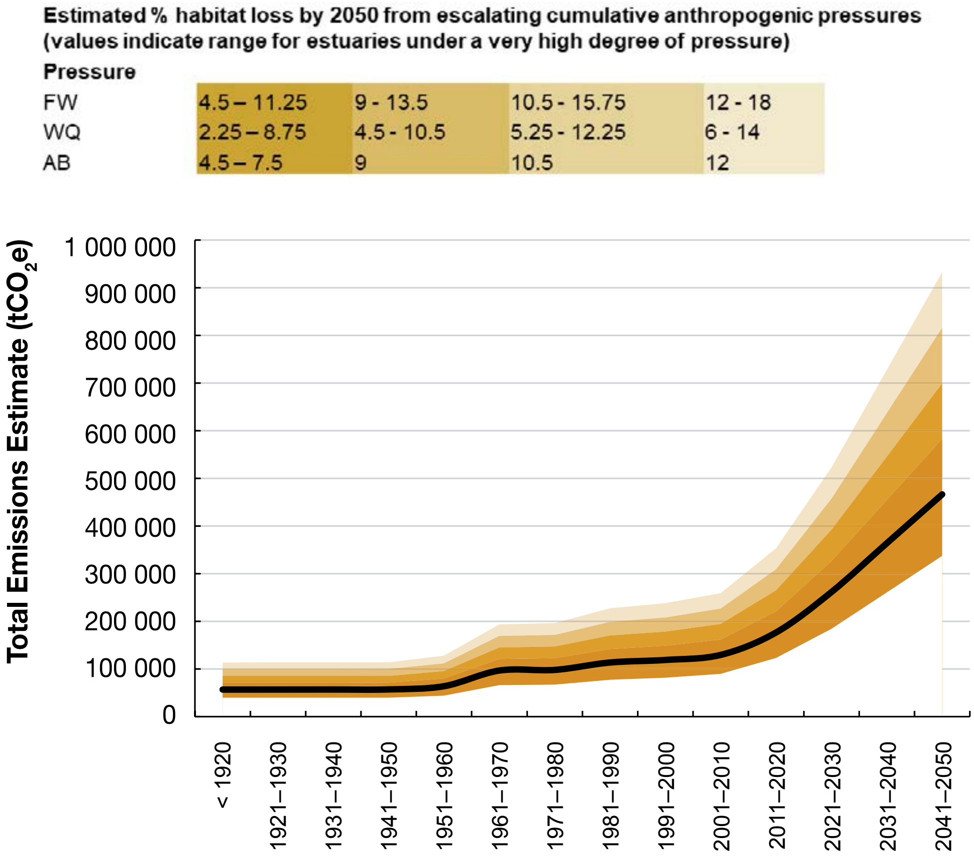


FIGURE 3.11: GHG EMISSIONS BASELINE FOR BLUE CARBON ECOSYSTEMS BASED ON EMISSIONS DUE TO TRANSFORMATION/LAND-USE CHANGE ONLY. THE RANGE OF PROJECTED HABITAT LOSS (PERCENT RELATIVE TO 2021 AREA) BY 2050 DUE TO TRANSFORMATION IS SHOWN FOR EACH MODEL.

of models with percentage range increases from the baseline model. In Figures 3.11–3.13, the shaded areas indicate the potential range of the baseline model if the predicted habitat loss in response to each pressure were scaled up by 25%, 50%, 75% and 100% respectively.

The GHG emissions baseline for blue carbon ecosystems for emissions only due to transformation shows a declining trend. In recent decades, emissions associated with transformation have declined as there has been limited development within EFZs as legislation has been implemented. Emissions due to transformation are projected to slightly increase in upcoming decades as recent work has shown there is an ongoing rapid rate of land-use change in coastal environments (Skowno et al. 2021)

The GHG emissions baseline for blue carbon ecosystems for emissions only due to abiotic pressures associated with water resource development and management shows a historical steady incline and a rapid increase is projected for upcoming decades. The impact of these pressures has been relatively low but is expected to compound due to several factors. The construction of dams has a significant impact on freshwater inflow, but these impacts are only being detected up to two decades post-construction. Water quality/eutrophication/pollution has increased over recent decades and is associated with population growth in coastal areas that exceeds the capacity of existing infrastructure. As freshwater abstraction continues, this could compound declining water quality as estuaries are not flushed by river flooding.



Estimated % habitat loss by 2050 from escalating cumulative anthropogenic pressures (values indicate range for estuaries under a very high degree of pressure)

Pressure				
FW	4.5 – 11.25	9 - 13.5	10.5 - 15.75	12 - 18
WQ	2.25 – 8.75	4.5 - 10.5	5.25 - 12.25	6 - 14
AB	4.5 – 7.5	9	10.5	12

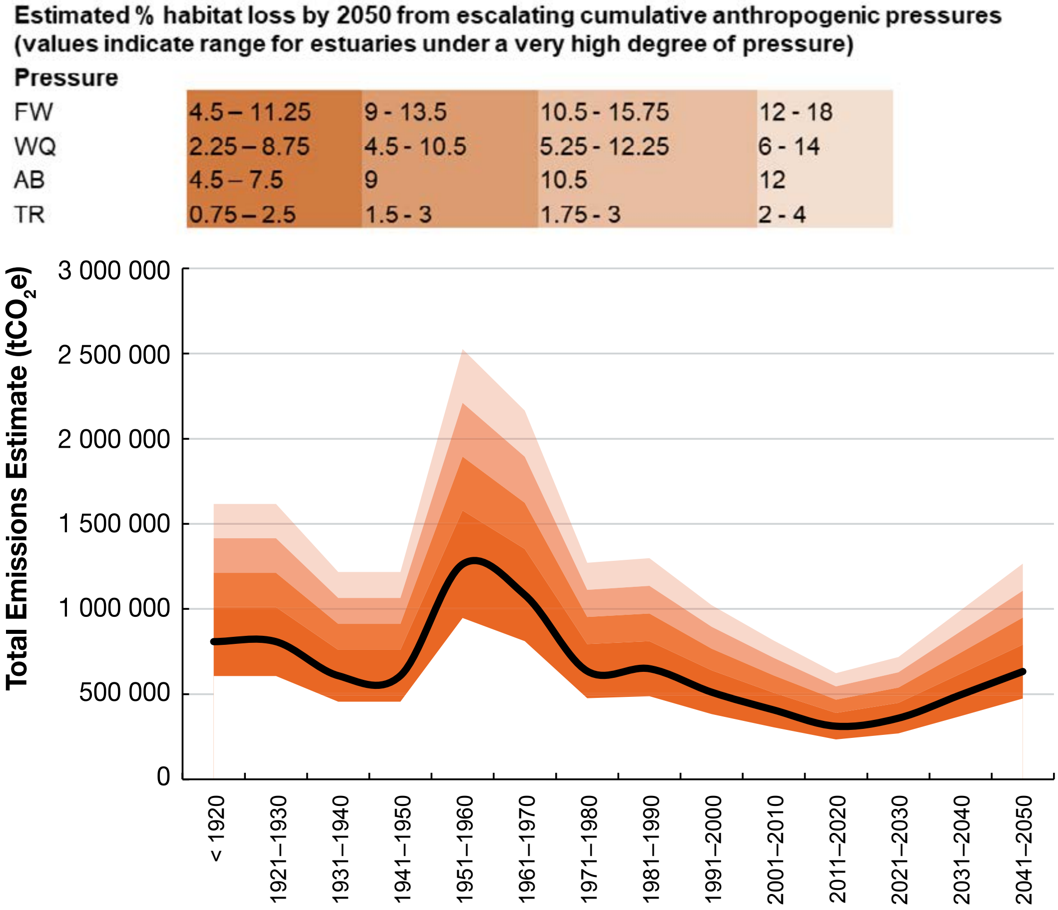
FIGURE 3.12: GHG EMISSIONS BASELINE FOR BLUE CARBON ECOSYSTEMS BASED ON EMISSIONS DUE TO COMPOUNDING ABIOTIC PRESSURES ASSOCIATED WITH WATER RESOURCE DEVELOPMENT AND MANAGEMENT ACTIVITIES ONLY. THE RANGE OF PROJECTED HABITAT LOSS (PERCENT RELATIVE TO 2021 AREA) BY 2050 DUE TO REDUCED FRESHWATER INFLOW/FLOW MODIFICATION (FW), WATER QUALITY/EUTROPHICATION/POLLUTION (WQ) AND ARTIFICIAL BREACHING (AB) IS SHOWN FOR EACH MODEL.

Similarly, if flows are reduced this can prevent some estuaries from breaching naturally to the ocean, thus requiring artificial breaching if stagnant water (which can be eutrophic or have pollution) leads to fish kills or flooding of low-lying properties.

The combined blue carbon emissions projected baseline (Figure 3.13) shows historical variability that is driven by emissions from transformation/land-use change. The incline from 2020 to 2050 is driven by emissions due to pressures associated with water resource development and management activities.

Between 2020 and 2030, emissions are projected to increase by ~47 200 t CO_2e (equal to 47.2 Gg CO_2e (Gigagram CO_2 equivalent)). In the following decade, from 2030 to 2040, emissions are projected to increase to 495.7 Gg CO_2e (184.2 Gg CO_2e more than 2020). Finally, from 2040 to 2050, emissions are projected to increase to 632.9 Gg CO_2e (321.2 Gg CO_2e more than 2020). The projected increase in emissions is the result of cumulative pressures that result in degradation and loss of blue carbon ecosystems.

Removals were not **incorporated as part of the baseline scenario, as these only occur following creation or**



Estimated % habitat loss by 2050 from escalating cumulative anthropogenic pressures (values indicate range for estuaries under a very high degree of pressure)

Pressure				
FW	4.5 – 11.25	9 - 13.5	10.5 - 15.75	12 - 18
WQ	2.25 – 8.75	4.5 - 10.5	5.25 - 12.25	6 - 14
AB	4.5 – 7.5	9	10.5	12
TR	0.75 – 2.5	1.5 - 3	1.75 - 3	2 - 4

FIGURE 3.13: GHG EMISSIONS BASELINE FOR BLUE CARBON ECOSYSTEMS BASED ON EMISSIONS FROM BOTH TRANSFORMATION/LAND-USE CHANGE AS WELL AS FROM ABIOTIC PRESSURES ASSOCIATED WITH ANTHROPOGENIC ACTIVITIES. THE RANGE OF PROJECTED HABITAT LOSS (PERCENT RELATIVE TO 2021 AREA) BY 2050 DUE TO REDUCED FRESHWATER INFLOW/ FLOW MODIFICATION (FW), WATER QUALITY/EUTROPHICATION/POLLUTION (WQ), ARTIFICIAL BREACHING (AB) AND TRANSFORMATION (TR) IS SHOWN FOR EACH MODEL.

restoration of habitats, and these are not included as part of the existing measures. Removals are included when restoration activities are considered as part of the potential mitigation activities (Section 5).

This baseline is a preliminary estimate based on the available data; however, it can be revised and updated as more information becomes available. Adjustments to the historical emissions and removals estimates will also impact the projected baseline, and this could occur following: 1) improved techniques for mapping coverage of blue carbon ecosystems and land-use change activities; 2) including additional activities or pressures that impact emissions from blue carbon ecosystems; and 3) updating the C stock values after more *in situ* quantitative assessments have been carried out, particularly for under-represented biogeographic regions.

4. IDENTIFICATION OF PRINCIPAL CLIMATE CHANGE MITIGATION AND ADAPTATION ACTIONS

The impacts of climate change are devastating for both natural and human systems, making it a collective global challenge that needs to be addressed using **transdisciplinary approaches that deliver sustainable and socially just outcomes** (Fam et al. 2017).

Climate change mitigation attempts to maintain greenhouse gas (GHG) levels in the atmosphere at a stable concentration to avoid dangerous impacts on the climate system. **Mitigation** is formally defined as '**the human intervention to reduce the sources or enhance the sinks of greenhouse gases**' (IPCC 2014b). In comparison, climate change adaptation focuses on actions to face the consequences of climate change. **Adaptation** refers to '**changes in ecological, social, or economic systems as a result of existing or anticipated climatic stressors**', as well as their ramifications or consequences (Schipper 2006). Together, adjustments in procedures, strategies and structures can be applied as adaptation actions that will also mitigate the effects of climate change or allow for taking advantage of the economic opportunities that come with these approaches.

Africa has contributed the least to global atmospheric GHG emissions, but the continent suffers from some of the worst climate change-related consequences and has limited capability to cope with climate change impacts. As an exception, **South Africa is one of the top 20 most carbon-intensive countries in the world** (currently ranked number 13) (UNFCCC 2011, Klausbruckner et al. 2016) because of high dependence on industrial activities that rely on the burning of coal, crude oil and natural gas (Arndt et al. 2013). As the largest CO$_2$ emitter in Africa, it is rated 27th in the Global Climate Risk Index. South Africa has therefore made international and national commitments towards GHG mitigation. **South Africa has since submitted a revised Nationally Determined Contribution (NDC) target of 398–510 MtCO$_2$e for 2025 and 350–420 MtCO$_2$e for 2030.** South Africa has stated its intention to commit to a net zero CO$_2$ target by 2050 as part of the visionary statement of the country's long-term strategy. The Just Transition Plan, which will define the vision compatible with the Paris Agreement goals, is yet to be finalised, and this process will update the Low-Emissions Development Strategy (SA-LEDS 2020). The government has stated that there is an urgent need to strengthen the resilience of our society and economy to climate change impacts and to develop and implement policies, measures, mechanisms and infrastructure that protect the most vulnerable communities.

Recognising and valuing **both the climate mitigation and adaptation benefits** of blue carbon ecosystems is important for long-term **coastal sustainability planning and decision- making** (Crooks et al. 2018a). As of 2016, 28 countries referenced coastal wetlands (including blue carbon ecosystems) as part of the mitigation component of their NDC, while 59 countries included coastal ecosystems in their adaptation strategies (Herr & Landis 2016). **Mitigation and adaptation can be synergistic**, as restoration for adaptation benefits will be associated with natural carbon (C) removal, and thus direct mitigation benefits can also be obtained.

Blue carbon ecosystems make a limited contribution towards global C sequestration potential due to their relatively small area coverage. However, these ecosystems are efficient at C storage and sequestration, can store more C per unit area than terrestrial forests, and serve as natural long-term C sinks for up to thousands of years (McLeod et al. 2011, Howard et al. 2014). Carbon sequestration by **blue carbon ecosystems can therefore play a significant role for climate change mitigation at the national level** if mitigation schemes are complemented with reductions in degradation and deforestation (Taillardat et al. 2018). **Climate-focused mitigation actions** for blue carbon ecosystems include: 1) **protection/maintenance** of existing areas (avoiding emissions associated with degradation and destruction of sinks); and 2) **restoration** of degraded areas to enhance GHG sink capacity. In this way, climate-focused mitigation actions can be carried out to offset national GHG emissions.

Blue carbon ecosystems can also **contribute towards climate change adaptation**, as they serve to protect the coast from sea-level rise (SLR) as well as the effects of flooding, erosion and storm surges that are predicted to increase in severity and frequency with climate change (Duarte et al. 2013). **Climate-focused adaptation actions** for blue carbon ecosystems include a strong focus on **land-use planning** to promote landward retreat of existing developments and prevent 'coastal squeeze' of blue carbon ecosystems, thus allowing these ecosystems to provide a natural buffer to coastal hazards.

Blue carbon ecosystems also provide **multiple ecosystem services** and maintain biodiversity, and these are viewed as co-benefits that are obtained when managing for the restoration and continued persistence of natural blue carbon ecosystems (Kelleway et al. 2020).

4.1 RECOMMENDED MITIGATION AND ADAPTATION ACTIONS FOR SOUTH AFRICAN BLUE CARBON ECOSYSTEMS

South Africa, like most countries, is faced with the ever-increasing threat of climate change and is currently grappling with solutions to overcome or at least manage the consequences of climate change. South Africa's approach to climate change mitigation aims to strike a balance that allows for the voluntary reduction of GHG emissions (as a good global citizen) while maintaining economic competitiveness, achieving developmental goals, and taking advantage of the economic opportunities that come with a lower C economy (DEA 2014). As the country is part of the UNFCCC, it is imperative to develop and have robust climate change mitigation measures. This makes mitigation a national priority.

Agriculture, Forestry and Other Land Use (AFOLU) mitigation opportunities that are **related to restoration, afforestation and reduced soil disturbance have the potential for application in blue carbon ecosystems**. Mitigation and adaptation actions can be climate- focused or development/transformation-focused.

Climate-focused mitigation actions either reduce sources of GHGs or enhance GHG sinks, while climate-focused adaptation actions reduce the vulnerability of society or ecosystems to harmful effects of climate change. Adaptation actions can also include beneficial opportunities associated with climate change. These are often referred to as synergies or co-benefits. For example, managing blue carbon ecosystems to provide resilience and protection from SLR (as an adaptation action) could lead to the expansion of these ecosystems, and thus increased potential for mitigation and provision of other ecosystem services.

Development/transformation actions are defined by Few et al. (2017) as: actions that must be taken to manage situations of environmental or ecosystem change that go beyond incremental adjustments to current practices. This process is termed '**transformational adaptation**' and describes **measures that fundamentally reduce exposure to anticipated or observed impacts** through a major change in the type, intensity or distribution of a practice.

Four pressures on blue carbon ecosystems were identified when the baseline projection was developed: **1) land-use change; 2) freshwater inflow/flow modification; 3) deteriorating water quality/eutrophication; and 4) artificial breaching**. Potential actions to reduce the impact of each pressure and the effect this would have on carbon storage and sequestration are tabulated below. Specific policies through which these actions can be carried out have been identified, and any gaps have been highlighted.

4.1.1 Mitigation and Adaptation Actions Related to Land-Use Change Pressures

Land-use change was shown to account for the largest source of historical GHG emissions from blue carbon ecosystems in South Africa (Section 3). **Activities that result in the irreversible removal of blue carbon ecosystems account for the most emissions**, as this causes release of stored C back into the atmosphere. The ecosystem is also lost as a C sink for future offsetting.

Actions related to land-use change are focused on **avoiding destruction and disturbance** to blue carbon ecosystems, as this leads to avoided emissions (Table 4.1). However, actions that can **enhance sequestration** in relation to land-use change are also important, and these are represented by **restoration** of degraded ecosystems (Table 4.1). This approach is aligned with the UN Decade on Ecosystem Restoration (2021–2030). The contribution of restoration to GHG removals depends on the type of blue carbon ecosystem and the extent thereof. **Per hectare, the largest GHG removals can be obtained through mangrove restoration** (Table 4.1). However, in South Africa the largest degraded blue carbon ecosystem areas would naturally have occurred as salt marsh. Restoration should be seen as being complementary to protection strategies (see the section 'Measures for the Protection of Blue Carbon Ecosystems') which will ensure the persistence of blue carbon ecosystems into the future.

Avoiding losses (including through protection) of blue carbon ecosystems and carrying out restoration are both forms of climate-based mitigation as **both will support GHG removals** (restoration can even enhance C sequestration) and lead to a **reduction in net AFOLU-sector emissions**. Actions that prevent clearing, disturbance and degradation of blue carbon ecosystems can largely be carried out With Existing Measures (WEM), with only minor additional efforts to highlight the importance of blue carbon ecosystems within current approaches (Table 4.1). Actions that are related to restoration will need to be carried out With Additional Measures (WAM), but policies and strategies that can be leveraged towards these measures have been highlighted (Table 4.1).

Actions related to land-use change that are focused on land-use planning to promote landward retreat of existing developments within estuarine functional zones (EFZs) are considered as **transformative adaptation actions**. New developments within EFZs will be vulnerable to future SLR. The EFZ encapsulates all habitat below the 5 m above mean sea-\level contour line. **Land-use planning actions can facilitate a managed retreat to provide coastal resilience to SLR as well as coastal floods and storms.** As these actions will allow for habitat expansion, GHG emissions reductions can also be delivered. The total CO_2 removals that can be gained by allowing for landward migration can only be estimated for certain estuaries. This calculation relies on having high-resolution digital elevation models which are not available at the national scale. Actions that are related to land-use planning will need to be carried out With Additional Measures (Table 4.1).

There is also **potential for active restoration to be carried out in all blue carbon ecosystem types** (Table 4.1). Areas with this potential were identified using the Blue Carbon Spatial Dataset and are located within the larger estuaries. These include blue carbon ecosystem **areas that have been degraded as well as areas that were drained and used for other activities, for example agriculture and salt extraction pans**. The estimated area for restoration is conservative, as only 25% of fallow agricultural lands, and 50% of both abandoned salt extraction pans and degraded areas, were included.

TABLE 4.1: POTENTIAL ACTIONS, ASSOCIATED STRATEGIES AND POLICIES, AND THEIR EXPECTED IMPACT ON C STORAGE AND SEQUESTRATION IN BLUE CARBON ECOSYSTEMS (MN = MANGROVES, SM = SALT MARSH, SG = SUBMERGED MACROPHYTES) IN RELATION TO LAND-USE CHANGE/TRANSFORMATION. POTENTIAL CO_2 REMOVALS CALCULATED ASSUMING THAT THE PRESSURE IS REMOVED, AND THE HABITAT IS ABLE TO SEQUESTER AT THE SAME RATE OF A NATURAL AREA IN ONE YEAR.

Carbon Storage/Sequestration Potential from 1 ha
Mangroves = 23.6–36.6 $tCO_2e.yr^{-1}$; Salt marsh = 1.5–3.4 $tCO_2e.yr^{-1}$; Submerged macrophytes = 0.5–1.5 $tCO_2e.yr^{-1}$
Potential Area Available for Active Restoration
MN: 50 ha by 2030, additional 50 ha by 2050; SM = 500 ha by 2030, additional 500 ha by 2050; SG = 30 ha by 2030, additional 30 ha by 2050

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Restore degraded blue carbon ecosystems.	↑ Increase in ecological function and health related to increase in extent of salt marsh, mangroves and submerged macrophytes.	WAM	Increase in area covered by blue carbon ecosystems by restoring degraded and agricultural areas and salt works to return to salt marsh, mangrove and seagrass habitats.	Develop Integrated Estuarine Restoration Strategy/Policy to coordinate and direct blue carbon restoration at national, provincial or even municipal levels.	2 years	National Biodiversity Act (2004) NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008)	Potential Ecosystems- based adaptation (EbA) opportunities for inclusion in Expanded Public Works Programmes (EPWP) such as Working for Wetlands and Working for Coast.
			Reduce fragmentation of all blue carbon ecosystems. ncrease forest density of mangroves.	Set restoration targets, allocate funding and develop monitoring and reporting structures.	2–4 years		

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Develop a land- exchange programme to reclaim accommodation space and facilitate blue carbon ecosystems persistence under rising sea level conditions	↑ Increase in extent of salt marsh and mangroves.	WAM	Develop a land- exchange programme.	No such exchange programme currently exists.		National Biodiversity Act (2004) NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008)	
			Acquire 100% of fallow and agricultural land below the 2.5 m MSL contour. This area will be naturally converted to estuarine habitat with SLR.	Fund land exchange programme and acquire private land inundated by flooding. Targets can be adjusted as an active coastal retreat policy is implemented to include built Infrastructure.	4–10 years		
Avoid clearing or infilling of estuarine habitat and soil disturbance within EFZ.	→ Maintain salt marsh and mangrove habitat extent.	WEM	100% of blue carbon ecosystems within the EFZ.	Do not permit future land-use change and disturbance.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process)	NEMA EIA Regulations (2014)	Include clearing of estuarine habitat from EFZ under Listing Notice 1 of EIA regulations, currently on Listing Notice 3.
				Re-evaluate existing permissions for biomass clearing and soil disturbance.			

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
			100% of blue carbon ecosystems are protected by Estuary Management Plans (EMPs). 100% new and existing EMPs explicitly protect estuarine habitats from development and land-use change.	Highlight and generate awareness of the importance of blue carbon ecosystems and the need to plan for their protection in estuary management planning processes.	2-4 years	Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021)	This process in ongoing (> 40 EMPs in various stages of completion). 40 estuaries identified as under High to Very High pressure from land use in NBA 2018 in urgent need of land- use planning.
			100% of blue carbon ecosystems listed as Critical Biodiversity Areas (CBAs).	Include blue carbon ecosystems as CBAs in Coastal CBA Map.	< 2 years	National Biodiversity Act (2004)	SANBI is currently developing a Coastal Critical Biodiversity Areas map that will include estuaries.
Develop and enforce conservative setback lines.	↑ Increase in extent of salt marsh and mangroves.	WEM	100% of estuaries have floodlines (1:100 year)/ setback/ management lines to maintain blue carbon ecosystems. No development to take place in this space.	Strict policies should be developed for the setting of estuary floodlines/setback/ management lines for inclusion in municipal Integrated Development Plans and Spatial Development Plans.	< 2 years (ongoing but blue carbon ecosystems need to be mainstreamed into process).	Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021)	Coastal management lines are currently being determined under the ICM Act. Incorporated as part of South Africa's Climate Change Adaptation Strategy sector measures for the coastal zone.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
		WAM	100% of blue carbon ecosystems under threat of coastal squeeze are identified.	Policies should support land-use planning practices that allow for upslope landward migration to avoid 'coastal squeeze' of blue carbon ecosystems with sea-level rise.	2–4 years		
Avoid all mining- related activities within EFZs as these have irreversible impacts on carbon storage and sequestration.	→ Maintain salt marsh, submerged macrophytes and mangrove habitat extent.	WAM	Policy developed and implemented.	Develop a policy that does not permit mining for sand, diamonds, minerals or establishment of salt works within a 1 km buffer of the EFZ.	2–4 years	NEMA EIA Regulations (2014) Mineral and Petroleum Resources Development Act (2002)	Mining in estuaries is not managed and there are no policies guiding mining activities in estuaries, e.g. sand mining is largely unregulated and destructive.
			100% of estuaries under pressure from mining or large dam developments have sediment budgets evaluated and resource quality objectives determined (see also Table 4.2).	Evaluate the impact of mining on associated sediment budgets and coastal processes.	4–10 years		

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Reduce the impact of boating activities.	↑ Increase in extent of salt marsh, submerged macrophytes and mangroves.	WEM	Develop boating policy that considers impacts on blue carbon ecosystems such as destruction and erosion of habitat.	Develop guidelines to control boating activities in estuaries.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process).	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008)	Estuary Management Plans include boating activities; these are uncoordinated and mostly address the activity as part of local municipal by-laws. National policy and guidelines are needed, to be inclusive of blue carbon ecosystem protection.
		WEM	100% of estuaries have zonation plans that protect blue carbon ecosystems from boating.	Do not permit launching and anchoring of boats in seagrass beds.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process).	National Estuarine Management Protocol (2021) Municipal by- laws	
Restore tidal exchange and connectivity with blue carbon ecosystems.	↑ Increase in extent of salt marsh, submerged macrophytes and mangroves.		80% of old jetties and causeways are removed. (100% targets over 10 years)	Actively remove old jetties to restore tidal exchange and improve hydrodynamics.	2-4 years (ongoing but blue carbon needs to be mainstreamed into process).	Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021) NEMA EIA Regulations (2014)	Currently, some EMPs identify the removal of old structures, but there is no drive to identify and systematically remove. Needs to be prioritised in relevant EMPs.

4.1.2 Mitigation and Adaptation Actions Related to Reduced Freshwater Inflow/Flow Modification Pressures

Reduced freshwater inflow and flow modification are significant anthropogenic pressures on South African blue carbon ecosystems because these ecosystems occur in estuaries. Salt marshes, mangroves and seagrasses depend on freshwater inflow to maintain salinity gradients, introduce nutrients and sediment, and thus maintain biodiversity. The baseline scenario for GHG emissions associated with blue carbon ecosystems showed that **this pressure is predicted to continue to increase in the future**. This pressure was predicted to have the highest impact on future GHG emissions as it is related to increasing trends in coastal population growth and the accompanying need for freshwater abstraction, as well as droughts which are expected to increase with climate change. **Water flow management is important to directly control water level in estuaries and indirectly to maintain suitable salinity and water quality conditions for blue carbon ecosystems.** Low water levels can dry out habitats, causing the plants to die back and GHGs to be released from soils that are no longer waterlogged. High water levels (as a result of prolonged inundation) can drown habitats, which can also lead to dieback of mangroves and salt marsh and therefore a loss in C storage and sequestration capacities. Freshwater inflow is also important to **reduce salinity, which in turn enhances plant growth and therefore also C sequestration**. Restoration of **hydrology improves ecological function** and therefore maintains C sequestration.

Actions related to reduced freshwater inflow/flow modification are focused on **maintaining existing freshwater inputs, reinstating those that are no longer received by blue carbon ecosystems in estuaries, maintaining sediment transport processes and improving riverine flow and tidal exchange** (Table 4.2). Reinstating freshwater inflow can be carried out as a restoration action to improve blue carbon ecosystem health, reverse degradation and therefore enhance C sequestration. **The contribution to GHG removals through reinstating flows is highest for mangrove ecosystems** (Table 4.2).

Maintaining and reinstating flows are forms of climate-based mitigation, as both will secure existing C sinks and enhance C sequestration, and thus contribute towards GHG removals. Actions that will maintain existing freshwater flows can be carried out With Existing Measures such as the freshwater flow allocations ('Reserves') and Resource Quality Objectives (RQOs) (for example for water quality and macrophytes) gazetted under the National Water Act (1998) by the Department of Water and Sanitation (DWS) (Table 4.2). In contrast, the reinstating of flows will need to be carried out With Additional Measures, as no monitoring or reporting structures currently exist to track progress in the implementation of environmental flow allocations, or the progress with achieving/meeting RQOs for macrophyte habitats, e.g., condition and extent of salt marsh or mangrove habitats.

Actions to protect and maintain sediment transport processes, actions to prevent over- abstraction of freshwater (which lowers the groundwater table), and actions to avoid new mining activities are also forms of climate-based mitigation. These actions contribute towards restoration and avoiding degradation of blue carbon ecosystems. Some of these actions can be carried out With Existing Measures, while others will require Additional Measures (Table 4.2).

4.1.3 Mitigation and Adaptation Actions Related to Poor Water Quality/ Eutrophication Pressures

Poor water quality and eutrophication are having significant negative impacts on South African blue carbon ecosystems. In the baseline scenario for GHG emissions, this pressure was ranked as having the second-highest impact, after reduced freshwater inflow/flow modification. This **pressure was predicted to increase significantly into the future, also related to coastal population growth**, which in many areas already is exceeding the existing capacity of infrastructure such as wastewater treatment works (WWTWs). This pressure is **linked to impacts from reduced freshwater inflow/flow requirements as regular flushing of estuarine systems (associated with adequate flows) can contribute to the improvement of water quality**. Although nutrient enrichment may initially promote productivity (and enhance growth and C sequestration), it can ultimately lead to explosive macroalgal growth which does not contribute towards blue carbon. For example, in the Knysna Estuary, the macroalgae *Ulva* grew exponentially and smothered salt marshes, resulting in dieback of these blue carbon ecosystems. **Eutrophication can also cause blooms of microalgae (phytoplankton)**, which, in turn, can shade subtidal seagrasses and submerged macrophytes, causing their dieback. Harmful microalgal blooms also have additional harmful impacts, such as fish kills.

Actions related to reduced water quality and eutrophication **focus on limiting and reducing the volume of WWTW discharges, improving the quality of return flow from agricultural land, and controlling urban stormwater runoff into estuaries** (Table 4.2). Nutrient management actions should focus on reducing loads from urban and agricultural areas in upstream catchments, and along the banks of estuaries. Because these interventions will improve estuary health, it will contribute towards restoration (and enhanced C sequestration) of blue carbon ecosystems and therefore count as climate-based mitigation actions.

TABLE 4.2: POTENTIAL ACTIONS, ASSOCIATED STRATEGIES AND POLICIES, AND THEIR EXPECTED IMPACT ON C STORAGE AND SEQUESTRATION IN BLUE CARBON ECOSYSTEMS IN RELATION TO REDUCED FRESHWATER INFLOW AND FLOW MODIFICATION. POTENTIAL CO_2 REMOVALS CALCULATED ASSUMING THAT THE PRESSURE IS REMOVED, AND THE HABITAT IS RESTORED TO THE EQUIVALENT NATURAL AREA.

Carbon Storage/Sequestration Potential from 1 ha

MN = 26.7–48.3 $tCO_2e.yr^{-1}$; SM = 1.7–3.9 $tCO_2e.yr^{-1}$; SG = 0.5–1.5 $tCO_2e.yr^{-1}$

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Protect/reinstate freshwater inputs through freshwater flow allocations (‘Reserves’) targeted at the maintenance of critical estuarine processes and blue carbon ecosystems.	↑ / → Increase in extent of salt marsh and mangroves.	WEM	100% of estuaries have allocated ‘Reserves’ and Resource Quality Objectives (RQOs) that protect blue carbon ecosystems.	Explicitly incorporate requirements of blue carbon ecosystems in the determination of ‘Reserves’ and RQOs gazetted by DWS.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process).	National Water Act (1998)	Water resource developments that impact estuaries should be evaluated for impact on blue carbon ecosystems. ‘Reserves’ and RQOs exist for 37% of estuaries.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
		WAM	100% of estuaries with blue carbon ecosystems have medium to high confidence 'Reserves', including drought allocations. Supported by increased compliance monitoring for implementation of Ecological Water Requirements.	No monitoring and reporting structures currently exist to track progress in the implementation of 'Reserves' and RQOs. Conduct medium- to high-confidence ecological water requirement (EWR) studies to inform 'Reserve' allocations and RQOs. Allocate explicit 'drought' flows to estuaries and ensure compliance. Strengthen compliance efforts to reduce illegal abstraction, particularly from small farm dams.	2-4 years	National Water Act (1998)	The 24 estuaries under High or Very High flow pressure need to be prioritised by DWS and/or catchment management authorities for detailed EWR studies.
		WEM	100% of blue carbon ecosystem catchments have been cleared of invasive alien plants.	Clear invasive alien plants in catchments to restore critical base flows and freshwater input to estuaries.	2-4 years	National Water Act (1998)	Suitable EbA for inclusion in EPWP Working for Wetlands & Working for Coast.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Protect/maintain sediment transport processes linked to freshwater inflow as they are critical to increasing elevation and preventing drowning of blue carbon ecosystems in response to sea-level rise impacts.	↑ / → Increase in extent of salt marsh and mangroves.	WAM	100% of estuaries under pressure have sediment budgets evaluated and resource quality objectives determined.	Assess regional- scale sediment processes and develop a regional sediment management (RSM) plan.	2-4 years	National Water Act (1998)	KwaZulu-Natal (KZN) and Western Cape (WC) provinces have requested such regional sediment management plans; neither Department of Forestry, Fisheries and the Environment (DFFE) nor DWS has instituted steps to develop such plans.
		WAM	Develop a land exchange programme so that blue carbon ecosystems can migrate landwards with rising sea level.	Develop a land exchange programme.	2-4 years	Biodiversity Act Integrated Coastal Management Act (2008)	This is a necessary but new measure.
Prevent over-abstraction and lowering of groundwater table.	→ Maintain salt marsh, submerged macrophytes and mangrove habitat extent.	WEM	100% of estuaries have had the groundwater requirements determined and allocated.	Ensure groundwater abstraction activities are licensed and do not impact estuaries.	2-4 years (ongoing but blue carbon needs to be mainstreamed into process).	National Water Act (1998)	Procedures are in place to assess and ensure groundwater requirements to estuaries. Future editions of the DWS Groundwater EWR methods should explicitly include estuary guidelines.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
		WAM	0% estuaries have commercial forest plantations within a 2 km buffer of EFZ.	Develop and implement a policy to phase out/not permit commercial forest plantations within a 2 km buffer of EFZ.	2–10 years	NEMA EIA Regulations (2014) National Water Act (1998)	There are policies/ guidelines in place. These need to be reviewed to ensure that impacts on estuaries are adequately addressed and strictly enforced.
		WAM	0% estuaries have mining within 2 km of the EFZ that could impact the groundwater table.	Evaluate mining within 2 km radius of an estuary to ensure mitigation of impacts to groundwater table.	4–10 years	National Water Act (1998) Mineral and Petroleum Resources Development Act (2002) Integrated Coastal Management Act (2008)	Presently no legal requirements to evaluate the impact of mines on estuaries. Opportunities exist to evaluate cumulative impacts under MINTECH Working Group 7.
Avoid all new mining activities.	→ Maintain salt marsh, submerged macrophytes and mangrove habitat extent.	WAM	0% estuaries have mining activities within the EFZ.	Do not permit mining within EFZ given the high risk to disturbance of the groundwater table and additional risk of wind-blown dust and pollution.	2–4 years	NEMA EIA Regulations (2014) National Water Act (1998) Mineral and Petroleum Resources Development Act (2002)	Given the significant and lasting impact of mining, there is an urgent need for lead authorities to engage collaboratively.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Improve freshwater inflow and tidal exchange along the length of the estuary.	↑ Increase in extent of salt marsh and mangroves.	WEM	80% of all barriers that restrict tidal exchange are removed.	Remove barriers that limit tidal exchange, including weirs and causeways. Remove or redesign transport infrastructure (old railways and bridges) that impede flow.	2–10 years (ongoing but blue carbon needs to be mainstreamed into process).	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021)	Existing estuary management frameworks can and have been used to facilitate the removal or redesign of structures that impede tidal or river flow in estuaries.

GHG removals are estimated to be similar for mangroves and salt marshes through restoring water quality (Table 4.3). If this pressure is alleviated, reduced shading by microalgal blooms can also improve GHG removals by facilitating the growth of submerged macrophytes. A sustainable development approach can be applied to achieve this through, for example, the construction of artificial wetlands to act as filters of urban runoff. In addition, the vegetation used in the artificial wetland also has C sequestration potential and provides other ecosystem services like biodiversity maintenance.

Actions to reduce and limit the volume of effluents from WWTWs, as well as to improve the water quality of effluents, can be carried out With Existing Measures under the existing national policy, but there needs to be better adherence and enforcement of such legislation. Actions to improve the water quality of return flows from agricultural areas in catchments and to control urban stormwater runoff into estuaries will need to be carried out With Additional Measures (Table 4.3). The development of a catchment-to-coast plan is recommended for these actions.

4.1.4 Mitigation and Adaptation Actions Related to Artificial Breaching Pressures

Artificial breaching is a complex pressure that impacts South African blue carbon ecosystems and is a practice that has been in place for decades. The **impact of artificial breaching on blue carbon ecosystems is less than other abiotic pressures** (e.g. freshwater inflow and reduced water quality/eutrophication), as this pressure affects fewer estuaries nationally. The need for artificial breaching is determined by the occurrence of low-lying infrastructure within EFZs. However, as applications for development within EFZs have declined in recent decades (following NEMA requirements for EIAs, etc.), it is unlikely that artificial breaching will increase significantly in the future but **will remain a pressure in those systems where it is already taking place**. Climate change may lead to **more artificial breaching occurring in estuaries where increased flows compounded by SLR can cause backflooding** and inundation of infrastructure, although increased flows should naturally allow for more natural breaching of estuary mouths.

Artificial breaching **interacts with both freshwater inflow and reduced water quality/eutrophication to impact blue carbon ecosystems**. For example, if water levels rise while the estuary is closed, adjacent areas (including blue carbon ecosystems) can become **inundated**. This can lead to vegetation dieback after extended periods and therefore loss of C stocks and sequestration capacity. Reduced flows during closed periods also allow for longer residence times, allowing build-up of nutrients, and promote harmful algal blooms and fish kills (as a result of reduction in oxygen during subsequent degradation of blooms or the production of toxins). Such deterioration in water quality can increase pressure from affected parties to artificially breach an estuary. Artificially **breaching an estuary** too frequently, or in suboptimal tidal conditions, can have further detrimental effects, such as build-up of sediments and increased flood risks. Inappropriate breaching can also result in scouring and erosion of submerged macrophytes, resulting in the loss of stored C. Also, breaching at low water levels dries out salt marshes and increases the occurrence of closed mouth conditions over time.

Actions related to artificial breaching include proper management of breaching operations to prevent unnecessary breaching, to prevent the development of new infrastructure in low-lying areas that could be subject to backflooding (and would require breaching to take place), and removal of poorly planned infrastructure in the

EFZ that is repeatedly damaged by backflooding (Table 4.4). Unnecessary breaching can cause degradation of blue carbon ecosystems, and loss of C stocks if there is erosion and scouring. Removing poorly planned, low-lying infrastructure can allow for blue carbon ecosystems to expand into these areas, therefore increasing C stocks and sequestration. GHG removals can be obtained from salt marshes and seagrasses if these actions are carried out (Table 4.4).

Preventing unnecessary breaching and removing poorly planned low-lying infrastructure are both climate-based mitigation and transformative adaptation actions (Table 4.4) and align with actions for landward retreat (see 'Land-Use Change' section). All actions for artificial breaching can be carried out With Existing Measures (Table 4.4).

TABLE 4.3: POTENTIAL ACTIONS, ASSOCIATED STRATEGIES AND POLICIES, AND THEIR EXPECTED IMPACT ON CARBON STORAGE AND SEQUESTRATION IN BLUE CARBON ECOSYSTEMS IN RELATION TO LOW WATER QUALITY AND EUTROPHICATION. POTENTIAL CO_2 REMOVALS ARE CALCULATED ASSUMING THAT THE PRESSURE IS REMOVED, AND THE HABITAT IS RESTORED TO THE EQUIVALENT NATURAL AREA.

Carbon Storage/Sequestration Potential from 1 ha

MN = 24.4–38.5 $tCO_2e.yr^{-1}$; SM = 1.7–3.5 $tCO_2e.yr^{-1}$; SG = 0.6–1.6 $tCO_2e.yr^{-1}$

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Limit and reduce the volume of effluent from WWTWs into estuaries (or just upstream of estuaries).	↑ / → Maintain salt marsh, submerged macrophytes and mangrove habitat extent.	WEM	20% reduction in WW effluent.	Reduce the volume of existing WWTW, and do not permit WWTW discharge into estuaries.	2–4 years (ongoing but blue carbon needs to be mainstreamed into process).	Integrated Coastal Management Act (2008) National Water Act (1998)	National policies to reduce/remove WWTW discharges to estuaries exist. However, most WWTW discharges still operate under uniform effluent standards. The existing national policies adopted a receiving water quality approach (as represented by Resource Quality Objectives) but most are not enforced as yet.
			50% reduction in WW effluent.		4–10 years		
			100% reduction in WW effluent.		10–20 years		

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Improve water quality of WWTW effluents.	↑ Increase in extent of salt marsh and mangroves	WEM	100% compliance to discharge permits standards.	Improve water quality from existing WWTW, with the intent of recycling or reusing effluent in the long term.	2–4 years (ongoing but blue carbon needs to be mainstreamed into process).	Integrated Coastal Management Act (2008) National Water Act (1998)	38 estuaries rated as High or Very High for water quality pressures; require urgent intervention to alleviate pollution.
Improve water quality of return flow from agriculture in catchments.	↑ Increase in extent of salt marsh and mangroves.	WEM	Agriculture best practice guidelines implemented. 10% reduction in nutrient levels in river inflow.	Develop agriculture best practice guidelines and generate awareness of the impact of over-fertilisation on estuaries. Develop industry standards that will support this.	2–4 years (ongoing but blue carbon needs to be mainstreamed into process).	Conservation of Agricultural Resources Act (1983) National Water Act (1998)	Develop catchment- to-coast plans for estuaries that support important blue carbon ecosystems to ensure an integrated management approach.
		WAM	0% agriculture return flow from estuarine floodplains.	No direct agriculture return flow of estuarine floodplains.	4–10 years		
		WAM	0% use of herbicide and pesticide in and around estuaries.	Control/discourage the use of herbicide and pesticide in and around estuaries.	2–4 years (ongoing as guidelines exist but not designed for estuaries).		

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Control and reduce urban stormwater runoff into estuaries.	↑ Increase in extent of salt marsh, mangroves and submerged macrophytes.	WAM	Develop a strategy/ best practice guide.	Develop strategies that encourage adaptive stormwater management practices that attenuate stormwater peak inflows.	2-4 years	National Integrated Coastal Management Act (2008) National Water Act (1998)	Develop appropriate stormwater legislation/ ordinances/by-laws for use by municipalities that require the use of green infrastructure.
						Buildings Regulations and Building Standards Act (No. 1977, as amended) Spatial Planning and Land Use	Provide training for municipal staff on green infrastructure and offer incentives for developers/ engineers to use green infrastructure designs, rather than relying on pipe-based systems.
		WAM	Make climate change considerations, e.g. increase in extreme rainfall events, compulsory in development applications.	Require developers to make decisions informed by future climate, and local governments to incorporate climate change into decision- making processes.	2–10 years	Management Act (2013)	

TABLE 4.4: POTENTIAL ACTIONS, ASSOCIATED STRATEGIES AND POLICIES, AND THEIR EXPECTED IMPACT ON CARBON STORAGE AND SEQUESTRATION IN BLUE CARBON ECOSYSTEMS IN RELATION TO PRESSURE FROM ARTIFICIAL BREACHING. POTENTIAL CO_2 REMOVALS CALCULATED ASSUMING THAT THE PRESSURE IS REMOVED, AND THE HABITAT IS RESTORED TO THE EQUIVALENT NATURAL AREA.

Carbon Storage/Sequestration Potential from 1 ha
SM = 1.8–4.7 $tCO_2e.yr^{-1}$; SG = 0.7–2.0 $tCO^2e.yr^{-1}$

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Prohibit artificial breaching of estuaries for unnecessary or invalid reasons.	↑ / → Increase in extent of salt marsh OR submerged macrophytes, depending on whether mouth is open or closed, respectively.	WEM	National Artificial Breaching Protocol has been developed. National and Provincial Disaster Risk Management engaged in the processes.	Develop a National Artificial Breaching Protocol for estuaries (informed by approaches developed in WC and KZN). Engage with National and Provincial Disaster Risk Management agencies to highlight the risk of poor breaching practices and to mitigate premature breaching.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process).	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021)	Breaching is a listed activity under the NEMA EIA regulations and is required for legally erected properties, but not for farmland (e.g. St Lucia and Klein estuaries).

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
		WEM	100% of estuaries have EIA approval (Maintenance Management Plan) that considers protection of blue carbon habitats as criteria.	Develop comprehensive Estuary Management Plans for all estuaries subjected to artificial breaching, including a Mouth Management Plan that stipulates the motivation for breaching and a pre- approved Maintenance Management Plan (under the EIA regulations) that details the criteria for and approaches to a breaching.	< 2 years (ongoing but blue carbon needs to be mainstreamed into process).	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021)	26 estuaries with blue carbon ecosystems are subjected to mouth manipulation, with 11 rated as under High or Very High pressure from artificial breaching. These require estuary Mouth Management Plans and potentially Maintenance Management Plans.
Prohibit development of new infrastructure in low-lying areas that could be prone to flooding, thus requiring artificial breaching of estuary mouths.	→ Maintain salt marsh, submerged macrophytes and mangrove habitat extent.	WEM	100% of blue carbon systems have 1:100 flood line/setback/ management line.	Ensure that a conservative flood line assessment is in place that demarcates the impact area of 1:100-year flood events under future climate conditions (e.g. SLR, increase wave energy and increase flooding).	2–10 years (ongoing but blue carbon needs to be mainstreamed into process).	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008)	Development within the EFZ is a listed activity under NEMA EIA Regulations. Coastal municipalities are required to develop coastal management lines that include estuaries.

RECOMMENDED ACTION	CARBON STORAGE/ SEQUESTRATION	WEM/ WAM	PROPOSED APPROACH	NECESSARY POLICY/STRATEGY	TIMEFRAME TO BEGIN REPORTING	RELEVANT LEGISLATION	IMPLEMENTATION/ SCOPE
Remove poorly planned, low- lying infrastructure and access routes (e.g. farm roads) where possible.	↑ Increase in extent of salt marsh and submerged macrophytes.	WEM	100% of poorly planned infrastructure is removed. 100% of access routes are diverted or raised.	As part of Coastal Climate Change Strategies, conduct surveys to investigate options to remove poorly planned, low-lying infrastructure and access roads (e.g. public ablution facilities too close to an estuary, farm roads through EFZ). This has the added benefit that it supports an active retreat policy in the face of sea-level rise.	4–10 years	NEMA EIA Regulations (2014) Integrated Coastal Management Act (2008) National Estuarine Management Protocol (2021) Disaster Management Act (No. 57 of 2002)	Poorly planned or illegal infrastructure can be removed under NEMA. Raising and/ or rerouting of access routes is generally done as part of disaster risk planning and can be done under the Integrated Coastal Management Act (2008).

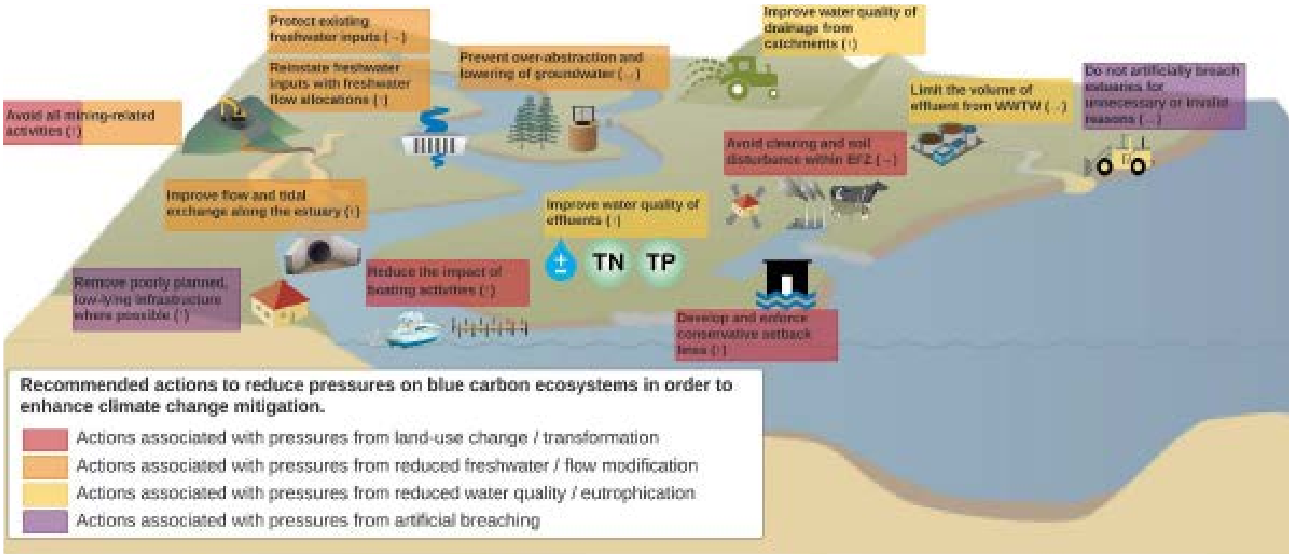


FIGURE 4.1: OVERVIEW OF ACTIONS ASSOCIATED WITH PRESSURES (LAND-USE CHANGE/ TRANSFORMATION, REDUCED FRESHWATER/FLOW MODIFICATION, REDUCED WATER QUALITY/EUTROPHICATION, AND ARTIFICIAL BREACHING) ON BLUE CARBON ECOSYSTEMS. ARROWS INDICATE WHETHER THE ACTION IS PREDICTED TO INCREASE C STORAGE AND SEQUESTRATION (↑) OR MAINTAIN EXISTING C STOCKS (→). (IMAGE CREATOR: J RAW)

4.1.5 Summary of the Status of Existing Mitigation/ Adaptation Measures that Support the Management of Blue Carbon Ecosystems

To provide a succinct evaluation of the status of government responses in terms of the management and control of key pressures on South African estuaries, an overview is provided in Table 4.5. This is a qualitative assessment and is largely aimed at assisting with prioritisation of management responses going forward. The table depicts the assessment of the status of existing legislation, as well as availability of supporting norms and standards (here defined as regulations, protocols, strategies, guidelines and methods). Finally, successes in terms of implementation and compliance (also including appropriate monitoring initiatives) across the various activities are assessed. The response status is rated (depicted as Good = Large green circle; Average = medium orange circle; Weak = small red circle). Weak responses indicate the need for urgent intervention.

South Africa has a **strong policy and legislative framework** with regards to estuary protection and management. However, the **supporting norms and standards are less well defined**, especially concerning the protection and management of blue carbon ecosystems. While significant progress has been made in the management of estuaries across several sectors, efforts are required to mainstream blue carbon ecosystem requirements within existing structures. In most cases, this can be achieved within existing structures with little effort. However, what is concerning is that **implementation and compliance are often lacking** with regards to estuarine management, and this poses an ongoing risk to blue carbon ecosystems (Table 4.5).

4.2 MEASURES FOR THE PROTECTION OF BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA

Resource and biodiversity protection of blue carbon ecosystems is slow, with only about 37% of estuaries having some limited overlap with protected areas. Therefore, urgent measures are required across the spectrum of responses to ensure a network of healthy and productive estuaries. The following section provides an **overview of available measures that contribute towards resource and biodiversity protection**. Table 4.6 provides a summary of area-based measures that protect blue carbon ecosystems, the responsible authority, if WEM or WAM, and the current status in addressing blue carbon protection requirements.

TABLE 4.5: STATUS ASSESSMENT OF GOVERNMENT'S RESPONSES TO MITIGATE, MANAGE AND CONTROL KEY PRESSURES AND ASSOCIATED ACTIVITIES IN ESTUARIES (ADAPTED FROM TALJAARD ET AL. (2019) AND VAN NIEKERK ET AL. (2019)).

	RESPONSE STATUS RATING			
LEGEND	Good = Large green circle	🟢		
	Average = Medium orange circle	🟠		
	Weak = Small red circle	🔴		

	PRESSURE/ACTIVITY	STATUS OF GOVERNMENT RESPONSE		
		Legislation	Norms & Standards	Implementation & Compliance
FLOW MODIFICATION	Surface water abstraction (i.e. run-of-river abstraction, large dam & weir development, hydro-electrical schemes, transfer schemes)	🟢	🟢	🟠/🔴
	Return flow (wastewater & agriculture)	🟢	🟠	🔴
	Alien vegetation infestation in catchment	🟢	🟢	🟠
	Groundwater abstraction	🟢	🟠	🔴
	Plantations	🟢	🟠	🔴
	Hardening of the catchment & stormwater	🟢	🟠	🔴

PRESSURE/ACTIVITY		STATUS OF GOVERNMENT RESPONSE		
		Legislation	**Norms & Standards**	**Implementation & Compliance**
POLLUTION	Wastewater disposal	🟢	🟠	🔴
	Agricultural return flow	🟠	🔴	🔴
	Urban stormwater runoff	🔴	🔴	🔴
LAND USE & URBAN DEVELOPMENT	Urban development (housing, resorts, hotels)	🟢	🟠	🟠
	Transport infrastructure (roads, bridges and culverts)	🟢	🟠	🟠
	Riparian infrastructure (fences and low-lying developments)	🟢	🟠	🔴
	In-stream infrastructure (jetties and boat launching sites)	🟢	🟠	🔴
	Agriculture (croplands & clearing)	🟢	🟠	🔴
	Livestock grazing/browsing of riparian zone	🟠	🔴	🔴
	Harvesting housing material (reeds/sedges & mangroves)	🟠	🔴	🔴
	Mining (including instream sandmining)	🟠	🟠	🔴
	Salt works	🟢	🔴	🔴
	Power-boating and water-skiing	🟢		🟠
MANIPULATIO N OF INLETS	Artificial breaching	🟢	🟠	🔴
	Mouth stabilisation/canalisation	🟢	🟠	🟠
	Inlet diversion	🟢	🟠	🟠

An indication is also provided if the listed protection measure is considered effective, with 'strong' measures providing long-term protection and 'weak' measures easily eroded or circumvented. Protection and sustainable management of blue carbon ecosystems allows for maintenance of existing C sinks, which can be incorporated into the AFOLU sector inventory.

4.2.1 NBA National Estuarine Biodiversity Plan

The National Biodiversity Assessment 2011 (NBA 2011) developed a **National Estuary Biodiversity Plan** for South Africa's estuaries that prioritises which systems should be assigned Protected Area (PA) status (Van Niekerk & Turpie 2012). The plan followed a systematic approach that took pattern, process and biodiversity persistence into account. The plan, which includes targets for habitats, species and ecosystem type, suggests that **a core set of 133 estuaries** (including those already formally protected) would be required to meet South Africa's biodiversity targets. Of these**, 61 should be fully protected, and 72 require partial (allow limited resource use) protection**. An additional six estuaries were subsequently highlighted as provincial conservation priorities by the relevant conservation authorities. Where estuaries are not in good condition, an effort should be made to restore functionality. The plan recommends that **all estuaries develop an Estuarine Management Plan in alignment with the National Estuary Biodiversity Plan**.

The National Estuary Biodiversity Plan is **relevant to blue carbon ecosystems** as it has a **100% inclusion target for mangrove areas larger than 5 ha, and a 20% target for supratidal and intertidal salt marsh and seagrass habitats**. It is strongly recommended that future updates of the National Biodiversity Plan prioritise all estuaries that support large expanses of blue carbon ecosystems and that area targets for those ecosystems be increased to 30% of remaining extent to ensure adequate protection and representation.

TABLE 4.6: SUMMARY OF AREA-BASED MEASURES THAT PROTECT BLUE CARBON ECOSYSTEMS, THEIR STATUS AND POTENTIAL EFFECTIVENESS.

PROTECTION MEASURES	DESCRIPTION	RESPONSIBLE AUTHORITY	WEM/WAM	STATUS	EFFECTIVENESS
National Estuary Biodiversity Plan	The plan prioritises which estuaries should be assigned Protected Area status. It provides the 'lens' through which all present and future resource allocations should be evaluated to ensure that national and international biodiversity targets are achieved.	SANBI/DFFE	WEM	Ongoing. There is a strategic plan, but it is not legally binding. Includes area targets for blue carbon habitats: Mangroves: 100% > 5 ha Salt marsh: 20% Seagrass: 20% There has been limited progress, with only small areas added in the last decade, e.g. uThukela and Sundays estuaries. The plan was last updated in 2012.	Limited support from national lead agent (DFFE), although provincial conservation authorities have started integrating priorities into provincial conservation plans.
Protected areas and stewardship programmes	The establishment of formally protected areas is a critical response to protecting blue carbon ecosystems from human activities. Protected areas are the most assured mechanisms for conserving species and ecosystems.	DFFE/ SANParks/ Provincial conservation agencies	WEM	Ongoing. Most estuarine protected areas are located in: Provincial Nature Reserves: > 30% National Parks: > 5% De facto Provincial Nature Reserves 8%	Strong, proven to be very effective in several PAs. However, depends on the political will of management authority, e.g., significant loss of swamp forest in iSimangaliso Wetland Park due to slash and burn and planting of crops.
Ramsar	A global intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources.	DFFE/ Provincial conservation agencies	WEM	Ongoing at nine estuaries (Orange, Verlorenvlei, Langebaan, Bot/Kleinmond, Touw/ Wilderness, Heuningnes, Kosi and St Lucia)	Weak, no legally binding requirements in place, but there are obligations to report back to an international body. Powerful mechanisms to drive future restoration targets in relevant estuaries.

PROTECTION MEASURES	DESCRIPTION	RESPONSIBLE AUTHORITY	WEM/WAM	STATUS	EFFECTIVENESS
Important Bird and Biodiversity Areas (IBAs)	Constitute a global network of sites that are defined by BirdLife International.	BirdLife	WEM	Ongoing at 19 estuaries.	Weak, no legislative binding requirements, but in most cases form part of existing PA.
Critical Biodiversity Areas (CBAs) and Ecological Support Areas (ESAs)	CBAs are areas required to meet biodiversity targets for ecosystems, species and ecological processes. ESAs play a vital role in supporting the ecological functioning of CBAs and Protected Areas and/or in delivering ecosystem services. National legislation makes provision for identifying CBAs and ESAs with accompanying land-use guidelines that are compiled into Biodiversity Sector Plans.	SANBI/ Provincial conservation agencies	WEM	Ongoing, SANBI developing CBA/ESA map for the coast that would include estuaries.	Strong, very effective in the terrestrial environment where it is used to guide planning (development and conservation) and EIA processes.
Other Effective Area-based Conservation Measures (OECMs)	Conservation designation for areas that are achieving the effective *in situ* conservation of biodiversity outside of protected areas. OECMs are areas other than Protected Areas, which are governed and managed in ways that achieve positive and sustained long- term outcomes for conservation. OECMs are a means of identifying and recognising biodiversity-rich areas on the global stage, where protected area status is not an option.	Private/ Provincial conservation agencies	WAM	Initiating/Pilot testing	Unknown – this is a new measure (introduced in 2018), but it has the potential to be used at smaller scales, e.g. targeting salt marsh of a specific estuary. However, it is largely voluntary with no legislative binding requirements but has an obligation to report back to an international body.

4.2.2 Formal Protected Areas and the Potential to Apply Stewardship Programmes

The establishment of protected areas is a key response to climate change and human activity pressures on estuarine biodiversity.

The UN Convention on Biological Diversity (CBD) Secretariat on 12 July 2021 released the first official draft of a new Global Biodiversity Framework to guide actions worldwide through 2030 to preserve and protect nature and its essential services to people. The draft framework calls for **at least 30% of land and sea areas globally** (especially areas of particular importance for biodiversity and its contributions to people) to be conserved through effective, equitably managed, ecologically representative and well-connected systems of protected areas (and other effective area-based conservation measures). In South Africa, less ambitious targets for estuaries are set in the 2016 National Protected Areas Expansion Strategy (NPAES) (DEA 2016a), which calls for **20% of estuarine ecosystems to be protected**. To be effective, **this target should be expanded to '30% of estuarine ecosystems, except estuarine lake ecosystem types which due to their high importance require a 100% target'**. In support of a more stringent target, the recently gazetted National Estuarine Management Protocol (2021) in terms of section 33(2) of the National Environmental Management: Integrated Coastal Management Act (Act No. 24 of 2008) calls for the **protection of a representative sample of estuaries in order to achieve overall estuarine biodiversity targets** as determined by the 2018 National Biodiversity Assessment (or the subsequent updates), with protection ranging from partial protection (72 systems) to full protection (61 systems). (While the 2018 National Biodiversity Assessment ecosystem targets were also about 20%, habitat [20%–100%] and species [20%–50%] targets were more generous.)

Protected areas are traditionally the most secure mechanisms for conserving species and ecosystems but **estuarine ecological processes**, which often operate over large spatial scales, are **not effectively protected through this mechanism**. A preliminary spatial assessment shows that **only about 38% of blue carbon ecosystem area in South Africa is currently formally protected** (Table 4.7), with only 48% of the total EFZ areas across all estuaries in South Africa under protection (Van Niekerk et al. 2019b). This assessment compared the spatial overlap between blue carbon ecosystems and the 'Protected Areas' spatial dataset that is available from SANBI.

The **highest protection is afforded to submerged macrophytes** as this habitat often forms part of Provincial Nature Reserves, National Parks and Marine Protected Areas. **Salt marsh (intertidal and supratidal) is the least protected blue carbon ecosystem.** Although **mangroves are protected under the National Forest Act** of 1998, only 54.1% of their habitat falls within protected areas. A comprehensive list of which protected areas contain blue carbon ecosystems is provided in Appendix X.

Of the 61.7% of blue carbon ecosystem area that is not protected, **land ownership belongs predominantly to erven and farmlands** (Table 4.8). This estimate was derived from the South African cadastral layer, which has some notable spatial discrepancies, including erven that overlap with open water areas. Some of the land listed as farmlands should possibly also be included in state land, given the historical use of these areas. Large areas within the EFZ are fallow land or 'secondary natural' as described by Skowno et al. (2021). This amounts to **12 245.7 ha of land which predominantly occurs in the floodplain salt marsh and terrestrial ecotone**. In most cases, this land was cropland in the 1960s, but agricultural activities are no longer practised. However, the land has not reverted to a natural state that is comparable to undisturbed sites, as indicated by the dominance of invasive species. This has **important implications for biodiversity and C sequestration potential in these areas**. These areas should therefore be considered as potential restoration sites. However, a higher resolution dataset will be needed to properly ground-truth overlap between the land ownership areas and blue carbon ecosystems.

TABLE 4.7: ESTIMATED PROPORTION OF BLUE CARBON ECOSYSTEM AREA THAT IS PROTECTED, DERIVED FROM THE 'PROTECTED AREAS' SPATIAL DATASET FROM SANBI (HTTP://BIODIVERSITYADVISOR.SANBI.ORG/PLANNING-AND-ASSESSMENT/).

HABITAT TYPE	TOTAL AREA (HA)	PROTECTED (HA)	PROTECTED (%)	NOT PROTECTED (HA)	NOT PROTECTED (%)
Submerged macrophytes	2 291.1	1 583.0	69.1	709.6	31.0
Zostera capensis	1 323.6	870.9	65.8	452.6	34.2
Salt marsh	13 978.7	4 562.0	32.6	9 416.7	67.4
Intertidal	3 495.3	795.3	22.8	2 700.0	77.2
Supratidal	10 483.4	3 766.7	35.9	6 716.7	64.1
Floodplain salt marsh	4 936.3	2 127.1	43.1	2 809.2	56.9
Mangroves	1 688.0	913.7	54.1	754.4	44.7
Ecotone (from estuarine to terrestrial habitat)	196.9	77.8	39.5	119.1	60.5
Total	**38 393.2**	**14 696.5**	**38.3**	**23 678.2**	**61.7**

TABLE 4.8: PRELIMINARY ASSESSMENT OF SPATIAL OVERLAP BETWEEN LAND OWNERSHIP CATEGORIES (ERVEN, FARMS, PARKS, STREETS, STATE LANDS) AND TOTAL BLUE CARBON ECOSYSTEM AREA IN SOUTH AFRICA. LAND OWNERSHIP DATA WERE EXTRACTED FROM THE SOUTH AFRICAN CADASTRAL LAYER.

AREA (HA) AND PERCENTAGE OVERLAP BETWEEN HABITAT AND LAND OWNERSHIP CATEGORIES						
Habitat Type	**Erven**	**Farms**	**Parks**	**Streets**	**State Land**	**Total**
Submerged macrophytes	3.3 (0.1)	237.5 (10.4)	13.6 (0.6)	2.8 (0.1)	11.0 (0.5)	**268.3 (11.7)**
Zostera capensis	2.6 (0.2)	175.5 (13.3)	1.1 (0.1)	2.7 (0.2)	5.4 (0.4)	**187.2 (14.2)**
Salt marsh	398.8 (2.9)	7 232.2 (51.8)	12.4 (0.1)	25.0 (0.2)	197.1 (1.4)	**7 865.3 (56.4)**
Intertidal	53.6 (1.5)	1 734.6 (49.6)	2.2 (0.1)	0.4 (< 0.01)	86.5 (2.5)	**1 877.3 (53.7)**
Supratidal	345.2 (33)	5 497.5 (52.6)	10.2 (0.1)	24.5 (0.2)	110.6 (1.1)	**5 988.1 (57.3)**
Floodplain salt marsh	235.1 (4.0)	2 271.0 (4.8)	4.5 (0.1)	0.7 (< 0.01)	36.1 (0.7)	**2 547.4 (51.6)**
Mangroves	213.8 (13.5)	102.9 (6.5)	0 (0)	0 (0)	0 (0)	**316.7 (20)**
Ecotone	56.8 (29.3)	46.3 (23.9)	0 (0)	0 (0)	0 (0)	**103.1 (53.2)**

Historically, the preferred mechanisms for creating protected areas in South Africa were by **proclamation of state-owned land or purchase and proclamation by the state**. More recently, **biodiversity stewardship programmes** have expanded, allowing for the proclamation of protected areas on privately owned land. This approach relies on the willingness of key landowners and has been shown to be 70 to 400 times cheaper to establishment stage, and 4 to 17 times cheaper to manage. In the last 10 years, ~830 000 ha have been added to the protected areas estate of South Africa, of which over 68% (564 000 ha) was through biodiversity stewardship agreements (Skowno et al. 2019).

Biodiversity stewardship recognises landowners as the custodians of biodiversity on their land and is based on **voluntary commitments from landowners**. Some types of biodiversity stewardship agreements are formally declared as protected areas in terms of the Protected Areas Act, providing long-term security for the sites involved. Biodiversity stewardship is particularly effective in multiple-use landscapes where biodiversity priority areas are embedded in a matrix of other land uses. **A flexible range of biodiversity stewardship agreements is available that can combine biodiversity protection and sustainable resource use.** It should be noted that biodiversity stewardship agreements are often confined to estuarine riparian areas and do not include open water areas. It is strongly recommended that there should be more engagement with biodiversity stewardship programmes to ensure that estuaries (in the form of EFZ protection) are more represented in the protected area network in the future. **Stewardship may also present an important opportunity to conserve salt marsh in particular, as supratidal areas can be located within private land.**

Protected areas that are declared as nature reserves and national parks in terms of the National Environmental Management Protected Areas Act (2003) (NEMPAA) are provided with a dedicated biodiversity tax incentive (Section 37D of the Income Tax Act 162). This allows the value of the land to be deducted from taxable income, and therefore supports the stewardship approach. Protected areas can be secured in this way through contractual agreements on non-state land.

4.2.3 Ramsar Convention

The Convention on Wetlands, called the Ramsar Convention, is a global intergovernmental treaty that provides the **framework for national action and international cooperation for the conservation and wise use of wetlands** and their resources. **South Africa currently has 23 sites designated** as Wetlands of International Importance (Ramsar sites), including nine estuaries, all of which support significant blue carbon ecosystems. Of these, only Langebaan and Kosi are in a Near Natural condition. Bot/Kleinmond was designated in 2017, representing the only Ramsar site added in the last decade. Of the nine estuaries, three estuaries do not have formal protection, but the responsible national and provincial authorities are in the process of addressing this gap. All nine of the listed systems support significant blue carbon ecosystems.

Whilst Ramsar status clearly recognises the global conservation value of a site, it does not provide any legal conservation status. It is the **responsibility of the South African government at the national and provincial levels to ensure that these sites receive legal conservation status**.

4.2.4 Important Bird and Biodiversity Area (IBAs)

IBAs are sites of global significance for bird conservation and defined by BirdLife International, of which **112 are found in South Africa**. **Nineteen estuaries form part of IBAs in South Africa and most of these systems support significant blue carbon ecosystems**, which can serve as critical habitats for birds. These sites are identified nationally through multi-stakeholder processes using globally standardised, quantitative and scientifically agreed criteria. Often IBAs form part of a country's existing protected area network, and so are protected under national legislation. Of the 19 estuaries, only seven are in a Natural or Near Natural state, with all but the Cebe Estuary part of the core set of estuaries identified as in need of formal protection. In some cases, IBAs also form part of Ramsar sites. Recreational activities (e.g. swimming, boating, bird watching, dog walking, picnic sites, hiking and kite surfing) need to be managed very effectively in IBAs to ensure that there is little disturbance of birds in roosting and feeding areas. Management of these activities, in turn, assists in managing the impacts of human disturbances on the blue carbon ecosystems.

4.2.5 Consideration of Critical Biodiversity Areas in Planning and Decision-Making

National legislation makes provision for the identification of **Critical Biodiversity Areas (CBAs) and Ecological Support Areas (ESAs)** with accompanying land-use guidelines that are compiled into Biodiversity Sector Plans. These represent the biodiversity sector's inputs into cross-sector planning and decision-making. A CBA map is a spatial plan for ecological sustainability that identifies a set of biodiversity priority areas, which, together with Protected Areas and ESAs, are needed for the long-term ecological functioning of the land- and seascapes (SANBI 2017). The purpose of a plan is to guide decision-making about where best to locate development. To date, this has only been systematically done with the terrestrial environment. Moving forward, **CBAs and ESAs should be designed across land- and seascapes**. Some progress has also been made in the identification of coastal and estuarine CBAs under the Biodiversity Act, with some estuaries listed as CBA due to their sensitivity and high productivity. This means that future development should not impair their functioning or put associated biodiversity at risk. This initial list needs to be expanded to include all important estuarine habitats and high-priority systems. It is also strongly **recommended that all blue carbon ecosystems be declared critical biodiversity areas to ensure their wise use and persistence**.

4.2.6 Other Effective Area-based Conservation Measures (OECMs)

OECMs are a conservation designation for **areas that are achieving the effective *in situ* conservation of biodiversity outside of protected areas**. OECMs are defined as 'geographically defined areas, other than Protected Areas, which are governed and managed in ways that achieve positive and sustained long-term outcomes for the *in-situ* conservation of biodiversity, with associated ecosystem functions and services, and where applicable, cultural, spiritual, socio-economic, and other locally relevant values'. **OECMs are a means of identifying and recognising biodiversity-rich areas on the global stage, where protected area status is not an option**. OECMs report to the World Database on OECMs, thereby potentially contributing to South Africa's national and international area-based targets. OECM is a relatively new approach that was only formalised in 2018 when parties to the CBD agreed on guiding principles, common characteristics and criteria for the identification of OECMs.

Identification of OECMs offers a significant opportunity to increase recognition and support for de facto effective long-term conservation that is taking place outside currently designated protected areas under a range of governance and management regimes, implemented by a diverse set of actors, including by Indigenous peoples and local communities, the private sector and government agencies.

4.3 REPORTING MEASURES IN SUPPORT OF BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA

4.3.1 South Africa Environment Outlook

The South Africa Environment Outlook (similar to the State of Environment Report) presents an extensive national **overview of the current condition of our environment, the pressures upon it and government's responses to those pressures**. It also provides a glimpse into what the future state of the environment will be if current trends continue and suggests mitigating interventions. In addition to a national report, detailed provincial reports are produced to highlight efforts made by provincial authorities in response to environmental change around a range of themes.

To **highlight the importance and enhance the reporting of blue carbon ecosystems**, for climate mitigation and adaptation measures, and as critical biodiversity and ecosystem infrastructure, it is recommended that **a sub-indicator be included in these national and provincial reports which explicitly addresses the condition, protection measures and restoration efforts pertaining to these ecosystems**. For example, the Blue Carbon Register, developed as part of this project, could serve as a baseline for such an indicator. This can be included as part of the State of the Coast reporting (ICM), or Outlook reporting. It has also been recommended to be included specifically on the next update of the NBA (2024).

4.3.2 National Biodiversity Assessment

The National Biodiversity Assessment (NBA) is the primary tool for **monitoring and reporting on the state of biodiversity in South Africa** and is used to inform policies, strategies and actions for managing and conserving biodiversity more effectively. The NBA assists in prioritising often-limited human and financial resources for managing and conserving biodiversity, thus preventing further loss and degradation of key ecosystems. Findings of the NBA also feed into strategic planning processes such as Strategic Environmental Assessments and bioregional plans. It also provides information for a range of national-level reporting processes such as the South Africa Environment Outlook report. It also serves as a key reference and educational product for scientists, students and decision-makers.

It is thus recommended that the **future editions of the NBA explicitly report on the condition, protection measures and restoration efforts of blue carbon ecosystems**. This will ensure that the NBA contributes both to keeping the information updated and mainstreaming key findings and recommendations. At present, the NBA Estuaries Realm report (Van Niekerk et al. 2019b) has a dedicated chapter focusing on estuarine habitats and thus aligns well with this recommendation.

4.3.3 Sustainable Development Goals

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which call for urgent actions by all countries as part of a global partnership. The SDGs recognise that elimination of poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality and spur economic growth – all while tackling climate change and working to preserve our oceans and forests.

South Africa, as a party to Agenda 2030, regularly reports on progress made towards achieving the SDG targets, where SDG 13 and 14 relate to blue carbon ecosystems. **To highlight the importance of blue carbon ecosystems, it is recommended that a sub-indicator be included that explicitly reports on the condition, protection measures and restoration efforts for blue carbon ecosystems.** Reporting can draw from progress captured through the national and provisional Outlook reports. The findings of the NBA (Estuaries Realm Report) and the Blue Carbon register (developed as part of this project) could serve as a baseline for such an indicator.

4.3.4 Natural Capital Accounting (NCA) as a Complementary Reporting System

In 2012 the United Nations (UN) launched the System of Environmental-Economic Accounting (SEEA), the first international statistical framework for measuring the environment and its relationship to economic and human activity. The framework is based on **internationally agreed accounting concepts** in terms of gathering and organising information in a consistent manner that enables integration with socio-economic information

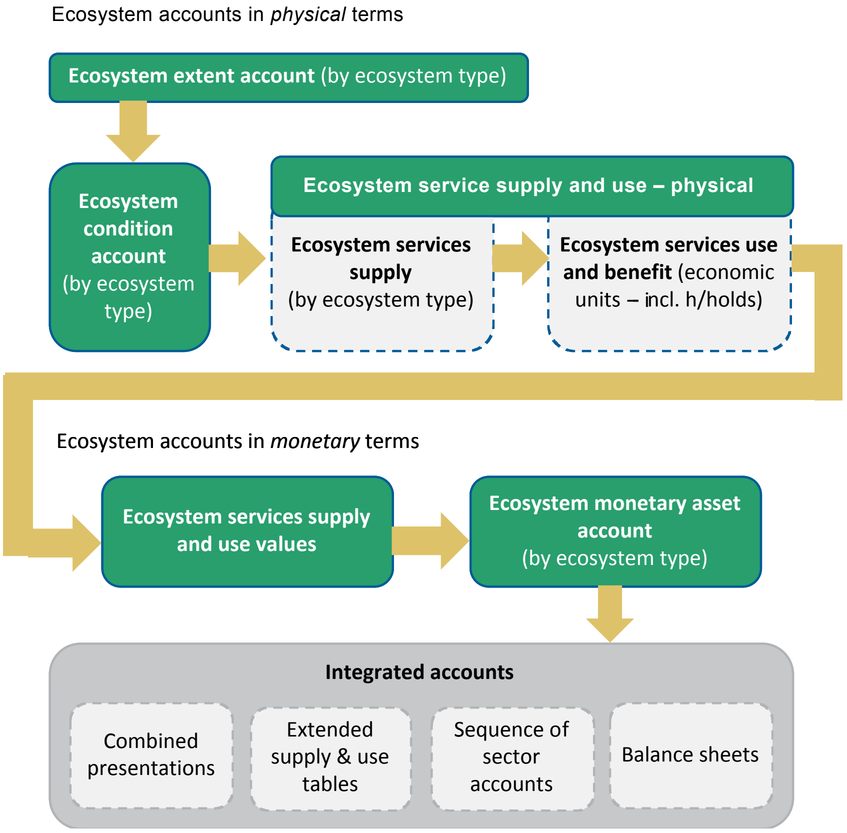


FIGURE 4.2: FIVE CORE ECOSYSTEM ACCOUNTS – THE ECOSYSTEM EXTENT ACCOUNT, THE ECOSYSTEM CONDITION ACCOUNT, THE ECOSYSTEM SERVICES SUPPLY AND USE ACCOUNTS IN PHYSICAL AND MONETARY TERMS, AND THE ECOSYSTEM MONETARY ASSET ACCOUNT (UNITED NATIONS 2017).

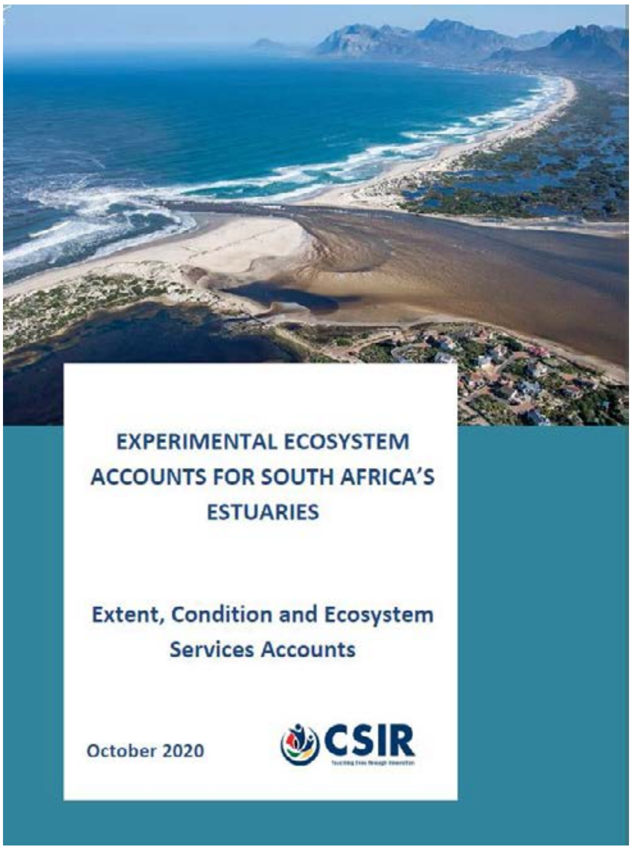
such as the System of National Accounts (United Nations 2014a). Specifically, the SEEA Ecosystem Accounting (SEEA EA) method (United Nations 2014b, 2017) includes the **measurement of the extent of ecosystem types, their condition, flows of ecosystem services provided by such ecosystems, and the estimated value (or benefit) to communities, governments and businesses** (based on either market transactions or non-market valuation). These parameters can be measured in physical and/or monetary terms (Figure 4.2).

Ecosystem accounting provides a means of **quantifying and tracking change in natural capital and associated ecosystem services over time**. This is intended to inform a range of policy, planning and decision-making processes relating to the management of ecosystems and the use of ecosystem services, and to **enable links to be made between the measurement of ecosystems and the measurement of the economy** (United Nations 2014a, 2017).

Estuaries constitute highly diverse habitats in the coastal space, providing **disproportionately high socio-economic benefits to society per unit area compared to other natural systems** (e.g. nursery areas for important fisheries, C sequestration). Estuaries thus form part of the set of small, high-value ecosystem types (< 5% of South Africa's territory) that function as critical ecological infrastructure that should be prioritised for planning, management and protection.

Stemming from their disproportionately high socio-economic value, it was critical to prepare their ecosystem accounts separately, and not aggregate these systems within larger freshwater or marine ecosystem accounts – running the risk of grossly undervaluing, or masking, their ecosystem service benefits to society.

The **ecosystem accounting methodologies** for South Africa's estuaries have therefore been developed to prepare the **first extent, condition and ecosystem services accounts for this often-overlooked ecosystem realm** (Van Niekerk et al. 2020). As part of this study, three important ecosystem service accounts were also considered, namely **C sequestration**, nursery function for important estuarine and marine fisheries, and habitat and refugia for rare endemic estuarine species. However, the C sequestration accounts were largely based on internationally derived values and old historical area estimates. These **accounts will need updating** with the more recent national estimates. There is therefore **scope for the results from this project on blue carbon sinks to contribute new information to the national natural capital accounts.**



EXPERIMENTAL ECOSYSTEM ACCOUNTS FOR SOUTH AFRICA'S ESTUARIES

Extent, Condition and Ecosystem Services Accounts

October 2020

CSIR

4.4 INCLUSION OF BLUE CARBON IN MITIGATION AND ADAPTATION GOALS OF NATIONALLY DETERMINED CONTRIBUTIONS

South Africa's NDC was submitted in 2016 and **includes both mitigation and adaptation objectives**. In the NDC, South Africa has committed to a peak, plateau and decline GHG emissions trajectory. The updated NDC (2021) reduced the **2025-2030 emissions target range from 398–614 Mt CO_2e** to **350–420 Mt CO_2e** (including the LULUCF component of AFOLU). The most recent national GHG inventory (DFFE 2021) estimates total emissions of **516 429.9 Mt CO_2e for 2017**, which represents a **17% increase** from the year 2000. South Africa intends to use **Sectoral Emission Targets** with several policies and measures (carbon budgets, GHG reporting regulation, carbon tax and carbon offset regulation) to achieve the proposed emission reduction targets.

In the AFOLU sector, **five measures for mitigation** have been recommended: afforestation, forest rehabilitation, thicket restoration, grassland rehabilitation and conservation agriculture. The Forest Land category is the largest contributor to the land C sink. In BUR4, the contributions of organic and humic soils to the land C sink were not incorporated, but these could be included in the next inventory (DEA 2019). Similarly, **CO_2 removals from wetlands were not evaluated** for BUR4, and wetlands have been assigned a 'Low' priority for proposed inclusion in BUR6 due to the lack of data and the relatively small area coverage of these ecosystems nationally. The 2013 update to the 2006 IPCC Guidelines for GHG Inventories provides explicit guidance for wetlands, and specifically **to account for CO_2 removals from coastal wetlands** (blue carbon ecosystems: mangroves, salt marshes and seagrasses) (IPCC 2014a). The ongoing blue carbon sink assessment project has shown that **these ecosystems cover ~19 800 ha** along the South African coastline. As these ecosystems sequester and store more C per unit area than terrestrial forests, **restoration of degraded blue carbon ecosystem areas should be considered as an additional mitigation measure** for the AFOLU sector.

Motivations for including blue carbon ecosystems in NDC include (Thomas et al. 2020):

- **High mitigation benefits**. These ecosystems sequester C at higher rates per unit area than terrestrial forests.
- **High adaptation benefits**. These ecosystems provide adaptation services such as protection from storm surges, flooding, SLR and coastal erosion, as well as livelihood options linked to intact ecosystem services – such as subsistence fishing and sustainable eco-tourism.
- **NDC progression**. Countries are encouraged to move towards economy-wide mitigation targets by the Paris Agreement and incorporating coastal ecosystems in the land sector contributes towards this.
- **High implementation value**. Conservation, restoration and sustainable management of coastal wetlands can support national policy priorities and is important as many sectors have impacts on the coast.
- **Sustainable blue economy**. Governments and private sector can work with coastal communities to align direct benefits with management and protection of coastal and ocean resources. Blue carbon ecosystems can serve as potential avenues for financial support and developing blue economies.

- **Climate finance**. NDCs can secure climate finance to support blue carbon actions, as under the Katowice Climate Package for reporting, the contribution of financial support to achieving the NDC of the recipient country must be reported.

The Blue Carbon Initiative (in collaboration with the IUCN) has released the **Guidelines on Enhanced Action**, which provides a tiered approach for countries to include blue carbon in their NDC at different levels of engagement depending on data availability (Thomas et al. 2020). Under this framework, **South Africa could be positioned to move from Engagement Level 1 to Level 2 following** the completion of the blue carbon sink assessment project (Table 4.9).

TABLE 4.9: LEVEL OF ENGAGEMENT FOR COUNTRIES TO INCORPORATE BLUE CARBON INTO THEIR NDC. ADAPTED FROM THE BLUE CARBON AND NATIONALLY DETERMINED CONTRIBUTIONS GUIDELINE (2020).

ENGAGEMENT LEVEL	STATUS OF BLUE CARBON DATA IN COUNTRY
Level 1	• No data available on area change in blue carbon ecosystems or associated GHG emissions. • Blue carbon ecosystems not included in conceptual documents for adaptation. • Blue carbon ecosystems are identified and included in the national plan.
Level 2	• Blue carbon ecosystems included in adaptation component of NDC or other adaptation communications. • Some advances towards quantification of the mitigation value of blue carbon ecosystems using IPCC guidance. • Progressing towards using at least IPCC Tier 1 for GHG inventory reporting of blue carbon ecosystems.
Level 3	• Comprehensive IPCC Tier 3 based inventory reporting for blue carbon ecosystems. • Blue carbon ecosystems are key components of adaptation and mitigation commitments.

South Africa's NDC does not reference blue carbon ecosystems directly, but there is reference to 'wetlands' in the Adaptation section. **Working for Water and Working in Wetlands are identified as programmes to be scaled up as supporting components of the NDC.** As South Africa has clear institutional arrangements to protect/ manage blue carbon ecosystems/coastal wetlands, the pathway to including them in the NDC is focused on designing policies, instruments and initiatives to advance restoration, protection and sustainable management for mitigation and adaptation. **Existing policies for the protection of blue carbon ecosystems are not strictly designed for mitigation and adaptation but are aimed at improving biodiversity and sustainability** – such as the

Draft Climate Change Sector Plan for Agriculture, Forestry and Fisheries, and the DFFE Strategic Plan. However, these policies can be leveraged towards mitigation and adaptation goals.

4.4.1 Examples of Blue Carbon Ecosystems in the Adaptation Component of the NDC

Including blue carbon ecosystems in the adaptation component of the NDC can take the form of a **qualitative statement on the importance of these ecosystems** and how they are being protected and managed in existing policy commitments, or the adaptation component can consider existing adaptation policy instruments (Adaptation Communications and National Adaptation Plans) (Thomas et al. 2020). **Policies, institutional arrangements and frameworks that are already in use can be aligned to the NDC process.** These include coastal management plans (under the ICM Act) that aim to coordinate key sectors and activities for restoration, protection and management, including blue carbon ecosystems. **Existing frameworks, such as EbA criteria, can be used to determine quantitative and qualitative indicators of climate, livelihood impacts and ecosystem health** (Thomas et al. 2020).

Belize has included the following specific measures/actions related to blue carbon ecosystems in their 2015 NDC:

- Increase and strengthen the capacity of coastal zone management and municipal authorities to ensure developments within the coastal zone include an adaptation strategy.
- Implement mangrove restoration as a defence structure to prevent coastal and riverine erosion.
- Include adaptation strategies in management and development planning in all coastal and marine sectors.
- Support management plans to protect blue carbon ecosystems and regulate provisioning from these ecosystems.
- Maintain and restore healthy forest ecosystems with sustainable forest management.

Chile has included the following specific measures/actions related to blue carbon ecosystems in their 2020 NDC:

- Establishing new marine protected areas to include under-represented marine ecoregions and coastal wetland ecosystems. Specific targets include protecting at least 10% of under-represented ecoregions by 2030; protecting at least 20 coastal wetlands as new protected areas by 2025.
- All marine protected areas will have a management or administration plan with a focus on adaptation.

Co-benefits of different ecosystems in marine protected areas will be assessed with respect to mitigation and adaptation. Specific targets include developing standardised metrics for evaluation as well as monitoring and verification approaches.

4.4.2 Examples of Blue Carbon Ecosystems in the Mitigation Component of the NDC

The NDC includes economy-wide targets for mitigation. **Blue carbon ecosystems can be integrated into both headline targets and specific or implementation targets** (Thomas et al. 2020). Headline economy-wide targets refer to the net total contributions, while sector-wide targets refer to specific components, where blue carbon ecosystems are generally included in the AFOLU/LULUCF sector. Implementation targets are linked to sector-wide targets and are specified over timeframes. Implementation targets can include specific emissions targets or can be expressed as other metrics – such as defining a percentage area of the ecosystem for restoration.

The Guidelines for Enhanced Action provide the following as a draft example:

> *'[Party] will conserve existing coastal wetlands and will also over the next five (5) years restore x hectares of previously removed or degraded coastal wetlands (mangroves, salt marshes, seagrasses). The measure is expected to generate x* tCO_2eq*. in [reduced], and/or [avoided], and/or [newly sequestered] emissions.'*

As South Africa intends to include wetlands in BUR6 as a component of AFOLU, **there is scope to also incorporate coastal wetlands** at this stage. The blue carbon sink assessment will provide a national spatial dataset on degraded areas and estimates on the GHG removals that can be obtained from restoration. This will allow implementation targets to be set.

4.5 OPPORTUNITIES FOR FINANCING BLUE CARBON PROJECTS AND SCOPE FOR BLUE CARBON CREDITS IN SOUTH AFRICA

The Paris Agreement expands on the International Emissions Trading mechanism of the Kyoto Protocol and serves as a framework for establishing a global C market (United Nations 2015). The Paris Agreement's **central aim is to keep global temperature to less than 2°C** (preferably less than 1.5°C) **above pre-industrial levels**. Instead of focusing on stabilising emissions, as was defined in the Kyoto Protocol, the Paris Agreement specifically calls for **emission reductions** to realise this goal. Further, the Agreement allows parties to specify their own Nationally Determined Contributions (NDC), as an ambitious encouragement to achieve the goals of the Agreement (United Nations 2015).

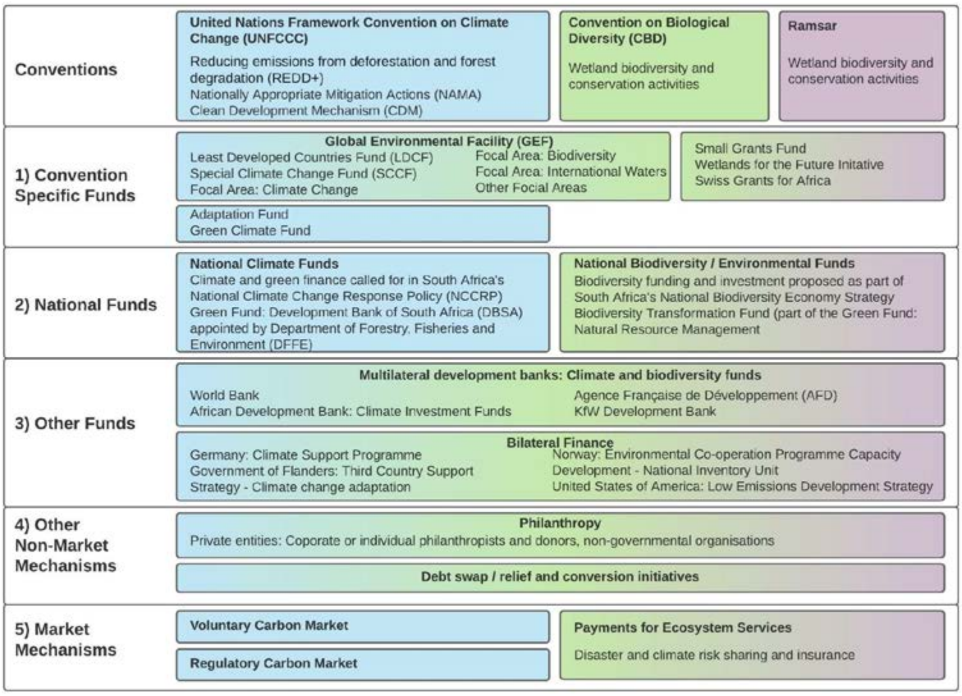
Climate finance mechanisms for coastal ecosystems have only recently emerged, unlike those that have been in place for terrestrial ecosystems. Appropriate funding for C projects and national C programmes does not always support all required management activities, often requiring **additional financial avenues to complement carbon activities (Figure 4.3)**.

As the potential to restore blue carbon ecosystems to enhance C sequestration can also deliver on other ecosystem services, such as providing protection from erosion, improved ecosystem health and protection of biodiversity, climate finance can be linked with and leveraged from other sources of funds and financing options (Figure 4.3).

4.5.1 UNFCCC Finance Mechanisms

The UNFCCC provides the **structure for internationally agreed GHG reduction measures** as well as technical details and dedicated funds for climate change mitigation activities. Blue carbon mitigation projects can be carried out independently, or as components of national programmes, and this influences which finance mechanisms are applicable.

National or sub-national programmes are large-scale efforts that aim to improve management of blue carbon



Conventions

United Nations Framework Convention on Climate Change (UNFCCC)
Reducing emissions from deforestation and forest degradation (REDD+)
Nationally Appropriate Mitigation Actions (NAMA)
Clean Development Mechanism (CDM)

Convention on Biological Diversity (CBD)
Wetland biodiversity and conservation activities

Ramsar
Wetland biodiversity and conservation activities

1) Convention Specific Funds

Global Environmental Facility (GEF)
Least Developed Countries Fund (LDCF)
Special Climate Change Fund (SCCF)
Focal Area: Climate Change
Focal Area: Biodiversity
Focal Area: International Waters
Other Focial Areas

Small Grants Fund
Wetlands for the Future Initative
Swiss Grants for Africa

Adaptation Fund
Green Climate Fund

2) National Funds

National Climate Funds
Climate and green finance called for in South Africa's National Climate Change Response Policy (NCCRP)
Green Fund: Development Bank of South Africa (DBSA) appointed by Department of Forestry, Fisheries and Environment (DFFE)

National Biodiversity / Environmental Funds
Biodiversity funding and investment proposed as part of South Africa's National Biodiversity Economy Strategy
Biodiversity Transformation Fund (part of the Green Fund: Natural Resource Management

3) Other Funds

Multilateral development banks: Climate and biodiversity funds
World Bank
African Development Bank: Climate Investment Funds
Agence Française de Développement (AFD)
KfW Development Bank

Bilateral Finance
Germany: Climate Support Programme
Government of Flanders: Third Country Support Strategy - Climate change adaptation
Norway: Environmental Co-operation Programme Capacity Development - National Inventory Unit
United States of America: Low Emissions Development Strategy

4) Other Non-Market Mechanisms

Philanthropy
Private entities: Coporate or individual philanthropists and donors, non-governmental organisations

Debt swap / relief and conversion initiatives

5) Market Mechanisms

Voluntary Carbon Market

Regulatory Carbon Market

Payments for Ecosystem Services
Disaster and climate risk sharing and insurance

FIGURE 4.3: SUMMARY OF CLIMATE (BLUE) AND BIODIVERSITY-RELATED (GREEN AND PURPLE) FINANCE MECHANISMS THAT ARE RELEVANT FOR C PROJECTS AND PROGRAMMES THAT ARE FOCUSED ON BLUE CARBON ECOSYSTEMS IN SOUTH AFRICA. ADAPTED FROM HERR ET AL. (2015).

ecosystem areas. **Guidance on developing both mitigation and adaptation programmes is provided by the UNFCCC.** There are specific mechanisms that have been developed to support mitigation and adaptation – these include **Nationally Appropriate Mitigation Activities (NAMAs)** and **Reducing Emissions from Deforestation and Forest Degradation (REDD+)**. The Clean Development Mechanism (CDM) was designed specifically to support project-level activities that result in measurable and verifiable GHG reductions.

UNFCCC-specific financial mechanisms include the Global Environment Facility (GEF), the Green Climate Fund (GCF) and the Adaptation Fund. The GEF is divided into the GEF Trust Fund and Focal Areas, the Special Climate Change Fund (SCCF) and the Least Developed Countries Fund (LDCF). The GEF Trust Fund is the central fund, financing focus areas such as biodiversity, climate change (mitigation and adaptation), land degradation and sustainable forest management (REDD+). **Blue carbon activities can fit within any of these mechanisms.**

4.5.2 Potential for Including Mangroves Within the Proposed Implementation of REDD+ in South Africa

In 2015, South Africa initiated the process towards developing a national REDD+ programme, focusing on **enhancement of carbon stocks, sustainable management of forests and conservation of forests**. REDD+ was identified as an important component of the climate change mitigation options proposed by the NTCSA for the AFOLU sector, where restoration and afforestation were recommended as actions to reduce GHG emissions in this sector (DEA 2015b). At present, REDD+ has been included as part of South Africa's land-based mitigation programme, which could facilitate the country's NDC under the UNFCCC and the Paris Agreement (DEFF 2020a).

A study was commissioned to assess South Africa's readiness to develop and implement a national REDD+ programme (also known as the Phase 0 study). This was followed by a study (Addressing Specific Elements of REDD+ in South Africa) to: 1) conduct a preliminary assessment of the scope of implementation of REDD+ in South Africa, using a tiered approach (DEFF 2020a); 2) determine effective institutional arrangements for the National REDD+ programme (DEFF 2020b); and 3) assess the drivers of deforestation and degradation at three pilot sites to identify strategic initial prevention measures and understand the associated costs (DEFF 2020c).

REDD+ programmes are primarily developed for terrestrial forests and are traditionally **not extended to include blue carbon ecosystems** (Jakovac et al. 2020). However, the **feasibility of including mangroves in national REDD+ programmes** has been advocated by several countries in Africa (Ajonina et al. 2014, Sitoe et al. 2014), South-East Asia (Vu et al. 2014, Aziz et al. 2016), as well as the southern USA and Mexico (Dai et al. 2018). **Mangroves can be easily included as these ecosystems fit the respective national definitions of 'forest'**, a cornerstone of REDD+. As part of the assessment of the potential to establish a national REDD+ programme in South Africa, a habitat is defined as a 'forest' if 1) the minimum height of the trees is 2 metres; 2) the minimum tree crown cover is > 30%; and 3) a minimum area of 0.05 ha is covered. **In South Africa, mangroves are classified as one of the indigenous forest types.**

Mangroves have historically been excluded from REDD+ programmes due to uncertainties with estimating ecosystem extent and C stocks as well as logistical constraints associated with their monitoring, which is more challenging than in terrestrial forests (Jakovac et al. 2020). Remote sensing can assist to resolve some of these issues (Fatoyinbo & Simard 2013, Atwood et al. 2017, Lagomasino et al. 2019), but this approach is only effective and accurate at the national **scale when mangrove areas are extensive and are not restricted to narrow coastal strips**. For example, global-scale remote sensing studies have misrepresented the change in mangrove area for South Africa as the resolution of these data is too coarse to detect changes in our relatively small mangrove forests in estuaries (Goldberg et al. 2020). Instead, for South Africa, **detailed maps of mangrove extent have been generated through various research efforts and are currently housed by SANBI as part of the NBA 2018** (Van Niekerk et al. 2019b, Adams & Rajkaran 2021). In the South African assessment on establishing a national REDD+ programme, mangroves were originally listed within the Tier A '**Scarp and coastal forests, tall woodland and thicket**' group, which has the highest priority. The prioritisation process to identify a practical and efficient way to implement the national REDD+ programme proposed that tall indigenous forest areas should be the sole focus of the first stage of the programme. Although this was a preliminary assessment, it is likely that **mangroves would only be considered for the national REDD+ programme at a later stage as they cover a small area nationally (~2 000 ha)**.

This blue carbon sink assessment has provided a spatial dataset of mangrove area cover in South Africa, including degraded areas. Additional data required for REDD+, such as the C sequestration, biomass and growth rates, are available for several mangrove sites. As this project will provide recommendations on areas for mangrove restoration, these can be considered as local-scale sites where projects, aligned with REDD+, could be first established.

4.5.3 Carbon Tax and Scope for Carbon Credits from Blue Carbon Ecosystems in South Africa

The Carbon Tax Act (No. 15 of 2019) came into effect in June 2019 and implements carbon taxes as part of South Africa's Paris Agreement Nationally Determined Contribution (NDC). South Africa updated their commitment in 2021 with the revised target to limit emissions in 2025 and 2030 to a range between 350–420 Mt CO_2e (DFFE 2021). **The carbon tax requires companies to pay a tax rate of ZAR 120 per tonne of C emissions** released from June 2019 until 2022. This rate will increase by 2% per year and from 2023 the rate will increase according to inflation. However, the first phase (until 2022) has extensive allowances for specific emitter circumstances, lowering the effective rate to between ZAR 6 and ZAR 48 per tonne, which is significantly lower than the price of ZAR 150 originally proposed in 2018 (Alton et al. 2014). **Companies can buy offsets or carbon credits verified under the CDM, VCS, GS and CCBS to meet 5–10% of their taxed liability** (emission reduction target) (National Treasury 2014).

Verra's Verified Carbon Standard (VCS) Program is an accredited standard under the South African tax regulation, allowing entities with tax obligations to use Verified Carbon Units to cover their tax liability. **Blue carbon ecosystems can be used to generate credits through the VCS Methodology for Tidal Wetland and Seagrass Restoration** (VM003 V1.0) (Emmer et al. 2015b). Restoration of blue carbon ecosystems contributes directly to CO_2 sequestration, which can be monitored and verified under a VCS project, and therefore can be used to generate eligible credits. Credits in the Verra registry can be deemed eligible and must be approved by the Carbon Offset Administration System, administered by the Department of Mineral Resources and Energy. These credits are then retired from the registry and identified as for use in the South African carbon tax system for compliance purposes.

The national demand for offsets has been estimated as 10 Mt $CO_2e.yr^{-1}$, but it is expected that the carbon tax could drive investments into GHG emissions reduction and removal activities. Verra projects support climate action across sectors and there is scope to develop new projects with carbon advisors. Additionally, **certification for projects is available against Sustainable Development Verified Impact Standard (SD VISta) or the Climate, Community & Biodiversity (CCB) Standard**. These accreditations can make projects more attractive or valuable to investors. As blue carbon ecosystems provide multiple ecosystem service benefits, including supporting livelihoods and maintaining biodiversity, these ecosystems could be eligible for accreditation under these alternative standards (Vanderklift et al. 2019b).

In South Africa, blue carbon ecosystems currently store ~2.9 million Mg C, equivalent to ~10.6 million tCO_2e (9.7 Mt CO_2e). These stocks have accumulated over time, and the loss or degradation of these ecosystems risks releasing this CO_2 into the atmosphere. There is ~7 000 ha of degraded blue carbon ecosystem area that can be restored, thus creating an opportunity to develop carbon offsetting projects. In salt marsh, if the area is increased by 1 ha, there is potential to sequester between 4.7–26.1 tCO_2eq in one year if the vegetation biomass is equal to that of a natural area. For mangroves and submerged macrophytes, the C sequestration potential for a 1 ha increase in area is estimated as 271.3–647.3 tCO_2eq and 7.63–16.7 tCO_2eq, respectively.

5. MITIGATION POTENTIAL ANALYSIS

5.1 HISTORICAL EFFECTS/WOM (WITHOUT MEASURES) OF CLIMATE CHANGE MITIGATION ACTIONS

The WOM scenario considers **historical emissions associated with specific anthropogenic activities** and develops a future projection of emissions under the assumption that no mitigation measures are implemented. **The WOM scenario is therefore the 'Business as Usual' projection for GHG emissions.**

The GHG Emissions Baseline (Section 3) represents the WOM scenario. **The WOM scenario projects that blue carbon ecosystems will decline in extent based on the pressure level assigned to each specific estuary in the 2018 National Biodiversity Assessment (NBA).** Pressure ratings have been assigned as L = Low, M = Medium, H = High, VH = Very High (Van Niekerk et al. 2019b). The baseline was calculated over the available historical dataset (< 1930–2021) and projected every decade to 2050 (Table 3.10). At the end of each decade, the difference in area in comparison to the current (2021) coverage was calculated and used to estimate the corresponding loss of C stocks and therefore GHG emissions (Table 5.1).

In the WOM model, all anthropogenic pressures are predicted to reduce the extent of blue carbon ecosystems into the future, and therefore result in CO_2 emissions (Table 5.1). Water quality/eutrophication is predicted to have the largest impact on blue carbon ecosystems by 2050. This pressure is predicted to reduce total blue carbon ecosystem extent by 4.3% by 2050 and this will result in CO_2 emissions of 214 216.8 tCO_2e. Reduced freshwater inflow/flow modification is predicted to reduce blue carbon ecosystem extent by 3.5%, generating 182 744.6 tCO_2e of emissions by 2050. Emissions from land-use change are estimated as slightly higher than this at 183 064.5 tCO_2e, even though the pressure is predicted to only reduce blue carbon extent by 1.6% by 2050. This is because land-use change activities result in complete loss of soil C stocks and conversion to CO_2, while only a portion of these are impacted by the abiotic pressures. Artificial breaching is predicted to have a lesser impact (52 905.6 tCO_2e).

TABLE 5.1: OTAL BLUE CARBON ECOSYSTEM AREA EXTENT PREDICTED AT THE END OF EACH DECADE IN RELATION TO EACH ANTHROPOGENIC PRESSURE MODELLED IN THE GHG BASELINE WITHOUT MEASURES (WOM) SCENARIO. VALUES IN BRACKETS INDICATE THE% DIFFERENCE FROM 2021 EXTENT. CO_2 EMISSIONS ASSOCIATED WITH HABITAT LOSS AT THE END OF EACH DECADE ARE ALSO REPORTED.

PRESSURE		2030	2040	2050
Reduced Freshwater Inflow/Flow Modification	Area (ha)	19 446.9 (-2.0%)	19 295.04 (-2.7%)	19 143.18 (-3.5%)
	CO_2 Emissions (tCO_2e)	105 970.2	144 357.4	182 744.6
Water Quality/Eutrophication	Area (ha)	19 477.9 (-1.8%)	19 233.46 (-3.0%)	18 989.1 (-4.3%)
	CO_2 Emissions (tCO_2e)	87 171.4	150 694.1	214 216.8
Artificial Breaching	Area (ha)	19 588.5 (-1.3%)	19 588.5 (-1.3%)	19 588.5 (-1.3%)
	CO_2 Emissions (tCO_2e)	52 905.6	52 905.6	52 905.6
Land-Use Change	Area (ha)	19 658.1 (-0.9%)	19 589.7 (-1.2%)	19 836.5 (-1.6%)
	CO_2 Emissions (tCO_2e)	112 947.1	148 005.8	183 064.5

5.2 MITIGATION POTENTIAL ANALYSIS PART I: WEM (WITH EXISTING MEASURES)

The WEM scenario considers the effect of existing measures on blue carbon ecosystems and their contribution towards enhancing the C sink capacity of these ecosystems. The WEM scenario is a future projection of CO_2 removals under the assumption that actions that can be carried out with existing measures will be implemented on the ground.

The WEM scenario was developed by considering the potential for the listed actions to either maintain or enhance C sink capacity of blue carbon ecosystems. Each action was ranked based on predicted effect to increase blue carbon ecosystem area and therefore increase C stocks (Appendix XI). As each action is linked to a specific pressure in the WOM scenario, the strength of the combined WEM actions to serve towards mitigation is equal to the inverse of the pressure, minus the contribution of the WAM actions (see next section). For example, the pressure of reduced freshwater inflow was projected to drive a 5% decrease in salt marsh area by the end of 2030 (Table 3.10); the WEM actions linked to this pressure were estimated to drive a 2.2% increase in salt marsh area over the same time period (Table 5.2).

CO_2 removals ($t\ CO_2e\ yr^{-1}$) associated with area expansion of blue carbon ecosystems were estimated as follows:

$$CO_2\ \textit{removals} = (\textit{C sequestration rate} \times \text{Area})\ 3.67$$

Where the *C sequestration* rate (Mg C ha^{-1} yr^{-1}) was multiplied by the area of expansion of the ecosystem (ha) and the conversion factor of 3.67 (ratio of C to CO_2).

C sequestration rates were calculated for each blue carbon ecosystem and accounted for biogeographic variability in C stocks. C sequestration was calculated as:

$$\begin{aligned}&C\ sequestration\ rate\\&= C\ concentration \times sediment\ surface\ elevation\end{aligned}$$

Where the *C concentration*ntration (g cm^{-3}) was obtained from the available literature for South African blue carbon ecosystems (Els 2017, 2019, Johnson 2019, Raw et al. 2019b, Adams et al. 2020a, Banda et al. 2021) and extrapolated across biogeographic regions using the same approach as was applied for C stocks (Section 3). Similarly, the sediment surface elevation rate (cm yr^{-1}) was obtained from available data for South African mangroves and salt marshes (Schmidt 2013, Bornman et al. 2016, Adams et al. 2020a, Raw et al. 2020, 2021). A default value from a global review of surface elevation change in submerged macrophytes/seagrasses was applied as there are no locally available data for this habitat type (Potouroglou et al. 2017).

The WEM scenario projects that blue carbon ecosystems will increase in area based on the 2021 pressure rating and the number of actions listed under this scenario. The WEM scenario was projected every decade to 2050 (Table 5.2).

At the end of each decade, the difference in area in comparison to the current (2021) coverage was calculated and used to estimate the corresponding gain of C stocks and therefore GHG removals (Table 5.3).

In the WEM model, all anthropogenic pressures are predicted to increase the extent of blue carbon ecosystems into the future, and therefore result in negative CO_2 emissions (CO_2 removals) (Table 5.3). Carrying out mitigation actions to reduce pressure from reduced freshwater inflow/flow modification is predicted to have the largest impact on enhancing CO_2 removals from blue carbon ecosystems by 2050. WEM actions to reduce this pressure can increase blue carbon ecosystem extent by 1.1% by 2050, and this will result in CO_2 removals of 13 189.8 tCO_2e.

TABLE 5.2: PREDICTED PERCENTAGE INCREASE IN BLUE CARBON ECOSYSTEM AREA PER DECADE IN RESPONSE TO MITIGATION ACTIONS THAT CAN BE CARRIED OUT WITH EXISTING MEASURES (WEM) WHICH ARE LINKED TO ABIOTIC AND LAND-USE CHANGE PRESSURES. PERCENTAGES REPRESENT GAIN RELATIVE TO 2021 AREA COVER AND ARE SCALED RELATIVE TO THE ASSIGNED PRESSURE RATING (L = LOW, M = MEDIUM, H = HIGH, VH = VERY HIGH).

PRESSURE: **REDUCED FRESHWATER INFLOW/FLOW MODIFICATION** (NO PROJECTED DIRECT IMPACT ON SUBMERGED MACROPHYTES AS THESE ARE LESS DEPENDENT ON FRESHWATER; SALT MARSHES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

		Predicted percentage increase in area relative to 2021 by the end of the decade		
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	2.46	3.08	3.69
	H	1.85	2.31	2.77
	M	1.23	1.54	1.85
	L	0.62	0.77	0.92
Salt Marsh	VH	1.54	2.15	2.77
	H	1.15	1.62	2.08
	M	0.77	1.08	1.38
	L	0.38	0.54	0.69

PRESSURE: **WATER QUALITY CHANGES/EUTROPHICATION** (SALT MARSHES AND SUBMERGED MACROPHYTES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

	Predicted percentage increase in area relative to 2021 by the end of the decade			
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	0.60	1.20	1.80
	H	0.45	0.90	1.35
	M	0.30	0.60	0.90
	L	0.15	0.30	0.45
Salt Marsh and Submerged Macrophytes	VH	1.80	3.00	4.20
	H	1.35	2.25	3.15
	M	0.90	1.50	2.10
	L	0.45	0.75	1.05

PRESSURE: **ARTIFICIAL BREACHING** (NO PROJECTED IMPACT ON MANGROVES AS THESE ECOSYSTEMS OCCUR IN SYSTEMS THAT ARE PREDOMINANTLY OPEN TO THE OCEAN; EFFECT OF ACTIONS PREDICTED TO REMAIN CONSTANT)				
	Predicted percentage increase in area relative to 2021 by the end of the decade			
	Estuary Score	2021–2030	2031–2040	2041–2050
Salt Marsh and Submerged Macrophytes	VH	6.00	6.00	6.00
	H	4.50	4.50	4.50
	M	3.00	3.00	3.00
	L	1.50	1.50	1.50
PRESSURE: **LAND-USE CHANGE/TRANSFORMATION** (NO PROJECTED IMPACT ON SUBMERGED MACROPHYTES AS THIS ECOSYSTEM IS GENERALLY NOT SUBJECTED TO LAND-USE CHANGE DUE TO BEING SUBMERGED)				
	Predicted percentage increase in area relative to 2021 by the end of the decade			
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	(N/A)	0.22	0.33	0.44
	No pressure rating assigned for transformation. The same% values are applied across all estuaries with mangroves.			
Salt Marsh	Intertidal	0.22	0.33	0.44
	Supratidal	0.22	0.44	0.88
	No pressure rating assigned for transformation. The same% values are applied across all estuaries with intertidal and supratidal salt marsh.			

Similarly, WEM actions to reduce pressure from water quality/eutrophication and artificial breaching are predicted to increase blue carbon ecosystem extent by 1.8% and 2.4% respectively by 2050, thus enhancing CO_2 removals by 11 394.5 tCO_2e and 10 146.9 tCO_2e. WEM actions to reduce pressure from LUC are predicted to increase blue carbon ecosystem extent from 0.2–0.6%, which is estimated to enhance removals by ~5 738.4 tCO_2e by 2050.

TABLE 5.3: TOTAL BLUE CARBON ECOSYSTEM AREA EXTENT PREDICTED AT THE END OF EACH DECADE IN RELATION TO MITIGATION ACTIONS THAT CAN BE CARRIED OUT WITH EXISTING MEASURES (WEM) TO ADDRESS THE PRESSURES PROJECTED IN THE BASELINE SCENARIO. VALUES IN BRACKETS INDICATE THE% DIFFERENCE FROM 2021 EXTENT. CO_2 REMOVALS ASSOCIATED WITH HABITAT GAIN AT THE END OF EACH DECADE ARE ALSO REPORTED.

PRESSURE LINKED TO ACTIONS		2030	2040	2050
Reduced Freshwater	Area (ha)	19 964.5	20 013.3	20 062.0
Inflow/Flow		(+0.7%)	(+0.9%)	(+1.1%)
Modification				
	CO_2 Emissions (tCO_2e)	-8 305.8	-10 747.8	-13 189.8
Water Quality/	Area (ha)	19 988.7	20 091.5	20 194.3
Eutrophication		(+0.8%)	(+1.3%)	(+1.8%)
	CO_2 Emissions (tCO_2e)	-4 474.6	-7 934.5	-11 394.5
Artificial Breaching	Area (ha)	20 330.6	20 330.6	20 330.6
		(+2.4%)	(+2.4%)	(+2.4%)
	CO_2 Emissions (tCO_2e)	-10 146.9	-10 146.9	-10 146.9
Land-Use Change	Area (ha)	19 873.2	19 903.12	19 956.1
		(+0.2%)	(+0.3%)	(+0.6%)
	CO_2 Emissions (tCO_2e)	-2 359.4	-3 794.0	-5 738.4

5.3 MITIGATION POTENTIAL ANALYSIS PART II: WAM (WITH ADDITIONAL MEASURES)

The WAM scenario considers the effect of additional measures on blue carbon ecosystems and their contribution towards enhancing the C sink capacity of these ecosystems. The WAM scenario is a future projection of CO_2 removals under the assumption that these actions as well as those described in the WEM scenario will be implemented fully with the described measures.

The WAM scenario was developed following the same approach as the WEM scenario to calculate CO_2 removals ($t\ CO_2e\ yr^{-1}$). The WAM scenario projects that blue carbon ecosystems will increase in extent based on the 2021 pressure rating and the number of actions listed under this scenario. The WAM scenario was projected every decade to 2050 (Table 5.4).

TABLE 5.4: PREDICTED PERCENTAGE INCREASE IN BLUE CARBON ECOSYSTEM AREA PER DECADE IN RESPONSE TO MITIGATION ACTIONS THAT CAN BE CARRIED OUT THROUGH IMPLEMENTATION WITH EXISTING MEASURES (WEM) AND WITH ADDITIONAL MEASURES (WAM) WHICH ARE LINKED TO ABIOTIC AND LAND- USE CHANGE PRESSURES. PERCENTAGES REPRESENT GAIN RELATIVE TO 2021 AREA COVER AND ARE SCALED RELATIVE TO THE ASSIGNED PRESSURE RATING (L = LOW, M = MEDIUM, H = HIGH, VH = VERY HIGH).

PRESSURE: **REDUCED FRESHWATER** INFLOW/FLOW MODIFICATION (NO PROJECTED DIRECT IMPACT ON SUBMERGED MACROPHYTES AS THESE ARE LESS DEPENDENT ON FRESHWATER; SALT MARSHES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

	Predicted percentage increase in area relative to 2021 by the end of the decade			
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	4.62	5.77	6.92
	H	3.46	4.33	5.19
	M	2.31	2.88	3.46
	L	1.15	1.44	1.73
Salt Marsh	VH	4.23	5.92	7.62
	H	3.17	4.44	5.71
	M	2.12	2.96	3.81
	L	1.06	1.48	1.90

PRESSURE: **WATER QUALITY CHANGES/EUTROPHICATION** (SALT MARSHES AND SUBMERGED MACROPHYTES PREDICTED TO BE MORE IMPACTED THAN MANGROVES)

	Predicted percentage increase in area relative to 2021 by the end of the decade			
	Estuary Score	2021–2030	2031–2040	2041–2050
Mangroves	VH	1.00	2.00	3.00
	H	0.75	1.50	2.25
	M	0.50	1.00	1.50
	L	0.25	0.50	0.75
Salt Marsh and Submerged Macrophytes	VH	3.00	5.00	7.00
	H	2.25	3.75	5.25
	M	1.50	2.50	3.50
	L	0.75	1.25	1.75

PRESSURE: **ARTIFICIAL BREACHING** (NO PROJECTED IMPACT ON MANGROVES AS THESE ECOSYSTEMS OCCUR IN SYSTEMS THAT ARE PREDOMINANTLY OPEN TO THE OCEAN; EFFECT OF ACTIONS PREDICTED TO REMAIN CONSTANT). NO WAM ACTIONS WERE IDENTIFIED FOR THIS PRESSURE.				
	Predicted percentage increase in extent relative to 2021 by the end of the decade			
	Estuary Score	2021-2030	2031-2040	2041-2050
Salt Marsh and Submerged Macrophytes	VH	6.00	6.00	6.00
	H	4.50	4.50	4.50
	M	3.00	3.00	3.00
	L	1.50	1.50	1.50
PRESSURE: **TRANSFORMATION** (NO PROJECTED IMPACT ON SUBMERGED MACROPHYTES AS THIS ECOSYSTEM IS GENERALLY NOT SUBJECTED TO LAND-USE CHANGE DUE TO BEING SUBMERGED)				
	Predicted percentage increase in extent relative to 2021 by the end of the decade			
	Estuary Score	2021-2030	2031-2040	2041-2050
Mangroves	(N/A)	0.50	0.75	1.00
	No pressure rating assigned for transformation. The same% values are applied across all estuaries with mangroves.			
Salt Marsh	Intertidal	0.50	0.75	1.00
	Supratidal	0.50	1.00	2.00
	No pressure rating assigned for transformation. The same% values are applied across all estuaries with intertidal and supratidal salt marsh.			

At the end of each decade, the difference in extent in comparison to the current (2021) coverage was calculated and used to estimate the corresponding gain of C stocks and therefore GHG removals (Table 5.5). In the WAM model, all anthropogenic pressures are predicted to increase the extent of blue carbon ecosystems into the future, and therefore result in negative CO_2 emissions (CO_2 removals) (Table 5.5). Carrying out mitigation actions to reduce pressures from reduced freshwater inflow/flow modification is predicted to have the largest impact on enhancing CO_2 removals from blue carbon ecosystems by 2050. WAM actions to reduce this pressure can increase blue carbon ecosystem extent by 3% by 2050, and this will result in CO_2 removals of 28 569.0 tCO_2e. Similarly, WAM actions to reduce pressure from water quality/eutrophication and artificial breaching are predicted to increase blue carbon ecosystem area by 3% and 2.5% respectively by 2050, thus enhancing CO_2 removals by 18 990.8 tCO_2e and 10 146.9 tCO_2e respectively. Removals associated with reducing land-use change pressures are estimated as 13 116.3 tCO_2e by 2050.

TABLE 5.5: TOTAL BLUE CARBON ECOSYSTEM AREA EXTENT PREDICTED AT THE END OF EACH DECADE IN RELATION TO MITIGATION ACTIONS THAT CAN BE CARRIED OUT WITH ADDITIONAL MEASURES (WAM) TO ADDRESS THE PRESSURES PROJECTED IN THE BASELINE SCENARIO. VALUES IN BRACKETS INDICATE THE% DIFFERENCE FROM 2021 EXTENT. CO_2 REMOVALS ASSOCIATED WITH HABITAT GAIN AT THE END OF EACH DECADE ARE ALSO REPORTED.

PRESSURE LINKED TO ACTIONS		2030	2040	2050
Reduced Freshwater	Area (ha)	20 174.3	20 304.8	20 435.3
Inflow/Flow		(+1.7%)	(+2.3%)	(+3.0%)
Modification				
	CO_2 Emissions (tCO_2e)	–17 705.7	–23 137.4	–28 569.0
Water Quality/	Area (ha)	20 090.1	20 261.5	20 432.8
Eutrophication		(+1.3%)	(+2.1%)	(+3.0%)
	CO_2 Emissions (tCO_2e)	–7 457.7	–13 224.2	–18 990.8
Artificial Breaching	Area (ha)	20 330.6	20 330.6	20 330.6
		(2.5%)	(2.5%)	(2.5%)
	CO_2 Emissions (tCO_2e)	–10 146.9	–10 146.9	–10 146.9
Land-Use Change	Area (ha)	19 920.5	19 988.8	20 109.9
		(+0.4%)	(+0.8%)	(+1.4%)
	CO_2 Emissions (tCO_2e)	–5 392.8	–8 671.9	–13 116.3

5.4 MITIGATION POTENTIAL ANALYSIS PART II: COMPARING THE WOM, WEM AND WAM SCENARIOS

Comparing the WEM and WAM scenarios to the WOM scenario shows the potential effects of the identified mitigation actions on CO_2 emissions. The effect of WEM and WAM actions on CO8 emissions is considered separately for the abiotic pressures (reduced freshwater inflow/flow modification, water quality/eutrophication, artificial breaching) (Figure 5.1) and pressures associated with land-use change (Figure 5.2). WEM and WAM actions only have a limited effect on the overall projected emissions trend, due to the expected ongoing impact from estuarine use pressures in these scenarios.

The baseline (WOM) model predicts emissions from blue carbon ecosystems due to abiotic pressures to be 449 867 tCO_2e by 2050. Actions to reduce abiotic pressures that can be carried out with existing measures (WEM scenario) have the potential to reduce emissions by 34 731.1 tCO_2e, which translates to net emissions of 415 135.9 tCO_2e by 2050 for blue carbon ecosystems. With additional measures, emissions from blue carbon ecosystems can be reduced to 392 160.4 tCO_2e by 2050.

For the land-use change pressure (Figure 5.2), the emissions trajectory for the WOM scenario was already predicted to be a slow incline from 2020-2050. The WEM and WAM actions contribute towards a further decline in this trend. However, the largest potential for enhancing CO_2 removals is through active restoration of degraded areas. This is predicted to allow a significant shift towards offsetting for managed blue carbon ecosystems.

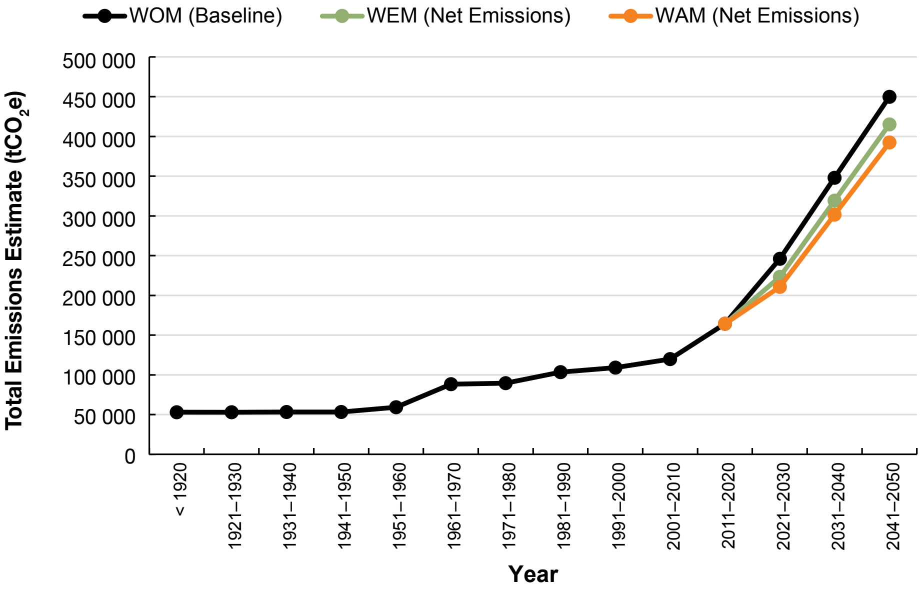


FIGURE 5.1: PROJECTED GHG EMISSIONS FOR THE WITHOUT MEASURES (WOM), WITH EXISTING MEASURES (WEM) AND WITH ADDITIONAL MEASURES (WAM) SCENARIOS. THE MODELS SHOW THE NET TRAJECTORY OF EMISSIONS ASSOCIATED WITH ABIOTIC PRESSURES (REDUCED FRESHWATER INFLOW/FLOW MODIFICATION, WATER QUALITY/ EUTROPHICATION, ARTIFICIAL BREACHING).

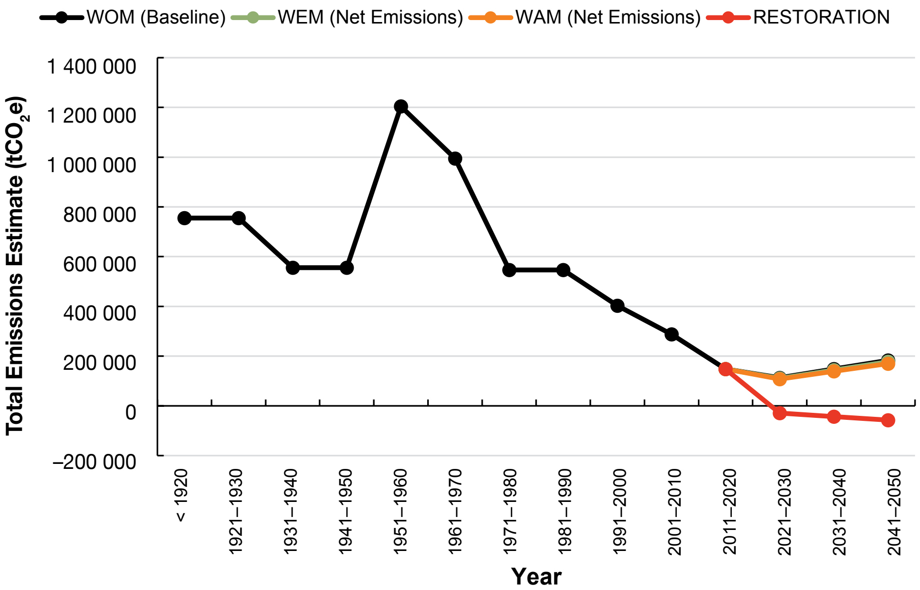


FIGURE 5.2: PROJECTED GHG EMISSIONS FOR THE WITHOUT MEASURES (WOM), WITH EXISTING MEASURES (WEM) AND WITH ADDITIONAL MEASURES (WAM) SCENARIOS. MODELS SHOW THE NET TRAJECTORY OF EMISSIONS ASSOCIATED WITH LAND-USE CHANGE PRESSURES.

The baseline (WOM) model predicts emissions from blue carbon ecosystems due to land-use change pressures to be 183 064.5 tCO_2e by 2050. Actions to reduce land-use change pressures that can be carried out with existing measures (WEM scenario) have the potential to reduce emissions by 5 738.4 tCO_2e, which translates to net emissions of 177 326.1 tCO_2e by 2050 for blue carbon ecosystems. With additional measures, emissions from blue carbon ecosystems can be reduced to 175 686.6 tCO_2e by 2050.

The CO_2 removals associated with active restoration were estimated by identifying areas within the larger estuaries where restoration could take place, and then calculating the potential C sequestration per decade. Areas suitable for restoration were obtained from the blue carbon sinks spatial dataset. The estimated area for restoration is conservative, as only 25% of fallow agricultural lands, and 50% of both abandoned salt extraction pans and degraded areas, were included. Larger active restoration targets will generate larger CO_2 removals from blue carbon ecosystems.

All WEM and WAM actions for all pressures were combined and compared to the composite WOM trajectory (Figure 5.3). The WEM and WAM actions lower the trajectory of the CO_2 emissions from 2020–2050. However, net CO_2 removals are only obtained through an investment in active restoration. Under the WOM scenario, CO_2 emissions are estimated at ~633 000 tCO_2e by 2050. If the WEM actions alone were implemented, this could be reduced to net emissions of ~592 000 tCO_2e. If the WEM and WAM actions were implemented together, net CO_2 emissions from blue carbon ecosystems are estimated at ~562 000 tCO_2e by 2050. Implementing active restoration could increase blue carbon ecosystem area by 1 160 ha by 2050, resulting in removals of ~57 000 tCO_2e by 2050.

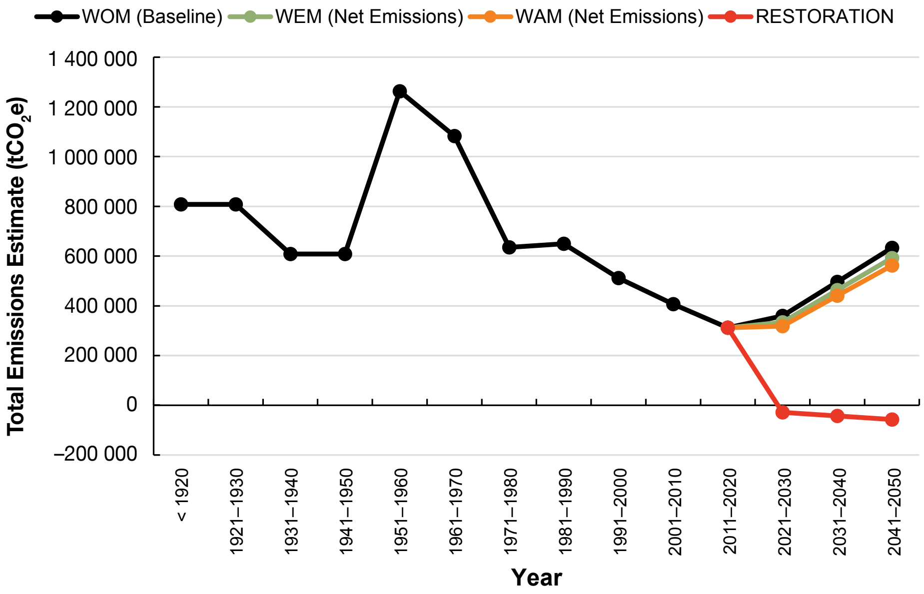


FIGURE 5.3: PROJECTED GHG EMISSIONS FOR THE WITHOUT MEASURES (WOM), WITH EXISTING MEASURES (WEM) AND WITH ADDITIONAL MEASURES (WAM) SCENARIOS. MODELS SHOW THE NET TRAJECTORY OF EMISSIONS ASSOCIATED WITH ALL PRESSURES. CO_2 REMOVALS ASSOCIATED WITH ACTIVE RESTORATION ARE ALSO INDICATED.

6. KEY FINDINGS AND RECOMMENDATIONS

BLUE CARBON ECOSYSTEMS PROVIDE OPPORTUNITIES TO MAXIMISE C SEQUESTRATION AS WELL AS OTHER IMPORTANT ECOSYSTEM SERVICES

South Africa is poised to embark on a process of developing effective adaptation strategies and to join global counterparts in emission control through the management and protection of blue carbon ecosystems. Blue carbon ecosystems are highly susceptible to anthropogenic impacts and the effects of climate change, which not only reduces their capacity to sequester C, but also results in the release of GHGs. The protection and restoration of these ecosystems provides an opportunity to maximise C sequestration as well as other important ecosystem services and socio-ecological benefits (e.g. nursery habitat for fish, water purification and support of local livelihoods). Blue carbon benefits should thus not be separated from the multiple ecosystem services provided to a wide range of beneficiaries by these habitats. This multi-use approach should be promoted and opportunities for job creation, eco-tourism, conservation and sustainable harvesting can be encouraged and coordinated in this way. **Overall, the management and protection of blue carbon ecosystems should be integrated into coastal management practices, national and provincial climate adaptation strategies, biodiversity conservation and blue economy planning.**

INVESTING IN HIGH-QUALITY SPATIAL DATA OF BLUE CARBON SYSTEMS

Any blue carbon sinks assessment strongly depends on the availability and quality of the underpinning spatial data. Without spatial data, it is not possible to evaluate trends in the extent of these ecosystems over time or to provide reliable estimates of GHG emissions and removals. The national geodatabase developed for this study includes information on the blue carbon ecosystems extent of 142 estuaries, and more estuaries will be added as new maps are generated. All blue carbon ecosystem areas > 10 ha have been captured in the spatial dataset. Non-spatial estuary habitat cover data for additional estuaries were extracted from reports and research articles so that all major blue carbon ecosystems are included in the dataset. Additionally, the geodatabase also includes the historical spatial data that allow changes in land use and ecosystem extent over time to be examined. Within the geodatabase, vegetated areas are categorised based on the plant species groups which will be used to reflect different carbon storage and sequestration potentials when the GHG emissions and removals baseline is developed. **While the focus was on blue carbon ecosystems, teal carbon freshwater ecosystems that are associated with estuaries – swamp forests, reeds and sedges – have also been mapped in some systems for future inclusion in the national database as these ecosystems can also serve as C sinks.** Degraded areas were identified that should be prioritised for restoration back to their near-natural ecosystem state.

Blue carbon ecosystems cover 19 838.8 ha in South Africa, while teal carbon ecosystems contribute an additional 17 654.9 ha. Supratidal salt marsh is dominant in both the cool-temperate (6 611.7 ha) and warm-temperate biogeographic regions (2 570.3 ha). Mangroves are restricted to the subtropical region, with a few estuaries in the warm-temperate region also supporting this ecosystem type. Present mangrove extent is 2 086.7 ha recorded for 34 estuaries in the country. Only 78 estuaries support submerged aquatic vegetation as these species are sensitive to changes to water level, turbidity, nutrients and salinity. The seagrass *Zostera capensis* occurs in 37 estuaries. Estuarine lakes provide the most suitable conditions for the establishment and the largest areas are found in this scarce estuary type.

The database can also serve as input to spatial planning initiatives and guide priority actions for restoration that will enhance C sequestration as well as other important ecosystem services (such as nursery habitat for fish, water purification and support of local livelihoods). This database can also provide information on mangroves for inclusion into the South African REDD+ programme. **Overall, the data should be integrated into existing national spatial datasets and therefore be included in climate change adaptation strategies, biodiversity conservation and blue economy planning.**

DEVELOPING A GHG EMISSIONS AND REMOVALS BASELINE

A GHG emissions and removals baseline for blue carbon ecosystems was developed by examining historical drivers of habitat loss, as well as considering the impacts of climate change. While substantial information is available on the current and historical extent of blue carbon ecosystems in South Africa, detailed studies to quantify C storage have only been carried out in four South African estuaries, and so estimates of C stocks for all other estuaries are extrapolated from these. Default values for emissions and removals provided by the IPCC 2013 Wetlands Supplement were thus used to calculate the historical and projected emissions of the baseline. Major C stock changes (and the associated emissions and removals) were estimated and related to a range of activities. Extraction activities that remove blue carbon ecosystems and replace them with hard infrastructure resulted in the largest historical emissions.

The base year for projections was determined **using available historical datasets and the ability to show GHG emissions and removals trends**. The year **2000** was selected as the base year from which GHG emissions and projections are made going forward. This would provide a trajectory along which future emissions and removals could be predicted.

The present-day (2021) carbon (C) stocks of blue carbon ecosystems were estimated following the internationally standardised IPCC guidelines. It was found that South African blue carbon ecosystems currently **contain a total of 2 891.9 Gg C (Gigagrams Carbon stock)**. The highest proportion **(64%) occurs in salt marshes** as these have the largest extent (area) of the South African blue carbon ecosystems. Examining the historical changes in distribution and area coverage of blue carbon ecosystems indicated that a total of **591.4 Gg C has been lost due to extraction activities**, and this equates to **~2 170.3 Gg CO_2e**. Comparing GHG emissions and removals between time periods (from 1930 to 2020) showed that most emissions occurred prior to 1990, and particularly between 1950–1970.

Post-1990, more stringent policies limited activities (such as the construction of new developments) within estuarine functional zones (EFZ).

The development of a baseline scenario of GHG emissions and removals also necessitates the inclusion of abiotic drivers such as changes to **freshwater inflow regime, water quality** (e.g. nutrient pollution) or **artificial breaching** (mouth management). Climate change drivers (sea-level rise, sea storms, floods, droughts, increased CO_2, increased temperature) have also been considered as these could have significant impacts on blue carbon ecosystems in the future.

It is recommended that the baseline is refined, improved and updated accordingly. As more data become available from *in situ* field studies, this will improve estimates of C stocks. This will improve the estimates calculated by extrapolation for sites that are currently data-limited. Additionally, the emissions estimates could be refined if *in situ* measurements of C fluxes are obtained, as site-specific data are preferable to the default values provided by the IPCC Guidelines. Finally, the baseline should be updated as ecosystem areas are expected to change in response to different pressures.

MITIGATION AND ADAPTATION STRATEGIES AND ACTIONS

Blue carbon ecosystems are efficient C sinks and highly valued ecosystems that provide ecosystem-based adaptation options that can be incorporated into climate change mitigation and adaptation strategies, and therefore can help countries achieve their NDC. From a blue carbon perspective, **climate-focused mitigation actions** are those that will **reduce climate change effects**, either by reducing sources of greenhouses gases (GHGs) or enhancing GHG sinks. **Climate-focused adaptation actions** are those that will **reduce the vulnerability** of people and the environment to the harmful effects of climate change.

However, blue carbon ecosystems are under multiple anthropogenic pressures that lead to habitat degradation and habitat loss. This in turn can drive GHG emissions from the large C pools stored in these ecosystems.

The study identified 18 potential mitigation and adaptation actions that can be carried out in blue carbon ecosystems in South Africa. Key actions include the restoration of blue carbon ecosystems and avoiding future developments or disturbance of blue carbon ecosystems, as well as specific management actions to regulate freshwater inflows, improve water quality from catchment areas and mitigate the impacts of artificial breaching. For each action, the **recommended strategy** and **relevant policy/legislation** are provided, as well as an overview of the current implementation or scope for the action to be carried out. Actions that can be readily carried out have been designated as 'With Existing Measures' (WEM), while those that require new policies are considered as 'With Additional Measures' (WAM).

Under the WEM model, GHG removals are estimated as ~48 345.3 tCO_2e by 2050, while under the WAM model, GHG removals are estimated as ~67 733.0 tCO_2e by 2050. Although all measures are predicted to contribute towards CO_2 removals, given the current level of estuary use, it is acknowledged that the impacts of existing pressures cannot be completely removed. Therefore, although the WEM and WAM models show a reduction in the impacts of the pressures (e.g. ongoing flow reduction or agricultural return flow), model results indicate a continued increasing trajectory of CO_2 emissions into the future.

There is thus an urgent need to carry out active restoration of degraded blue carbon habitats, which will contribute directly to CO_2 removals. Following this approach, up to 1 160 ha of blue carbon ecosystems can be restored by 2050 (100 ha of mangroves, 1 000 ha of salt marsh and 60 ha of submerged macrophytes). This will result in an additional 57 219.6 tCO_2e reduction by 2050. These calculations are based on conservative assumptions around restoration potential, and a significant investment in active restoration has the potential to arrest or reverse the CO2 emissions trajectory from managed blue carbon ecosystems. Note that this will only be successful if supported by WEM and WAM measures.

Important supporting legislation for achieving mitigation and adaptation include the **National Environmental Management Act: Environmental Impact Assessment Regulations, the Integrated Coastal Management Act, the National Biodiversity Act and the National Water Act**. However, while South Africa has a well-defined and strong legislative framework, supporting norms and standards are less developed and will require some refinements. Furthermore, across most sectors implementation, compliance and enforcement are lacking. This includes a lack of continuity of established compliance institutional structures, such as the Blue and Green Scorpions. **While the country has a supporting legal framework, significant work is still needed to acknowledge the value of blue carbon ecosystems to coastal communities so that measures can be taken to preserve these benefits as intended by key policies and frameworks.**

As only 38% of blue carbon ecosystem area in South Africa is currently protected, the way forward includes investing in measures for the protection of blue carbon ecosystems, such as the **increasing formal protection and stewardship programmes as outlined in the National Estuarine Biodiversity Plan (or future updates), incorporating into the national Critical Biodiversity Area spatial planning framework, increasing investment in existing and new Ramsar sites and International Bird and Biodiversity Areas**. OECMs may also present an opportunity to increase the protection of larger expanses of blue carbon ecosystems.

CLIMATE FINANCING OPTIONS

There are opportunities for financing blue carbon projects through climate financing options and additional financial avenues that complement carbon activities. In South Africa, finance options include those related to conventions (UNFCCC, the CBD and Ramsar); national climate and biodiversity/environmental funds (NCCRP, DBSA Green Fund); multilateral and bilateral financing (World Bank, African Development Bank, Germany Climate Support Programme); as well as market-based mechanisms (voluntary and regulatory carbon markets).

Specifically, South Africa is considering the potential for including mangroves within a national REDD+ programme (under the UNFCCC). Although mangroves would be eligible for inclusion in REDD+, there are a few additional considerations for measuring and monitoring C in these ecosystems that diverge from the methods applied in terrestrial forests. Furthermore, as mangroves cover a relatively small area (2 086 ha) in South Africa, it is unlikely that these ecosystems will be prioritised in the first phase of the national REDD+ programme. **However, the blue carbon sink assessment should be used to inform on which mangrove estuaries are candidates for restoration projects, C stock enhancement and sustainable forest management.**

The voluntary carbon market presents an opportunity for trading carbon credits generated through blue carbon projects carried out in South Africa. In particular, the South

African tax regulation recognises credits obtained through the Verra VCS, which includes a specific methodology for projects that carry out restoration of blue carbon ecosystems. Presently, the national demand for offsets has been estimated as 10 Mt CO_2e.yr^{-1}. **Restoration of blue carbon ecosystems is estimated to sequester 4.7–647.3 tCO_2e.yr^{-1} for 1 ha, depending on ecosystem type. With ~7 000 ha of degraded blue carbon ecosystem area, there is scope to develop restoration projects that could generate carbon credits and contribute towards offsetting strategies.**

RECOMMENDATIONS TOWARDS PROTECTING BLUE CARBON ECOSYSTEMS

Resource and biodiversity protection of blue carbon ecosystems is slow (only 38% of overlap with protected areas), thus the following urgent measures are required to ensure a network of healthy and productive estuaries:

- The establishment of more formally protected areas is a critical response to protecting blue carbon ecosystems from human activities. Protected areas are the most assured mechanisms for conserving species and ecosystems. Stewardship also presents an important opportunity to conserve salt marsh in particular, as supratidal areas can be located within private land.

- The National Estuary Biodiversity Plan prioritises which estuaries should be assigned Protected Area status and provides the 'lens' through which all present and future resource allocations should be evaluated to ensure that national and international biodiversity targets are achieved. It is strongly recommended that future updates of the plan prioritise all estuaries that support large expanses of blue carbon ecosystems and that area targets for those ecosystems be increased to 100% of mangroves and 30% of salt marsh remaining extent to ensure adequate protection and representation.

- There is an urgency to better define land ownership within the national EFZ area so that state-owned land can be proclaimed as protected, or to identify areas suitable for stewardship. A preliminary assessment of land ownership found significant discrepancies between the South African cadastral layer and the boundaries of estuarine habitats. These and other data gaps need to be resolved so that potential areas for protection can be appropriately identified.

- Reporting on the condition, protection and restoration of blue carbon ecosystems should be integrated into South Africa's National GHG Inventory, Environmental Outlook Report, National Biodiversity Assessment, SDG reporting and into STAT SA Environmental Ecosystems Accounting processes. Furthermore, parameters used globally for blue carbon sink assessments should be incorporated within the existing South African Department of Forestry, Fisheries and Environment (DFFE) Ocean and Coast monitoring framework to allow for regular updates in progress towards conservation and restoration targets.

RECOMMENDATIONS TO REDUCE PRESSURES ON BLUE CARBON ECOSYSTEMS

Key strategies/actions required to reduce the impact of land-use change include:

- Develop Integrated Estuarine Restoration Strategy/Policy to coordinate and direct blue carbon restoration at national, provincial or even municipal levels. Actively restore degraded blue carbon ecosystems, including the setting of restoration targets, allocating funding, and developing monitoring and reporting structures.

- Develop policies that support land-use planning practices that allow for upslope landward migration to avoid 'coastal squeeze' of blue carbon ecosystems with sea-level rise, including the development of strict protocols for the setting of estuary flood/ setback/management lines for inclusion in municipal Integrated Development Plans and Spatial Development Plans.
- Develop a land-exchange programme to reclaim 'accommodation space' and facilitate blue carbon ecosystems persistence under rising sea level conditions.
- Integrate blue carbon spatial datasets into national/ provincial datasets (e.g. national biodiversity assessment, national vegetation map, provincial biodiversity maps) to ensure inclusion in land-use planning and biodiversity conservation (e.g. National Estuary Biodiversity Plan, Coastal/Estuary Critical Biodiversity Map, EIA processes, Municipal Spatial Development Plans).
- Acquire all fallow and agricultural land below the 2.5 m MSL contour. This area will be naturally converted to estuarine habitat with SLR and should be proactively acquired.
- All blue carbon ecosystems should be protected by Estuary Management Plans, with new and existing EMPs explicitly protecting estuarine habitats from development and land-use change.
- As part of EIA processes, avoid clearing or infilling of estuarine habitat and soil disturbance within EFZ. Do not permit future land-use change and disturbance; in addition, re-evaluate existing permissions for biomass clearing and soil disturbance.
- Avoid all mining-related activities within EFZs as these have irreversible impacts on carbon storage and sequestration. Develop a policy that does not permit mining for sand, diamonds, minerals or the establishment of salt works within a 1 km buffer of the EFZ. Evaluate the impact of mining on associated sediment budgets and coastal processes.
- Reduce the impact of boating activities through the development of a boating policy that considers impacts on blue carbon ecosystems such as destruction and erosion of habitat. Estuary zonation plans should protect blue carbon ecosystems from boating activities. Do not permit launching and anchoring of boats in seagrass beds.
- Improve tidal exchange along the length of the estuary in degraded systems, including the removal of barriers that limit tidal exchange, including weirs and causeways. Remove or redesign transport infrastructure (old railways and bridges) that impede flow.
- Generate awareness of the importance of blue carbon ecosystems and the need to plan for their protection in estuary management planning processes.

Key strategies/actions required to reduce the impact of freshwater flow modification include:

- Protect/reinstate freshwater inputs through freshwater flow allocations ('Reserves') targeted at the maintenance of critical estuarine processes and blue carbon ecosystems. Assessments should explicitly incorporate requirements of blue carbon ecosystems in the determination of 'Reserves' and 'Resource Quality Objectives' gazetted by DWS. Estuaries with blue carbon ecosystems should have medium to high confidence 'Reserves' determinations, including drought allocations. This should be supported by increased compliance monitoring for the implementation of ecological water requirements.

- Clear invasive alien plants in catchments to restore critical base flows and freshwater input to estuaries.

- Assess regional-scale sediment processes and develop a regional sediment management (RSM) plan. Protect/maintain sediment transport processes linked to freshwater inflow as they are critical to increasing elevation and preventing drowning of blue carbon ecosystems in response to sea-level rise impacts. All estuaries under pressure should have sediment budgets evaluated and Resource Quality Objectives set to support sediment processes.

- Prevent over-abstraction and lowering of groundwater table and ensure all groundwater abstraction activities are licensed and do not impact estuaries.

- Develop and implement a policy to phase out/not permit commercial forest plantations within a 2 km buffer of EFZ to protect groundwater table.

- Do not permit mining within EFZ given the high risk to disturbance of the groundwater table and additional risk of wind-blown dust and pollution. Evaluate mining within 2 km radius of an estuary to ensure mitigation of impacts to groundwater table.

Key strategies/actions required to reduce the impact of pollution and poor water quality include:

- Limit and reduce the volume of effluent from exiting WWTWs into estuaries (or just upstream of estuaries) and improve water quality from existing WWTW, with the intent of recycling or reusing effluent in the long term. Do not permit new WWTW discharge into estuaries.

- Develop agriculture best practice guidelines to reduce agricultural return flow and generate awareness of the impact of over-fertilisation on estuaries, including control/discourage the use of herbicide and pesticide in and around estuaries.

- Develop strategies that encourage adaptive urban stormwater management practices that attenuate stormwater peak inflows.

- Require developers to make decisions informed by future climate, and local governments to incorporate climate change into decision-making processes. Make climate change considerations, e.g. increase in extreme rainfall events, compulsory in development applications.

Key strategies/actions required to reduce the impact of artificial breaching include:

- Prohibit artificial breaching of estuaries for unnecessary or invalid reasons.

- Prohibit development of new infrastructure in low-lying areas that could be prone to flooding and thus requiring artificial breaching of estuary mouths.

- Develop a 'National Artificial Breaching Protocol' for estuaries (informed by approaches developed in the WC and KZN) and engage with national and provincial disaster risk management agencies to highlight the risk of poor breaching practices and to mitigate premature breaching.

- Develop comprehensive Estuary Management Plans for all estuaries subjected to artificial breaching, including a Mouth Management Plan that stipulates the motivation for breaching, and a pre-approved Maintenance Management Plan (under the EIA regulations) that details the criteria for and approaches to a breaching.
- Set conservative flood line/set back lines/coastal management lines that demarcate the impact area of 1:100-year flood events under future climate conditions (e.g. SLR, increase wave energy and increase flooding).
- As part of coastal climate change strategies, conduct surveys to investigate options to remove poorly planned, low-lying infrastructure and access roads (e.g. public ablution facilities too close to an estuary, farm roads through EFZ). This has the added benefit that it supports an active retreat policy in the face of sea-level rise.

RECOMMENDATIONS FOR FUTURE RESEARCH AND MONITORING

- Detailed studies to quantify C storage have only been carried out in four South African estuaries. More estuaries should be evaluated across all four biogeographical regions for the estimations of C storage and the current baseline to be adjusted when more information becomes available.
- Teal carbon freshwater ecosystems that are associated with estuaries – swamp forests, reeds and sedges – represent over 17 000 ha that contribute to carbon storage. However, little is known about their carbon sequestration potential and their past and present spatial extent. It is recommended that similar to the blue carbon assessment, research also be conducted on teal carbon habitats in estuaries.
- Detailed 1:3 000 fine-scale mapping to the edge of the EFZ of all blue and teal carbon habitats in all 300 estuaries is needed to refine future C assessments. This needs to be supported by LiDAR (to mean sea level) and drone studies, as well as ground truthing at selected sites. Mapping methods need to be standardised and metadata captured.
- The degree of pressures (i.e. flow reduction, pollution, artificial breaching) on blue carbon ecosystems should be updated every five years to reflect progress in the management of these habitats.
- Research is needed on the development of a standardised approach to reflect the condition of mangroves, salt marsh and seagrass that are in a degraded state. This in turn should be linked to C carbon sequestration potential.
- To ensure future persistence of blue carbon ecosystem and support protection, restoration and management efforts, urgent research is required on the impact of sea- level rise on blue carbon ecosystems to identify areas most at risk and in need of interventions.
- It is recommended that the blue carbon sink register be updated every five years to reflect change in the extent of blue carbon ecosystems, evaluate the degree of pressure on blue carbon ecosystems, and report on restoration and protection progress.

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APPENDICES

APPENDIX I:
METADATA REPORT OF THE BLUE CARBON GEODATABASE

Description

This layer represents the distribution of macrophyte habitats in South African estuaries within the Estuarine Functional Zone (EFZ) delineated by the 5 m contour. Some maps were generated during Estuarine Health Index assessments (EWRs/RDMs) to determine the Present Ecological Status of a system. Some estuaries were mapped as part of Nelson Mandela University student theses. Additional shapefiles were also obtained from other organisations such as SANParks. Not all estuaries are mapped to the EFZ. Macrophyte habitat descriptions may have been altered from the original published maps to standardise the naming of the macrophyte habitat types. Distribution maps differ in extent, scale and accuracy as they were produced for different outcomes. The shapefiles are formatted in accordance with SANBI specifications. These maps represent a moment in time, and changes in habitat extent and position may occur in response to natural drivers. In some estuaries, the assigned categories were based on visual assessment of aerial imagery without ground truthing.

Contact ***Janine Adams*** (Janine.Adams@mandela.ac.za) for further information.

Projections

Projected Coordinate System: AEA_RSA_WGS84

Projection: Albers

False_Easting: 0,00000000

False_Northing: 0,00000000

Central_Meridian: 25,00000000

Standard_Parallel_1: –24,00000000

Standard_Parallel_2: –33,00000000

Latitude_Of_Origin: 0,00000000 Linear Unit: Meter

Geographic Coordinate System: GCS_WGS_1984 Datum: D_WGS_1984

Prime Meridian: Greenwich Angular Unit: Degree

Fields

FIELD	TYPE	DESCRIPTION
OBJECT_ID	Object ID	Default field
SHAPE	Geometry	Default field
ESTUARY_NAME		Estuary name according to updated 2018 National Biodiversity Assessment.
ESTUARY_TYPE		Estuarine types as described by Van Niekerk et al. (2019).
MACROPHYTE_HABITAT		Broad macrophyte habitats. See Adams et al. (2016) for further description.
MACROPHYTE_HABITAT_ SUBTYPE		Further categorisation of habitat and, where possible, species names have been included.
Ocean		Sea water occurring within the boundary of the EFZ. Ocean is included in the EFZ recognising the connectivity between estuary and near shore environment.
Beach and dune sand		Beach sand included within the EFZ of estuaries. Sand dune habitat with an elevation unsuitable for macrophyte establishment, may be sand or vegetated.
Open water		This represents the habitat associated with the water column of an estuary and is measured as the water surface area. The primary producers are the phytoplankton consisting of flagellates, dinoflagellates, diatoms and blue – green algae which occur in a wide range of salinity from freshwater to marine conditions. It includes water – filled pans and tributaries falling within the EFZ.
Sand and mudbanks		The dominant primary producers of these habitats are the benthic microalgae. Where possible, sediment type has been described, either sand or mud.
Rocks		Boulders and rocky habitat that can be distinguished from aerial photographs.
Macroalgae		Macroalgae may be intertidal (intermittently exposed) or subtidal (always submerged); they may be attached or free floating. Filamentous macroalgae often form algal mats and increase in response to nutrient enrichment or calm sheltered conditions when the mouth of an estuary is closed. Typical genera include *Enteromorpha* and *Cladophora*. Many marine species can get washed into an estuary and providing the salinity is high enough, can proliferate. These include *Codium*, *Caulerpa*, *Gracilaria* and *Polysiphonia*.

FIELD	TYPE	DESCRIPTION
Submerged macrophytes		Submerged macrophytes are those plants that are rooted in the bottom substrate with their leaves and stems completely submersed (e.g. *Stukenia pectinata* and *Ruppia cirrhosa*) or exposed on each low tide (e.g. the seagrass *Zostera capensis*). *Zostera capensis* occupies the intertidal zone of most predominantly open Cape estuaries, whereas *Ruppia cirrhosa* is common in temporarily closed estuaries. *Stukenia pectinata (=Potamogeton pectinatus)* occurs in closed systems or in the upper reaches of open estuaries where the salinity is less than 10 ppt.
Intertidal salt marsh, supratidal salt marsh and salt pans		Salt marsh plants show distinct zonation patterns along tidal inundation, elevation and salinity gradients. Zonation is well developed in estuaries with a large tidal range, e.g., Groot Berg, Knysna and Swartkops estuaries. Common genera are *Salicornia*, *Triglochin*, *Limonium* and *Juncus*. Halophytic grasses such as *Sporobolus virginicus* and *Paspalum* spp. are also present. Intertidal salt marsh occurs below mean high water spring and supratidal salt marsh above this. Where ground truthing has taken place, the species names have been included in the subtype. Intertidal salt marsh (ISM), supratidal salt marsh (SSM).
Floodplain		Area within the EFZ that does not have a high cover of estuarine species but has the potential to be estuarine habitat. This habitat occurs above the 2.5 m contour and is where most disturbance and development has taken place. Listed as floodplain salt marsh where high confidence, otherwise simply as floodplain. In this situation it often represents an ecotone between estuarine and terrestrial habitat.
Mangroves		Mangroves are trees that establish in the intertidal zone in permanently open estuaries along the east coast of South Africa north of East London, where water temperature is usually above 20°C. The white mangrove *Avicennia marina* is the most widespread, followed by *Bruguiera gymnorrhiza* and then *Rhizophora mucronata*. *Lumnitzera racemosa*, *Ceriops tagal* and *Xylocarpus granatum* only occur in the Kosi Estuary.
Reeds and sedges		Reeds, sedges and rushes are important in the freshwater and brackish zones of estuaries. Because they are often associated with freshwater input, they can be used to identify freshwater seepage sites along estuaries. The dominant species are the common reed Phragmites australis, Schoenoplectus scirpoides, Typha capensis and Bolboschoenus maritimus. Species names have been included where ground truthing has taken place. In places, ephemeral pans can occur in the floodplain area.

FIELD	TYPE	DESCRIPTION
Swamp forest		Swamp forests, unlike mangroves, are freshwater habitats associated with estuaries in KwaZulu – Natal. Common species include *Hibiscus tiliaceaus*, *Syzygium cordatum*, *Barringtonia racemosa* and *Ficus trichopoda*. It is often difficult to distinguish this habitat from coastal forest in aerial photographs. Species names have been included where ground truthing has taken place.
Ecotone		This area often represents a mix of supratidal salt marsh and terrestrial species and mostly falls within the floodplain area above 2.5 m.
Terrestrial vegetation		Terrestrial habitat within the EFZ is mapped according to Mucina and Rutherford's Vegetation Map (2006) of South Africa.
Degraded		These areas have usually lost more than 50% biodiversity, being replaced with grassed areas and other such soft development. They represent areas that could potentially act as restoration sites, especially under future sea – level rise scenarios. This class often contains fallow land and old fields.
Developed		These are areas that have been completely transformed by human activities and no longer support estuarine functioning. They consist of hard structures such as residential and industry that are unlikely to be removed. They also include agricultural land, road and railway as well as wastewater treatment works, marinas and golf courses.
Invasives		Stands of non – natural habitat occurring in the floodplains of estuaries. Represents a loss of natural habitat and could be a management/restoration project. Species names have been included where ground truthing has taken place. These do not refer to invasive aquatic plants.
DATA_CAPTURER		Name of mapper and organisation in brackets.
DATE_MAPPED		Year the estuary was mapped.
IMAGE_SOURCE		Source of aerial photographs: National Geo – Spatial Information (NGI), Google Earth (GE) and Bing.
IMAGE_DATE		Year of aerial photographs used for mapping.
MAPPED_TO_5M		Mapped to the full 5 m EFZ, yes or no.
REFERENCE		Reference to thesis or report where original spatial data is sourced.
SHAPE_LENGTH	Double	Default field

FIELD	TYPE	DESCRIPTION
SHAPE_LENGTH	Double	Default field
SHAPE_AREA	Double	Default field
AREA	Double	Area of specific macrophyte habitat calculated in Albers Equal Area, represented in Ha.
CSIR		CSIR identification number.
HABITAT_LO		The original habitat prior to disturbance or development was determined using aerial imagery and literature, i.e., habitat lost.
SANCL_class		The South African Land Cover layer file was used to determine the equivalent land cover class name to integrate these files with the SANLC in the future.
SANLC_Tier1		Aligned to the South African Land Cover Class Tier 1.
SANLC_Tier2		Aligned to the South African Land Cover Class Tier 2.
Restoration		The category into which habitat falls for purposes of potential restoration.

Disclaimer

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APPENDIX II:
LAND COVER CATEGORIES/TYPES AND SUBTYPES WITH ASSOCIATED DESCRIPTIONS THAT WERE USED IN THE COLLATION OF THE BLUE CARBON GEODATABASE.

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Beach and dune sand	Beach and dune sand	Coastal Sand & Dunes	Unconsolidated	Barren Land
Degraded	Degraded	Cultivated Commercial	Commercial Crops	Cultivated
Degraded	Degraded	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Degraded	Degraded	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Degraded	Degraded	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Degraded	Degraded – agriculture	Commercial Crops	Cultivated Commercial	Cultivated
Degraded	Degraded – aquaculture			
Degraded	Degraded – beach access	Roads & Rail (Major Linear)	Transport	Built-up
Degraded	Degraded – bridge	Roads & Rail (Major Linear)	Transport	Built-up
Degraded	Degraded – cleared			
Degraded	Degraded – dams	Artificial Dams		Built-up
Degraded	Degraded – desertified salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Degraded	Degraded – ecotone			
Degraded	Degraded – farm	Cultivated	Cultivated	Cultivated
Degraded	Degraded – floodplain			
Degraded	Degraded – footpaths			Built-up
Degraded	Degraded – grassed/ residential	Urban Residential	Urban	Built-up
Degraded	Degraded – gravel road		urban	Built-up
Degraded	Degraded – invasives			

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Degraded	Degraded – modified land			
Degraded	Degraded – open water polluted pan	Mines: Extraction Sites: Salt Mines		
Degraded	Degraded – recreational (camping)	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Degraded	Degraded – recreational (camping)	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Degraded	Degraded – residential	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Degraded	Degraded – residential/ farm	Cultivated	Cultivated	Cultivated
Degraded	Degraded – roads	Roads & Railways (Major Linear)	Transport	Built-up
Degraded	Degraded – salt marsh	Natural Estuaries & Lagoons		
Developed	Developed	Natural Estuaries & Lagoons		
Developed	Developed – agriculture	Cultivated Commercial	Commercial crops	Cultivated
Developed	Developed – agriculture (crops)	Cultivated Commercial	Commercial crops	Cultivated
Developed	Developed – agriculture (pivot)	Cultivated Commercial	Commercial crops	Cultivated
Developed	Developed – agriculture (pivot)	Cultivated Commercial	Commercial crops	Cultivated
Developed	Developed – agriculture (sugar cane)	Cultivated Commercial Sugarcane Non – Pivot (all other)	Commercial crops	Cultivated
Developed	Developed – airstrip	Roads & Rail (Major Linear)	Transport	Built-up
Developed	Developed – aquaculture	Commercial	Commercial	Built-up
Developed	Developed – beach shacks	Village Scattered	Urban	Built-up
Developed	Developed – breakwater wall			Built-up
Developed	Developed – CapeNature offices	Commercial	Urban	Built-up

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Developed	Developed – car park	Urban Built-up	Urban	Built-up
Developed	Developed – clubhouse	Urban Built-up	Urban	Built-up
Developed	Developed – commercial	Commercial		Built-up
Developed	Developed – craft harbour	Urban Recreation	Urban	Built-up
Developed	Developed – dam	Artificial Dams		Built-up
Developed	Developed – ex agriculture	Semi-natural	Semi-natural	Semi-natural
Developed	Developed – farm house	Residential Formal (Tree)	Urban	Built-up
Developed	Developed – golf course	Urban Parkland	Urban	Built-up
Developed	Developed – grassed	Urban Parkland	Urban	Built-up
Developed	Developed – grassed/ car park	Urban Parkland	Urban	Built-up
Developed	Developed – grassed/ residential	Urban Residential	Urban	Built-up
Developed	Developed – grassed/ roads/Degraded	Urban Parkland	Urban	Built-up
Developed	Developed – gravel road			Built-up
Developed	Developed – housing	Commercial		Built-up
Developed	Developed – industrial	Industrial	Industrial	Built-up
Developed	Developed – jetty	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Developed	Developed – marina	Residential Formal (Tree, Bush, low veg/grass)	Urban	Built-up
Developed	Developed – pipes/ pump			Built-up
Developed	Developed – open space	Urban Recreational Fields (Bare)	Urban	Built-up
Developed	Developed – quarry	Mines: Extraction Sites: Open Cast & Quarries		Built-up
Developed	Developed – railway	Roads & Rail (Major Linear)		Built-up
Developed	Developed – recreational	Urban Parkland	Urban	Built-up
Developed	Developed – residential	Urban Residential	Urban	Built-up

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Developed	Developed – residential/ commercial		Urban	Built-up
Developed	Developed – residential/ industrial	Urban	Urban	Built-up
Developed	Developed – residential/ industrial	Urban	Urban	Built-up
Developed	Developed – residential/ industrial	Urban	Urban	Built-up
Developed	Developed – road embankment terrestrial vegetation	Roads & Rail (Major Linear)	Transport	Built-up
Developed	Developed – road verge	Roads & Rail (Major Linear)	Transport	Built-up
Developed	Developed – road/car park	Roads & Rail (Major Linear)	Transport	Built-up
Developed	Developed – roads	Roads & Rail (Major Linear)	Transport	Built-up
Developed	Developed – salt works	Mines: Extraction Sites: Salt Mines	Mines	Mines
Developed	Developed – subsistence agriculture	Subsistence Annual Crops	Subsistence Crops	Cultivated
Developed	Developed – subsistence agriculture	Subsistence Crops	Subsistence Crops	Cultivated
Developed	Developed – villages	Urban Village	Urban	Built-up
Developed	Developed – WWTW	Artificial Sewage Ponds	Urban	Built-up
Ecotone	Dune/salt marsh			
Ecotone	Floodplain/terrestrial vegetation	Contiguous Low Forest & Thicket	Natural	Natural
Ecotone	Floodplain salt marsh/ terrestrial vegetation	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Ecotone	Supratidal salt marsh/ floodplain/terrestrial	Natural Estuaries & Lagoons		
Ecotone	Supratidal salt marsh/ terrestrial (50:50)	Natural Estuaries & Lagoons		
Estuary	Estuary	Natural estuaries & Lagoons	Natural Waterbodies	Waterbodies

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Floodplain	Floodplain	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Floodplain	Floodplain salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Invasives	Invasives	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Acacia cyclops	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Acacia cyclops	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Casuarina	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Casuarina	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Casuarina	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Degraded forest	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Invasives	Invasives – Degraded grasses	Invasive Alien Plants	Invasive Alien Plants	Invasive Alien Plants
Macroalgae	Macroalgae	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Macroalgae	Macroalgae – Asparagopsus mixed	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Macroalgae	Macroalgae – Caulerpa	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Macroalgae	Macroalgae – Caulerpa mixed	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Mangroves	Mangroves	Mangrove wetlands	Woody Wetlands	Wetlands
Mangroves	Mangroves – Hibiscus	Mangrove Wetlands	Wooded Wetlands	Wetlands
Ocean	Ocean	Natural Ocean	Natural Waterbodies	Waterbodies
Open water	Open water	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Reeds and sedges	Ephemeral pans	Herbaceous Wetlands	Herbaceous Wetlands	Waterbodies

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Reeds and sedges	Freshwater ephemeral pan	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Bolboschoenus maritimus	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – brackish wetland	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Cladium mariscus	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Cyperus durus	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Ficinia nodosus	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Juncus mix	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Palmiet	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Phragmite australiss	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Schoenoplectus scirpoides	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges – Typha capensis	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges (seepage area)	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Reeds and sedges/ Swamp Forest	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Salt marsh – reeds and sedge mix	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Reeds and sedges	Wetlands	Herbaceous Wetlands	Herbaceous Wetlands	Wetlands
Rocks	Rocks	Natural Rock Surfaces	Consolidated	Barren Land
Rocks	Supratidal salt marsh/ rocks	Natural Rock Surfaces	Consolidated	Barren Land

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Salt marsh	Ephemeral pans	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Ephemeral pans	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Spartina maritima	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Bassia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Salicornia meyeriana	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Salicornia tegetaria	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – saline grasses	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Spartina maritima	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh – Triglochin	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh/ floodplain	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Intertidal salt marsh/ rocks	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	ism:ssm (30:70)	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	ism:ssm (50:50)	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	ism:ssm (60:40)	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	ism:ssm (70:30)	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh – arid estuarine salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Salt marsh	Salt marsh – intertidal mosaic	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh – intertidal/ supratidal mosaic	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh – saline grasses	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh mosaic	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Salt marsh mosaic	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh/ rocks	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Cotula coronopifolia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – desertified salt pans	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – floodplain	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Juncus krausii	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Juncus krausii/grasses	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – salt pans	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Salicornia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Salicornia / Bassia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Salicornia pillansii	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – saline grasses	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – salt pans	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Salt marsh	Supratidal salt marsh – Sporobolus virginicus	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh – Stenotaphrum secundatum	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh/ floodplain	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Salt marsh	Supratidal salt marsh/ floodplain	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Sand and mudbanks	Sand and mudbanks	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Sand and mudbanks	Sand and mudbanks – mud	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Sand and mudbanks	Sand and mudbanks – sand	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – floating fresh macrophytes	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Ruppia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Ruppia/Stuckenia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Ruppia cirrhosa	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Stuckenia pectinata	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Zostera/Ruppia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Zostera/Ruppia/ Stuckenia	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Zostera capensis	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Zostera capensismixed	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies

MACROPHYTE_HABITAT	MACROPHYTE_HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Submerged macrophytes	Submerged macrophytes – Zostera?	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Submerged macrophytes	Submerged macrophytes – Zostera? Ruppia?	Natural Estuaries & Lagoons	Natural Waterbodies	Waterbodies
Swamp Forest	Swamp forest	Herbaceous Wetlands	Natural Wooded Land	Forested Land
Swamp Forest	Swamp forest – Barringtonia racemosa	Herbaceous Wetlands	Natural Wooded Land	Forested Land
Swamp Forest	Swamp forest – Hibiscus tiliaceus	Herbaceous Wetlands	Natural Wooded Land	Forested Land
Swamp Forest	Swamp or riparian forest			
Terrestrial vegetation	Terrestrial vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Agulhas Limestone Fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Agulhas Sand Fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany alluvial vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany coastal belt	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany coastal forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany coastal thicket	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany dune strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Albany Thicket	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Alluvial vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Buffels thicket	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Cape flats dune strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Cape flats sand fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Terrestrial vegetation	Terrestrial – Cape Seashore Vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Central Ruens Shale Renosterveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Coastal forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Coastal forest and grassland	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Dune forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Dune vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Eastern ruins shale renosterveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Eastern Valley Bushveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Elim Ferricrete Fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Gamtoos thicket	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Garden route shale fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Groot Brak dune strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Hangklip Sand Fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Kogelberg sandstone fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Kowie thicket	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Kwazulu Natal coastal belt grassland	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Terrestrial vegetation	Terrestrial – Lamberts bay strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Langebaan dune strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Maputoland coastal belt	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Namaqualand coastal duneveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Namaqualand riviere	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Namaqualand seashore vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Namaqualand Strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Northern coastal forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Overberg Dune Strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Overberg sandstone fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Ruens Silcrete Renosterveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Saldanha granite strandveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Scrub trees	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Southern afromontane forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Southern cape dune fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Southern Coastal Forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Southern garden route granitefynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land

MACROPHYTE_ HABITAT	MACROPHYTE_ HABITAT_SUBTYPE	SANLC_CLASS	SANLC_TIER2	SANLC_TIER1
Terrestrial vegetation	Terrestrial – southern outeniqua sandstone fynbos	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Subtropical seashore vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Subtropical seashore vegetation	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Transkei Coastal Belt	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial – Ugu Sandstone Coastal Sourveld	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land
Terrestrial vegetation	Terrestrial Dune forest	Contiguous Low Forest & Thicket	Natural Wooded Land	Forested Land

APPENDIX III:
EXTENT OF LOSS OF BLUE CARBON AND TEAL CARBON ECOSYSTEMS DUE TO LAND – USE CHANGE FROM NATURAL ECOSYSTEMS TO AGRICULTURE WITHIN THE ESTUARINE FUNCTIONAL ZONES (EFZs) OF SOUTH AFRICAN ESTUARIES. THERE IS NO DISTINCTION BETWEEN ACTIVE FARMING AND FALLOW AGRICULTURAL LANDS. AREA WAS ESTIMATED FROM THE PERCENTAGE OF NATURAL HABITAT THAT HAS BEEN LOST WHICH IS RECORDED IN THE GEODATABASE.

ESTUARY	HABITAT SUBTYPE	AREA (HA)	NATURAL HABITAT
Bot/Kleinmond	Developed – agriculture	0.56	Salt marsh
	Developed – agriculture	1	Reeds and sedges
	Developed – agriculture	3.2	Floodplain
Bulungula	Developed – subsistence agriculture	15.1	Floodplain
Gamtoos	Developed – agriculture	215	Supratidal/floodplain
Goukou	Developed – agriculture	3.9	Floodplain
Gouritz	Developed – agriculture	540.8	Floodplain
Groot Berg	Developed – agriculture	2 250	Floodplain/terrestrial
Groot Brak	Developed – agriculture	17.80	Supratidal/Floodplain
Heuningnes	Developed – agriculture	3 720.2	Salt marsh/ floodplain/terrestrial
	Degraded – agriculture	2 262	Salt marsh/floodplain
iFafa	Developed – agriculture	3.8	Reeds and sedges
Kasouga	Developed – agriculture	47.5	Floodplain
Keiskamma	Developed – agriculture	83.1	Supratidal salt marsh
	Degraded – agriculture	83.1	Floodplain
Klein	Developed – agriculture	105.3	Floodplain/terrestrial

ESTUARY	HABITAT SUBTYPE	AREA (HA)	NATURAL HABITAT
Klein Brak	Developed – agriculture	201.7	Salt marsh/floodplain
Knysna	Developed – agriculture	13.46	Supratidal/floodplain
Kosi	Developed – agriculture	4.3	Supratidal/floodplain
Kowie	Developed – agriculture	66.63	Floodplain
Mbashe	Developed – agriculture	9.7	Floodplain
Mdumbi	Developed – agriculture	45.5	Floodplain
Mntafufu	Developed – agriculture	55.8	Floodplain
Olifants	Developed – agriculture (crops)	631.1	Floodplain
Orange	Developed – agriculture	119	Floodplain
St Lucia	Developed – agriculture	680.3	Floodplain
Sundays	Degraded – agriculture	15.8	Floodplain
Swartkops	Developed – agriculture	36.9	Terrestrial
Swartvlei	Developed – agriculture	142.7	Supratidal salt marsh/ floodplain
uMhlali	Developed – agriculture (sugar cane)	37.8	Floodplain
uMkhomazi	Developed – agriculture (sugar cane)	19.4	Floodplain
uMlalazi	Developed – agriculture	128.8	Floodplain
		3.1	Reeds and sedges
uMvoti	Developed – agriculture	95.7	Floodplain

APPENDIX IV:
EXTENT OF LOSS OF BLUE CARBON AND TEAL CARBON ECOSYSTEMS DUE TO LAND – USE CHANGE FROM NATURAL ECOSYSTEMS TO HARD INFRASTRUCTURE WITHIN THE ESTUARINE FUNCTIONAL ZONES (EFZs) OF SOUTH AFRICAN ESTUARIES (ISM = INTERTIDAL SALT MARSH, SSM = SUPRATIDAL SALT MARSH).

ESTUARY NAME	TYPE OF DEVELOPMENT	AREA (HA)	HABITAT LOST
aManzimtoti	Developed – roads	0.8	Floodplain
aMatigulu/iNyoni	Developed – quarry	0.5	Swamp forest
Berg	Developed – roads	3.8	Floodplain
	Developed – residential	456.6	Floodplain/terrestrial
	Developed – salt works	608.4	Supratidal/floodplain
	Developed – recreational	0.01	Floodplain
Bot/Kleinmond	Developed – roads	1.1	Salt marsh/floodplain/reeds and sedges/terrestrial
	Developed – recreational	0.04	Salt marsh
		4.2	Reeds and sedges
		0.3	Terrestrial
	Developed – residential	17.4	Terrestrial
Buffels	Developed – golf course	10.8	Floodplain/reeds and sedges
Bushmans	Developed – residential	24.2	Terrestrial
Cefane	Developed – residential	2.3	Salt marsh/floodplain
	Developed – dam	0.24	Floodplain
Cintsa	Developed – golf course	7	Floodplain/terrestrial
	Developed – dam	11.3	Floodplain/terrestrial
	Developed – residential	1.3	Salt marsh/floodplain
Diep/Rietvlei	Developed – residential	429.8	Reeds/salt marsh
	Developed – residential	21.7	Reeds/salt marsh
	Developed – roads	0.4	Reeds/salt marsh
Eerste	Developed – industrial	12.7	Reeds/terrestrial

ESTUARY NAME	TYPE OF DEVELOPMENT	AREA (HA)	HABITAT LOST
Gamtoos	Developed – recreational	6.9	Floodplain/terrestrial
	Developed – roads	2.5	Salt marsh/floodplain/terrestrial
Goukou	Developed – residential	38.1	Floodplain
	Developed – roads	3	Floodplain
Gouritz	Developed – roads	19.6	Floodplain
	Developed – residential	8.3	Terrestrial
Gqunube	Developed – residential	9.6	Floodplain
Great Fish	Developed	2.7	Salt marsh
Groen	Developed – buildings	1.4	Terrestrial
Groot (Wes)	Developed – residential	6.5	Supratidal salt marsh/terrestrial
Groot Brak	Developed – residential	33	Terrestrial
Gxulu	Developed – residential	8.1	Floodplain/terrestrial
	Developed – roads	0.2	Salt marsh
Hartenbos	Developed – residential	15.6	Floodplain
	Developed – roads	11	Floodplain
Heuningnes	Developed – roads	23.9	Salt marsh/floodplain
	Developed – residential	0.04	Terrestrial
iBilanhlonhlo	Developed – residential	0.8	Terrestrial
iKhandalendlovu	Developed – roads	0.4	Swamp forest
iMpenjani	Developed – roads	1.3	Swamp forest
Jakkals	Developed – car park	0.8	Salt marsh/terrestrial
Kaaimans	Developed – residential	1.9	Terrestrial
Kasouga	Developed – residential	0.4	Salt marsh/floodplain
	Developed – road/car park	2.3	Salt marsh/floodplain
Keiskamma	Developed – roads	4.9	Reeds and sedges/floodplain
	Developed – dam	21.5	
	Developed – residential	2.6	Terrestrial

ESTUARY NAME	TYPE OF DEVELOPMENT	AREA (HA)	HABITAT LOST
Keurbooms	Developed – roads	6	Floodplain
	Developed – residential/ commercial/oth er	41.3	Floodplain
Klein	Developed – residential	32.4	Terrestrial
Klein Brak	Developed – residential	85.1	Salt marsh
Knysna	Developed – residential	446.2	Supratidal salt marsh/floodplain
Kosi	Developed – rural villages	22.9	Supratidal salt marsh/floodplain
Kowie	Developed – marina/residential/ industrial	123.9	Supratidal salt marsh/floodplain
Kromme (Oos)	Developed – roads	2.4	Salt marsh
	Developed – residential	28.8	Supratidal salt marsh/floodplain
	Developed – marina	62.8	Floodplain/terrestrial
Lourens	Developed – residential/ industrial	91.51	Salt marsh
Kwelera	Developed – residential	11.8	Supratidal salt marsh/floodplain
Langebaan	Developed – residential	99.1	Terrestrial
Lourens	Developed – residential/ commercial	118.7	Salt marsh
Mngazana	Developed – residential	3.2	Terrestrial
Mntafufu	Developed – residential	7.5	Floodplain
Mpekweni	Developed – residential	0.5	Floodplain
Msikaba	Developed – residential	0.8	Terrestrial
Mzimvubu	Developed – residential	10.5	Floodplain
Nahoon	Developed – residential	29.6	Floodplain/terrestrial
Noetsie	Developed – residential	0.2	Reeds and sedges
Nxaxo/Ngqusi	Developed – commercial	3.2	Terrestrial
Olifants	Developed – salt works	759.0	Floodplain/terrestrial
	Developed – roads	0.05	Floodplain
Onrus	Developed – recreational	1.9	Terrestrial
Orange	Developed – salt works	115.8	Supratidal salt marsh/terrestrial
Palmiet	Developed – roads	0.2	Terrestrial vegetation

ESTUARY NAME	TYPE OF DEVELOPMENT	AREA (HA)	HABITAT LOST
Piesang	Developed – residential	47.9	Floodplain/terrestrial
Quinira	Developed – residential	5.4	Salt marsh/floodplain/terrestrial
Rooisels	Developed – roads	0.5	Terrestrial
Seekoei	Developed – airstrip	1.1	Floodplain/terrestrial
	Developed – farm house	0.7	Floodplain
	Developed – dam weir	0.2	Open water
	Developed – residential	20.1	Floodplain
	Developed – road/car park	1.7	Salt marsh/floodplain/reeds
	Developed – roads	4.3	Flooplain/terrestrial
Sout (Noord)	Developed – salt works	82.4	Salt marsh
	Developed – salt works	4.3	Terrestrial
Sout (Wes)	Developed – industrial	834.1	Reeds/salt marsh
	Developed – residential	52.8	Reeds/salt marsh
	Developed – roads	65.2	Reeds/salt marsh
	Developed – WWTW	7.8	Reeds/salt marsh
St Lucia	Developed – roads	5.4	Terrestrial
Sundays	Developed – residential	77.1	Salt marsh/floodplain/terrestrial
Swartkops	Developed – residential	109.2	Salt marsh/floodplain/terrestrial
	Developed – industrial	58.6	Salt marsh/floodplain/terrestrial
	Developed – salt pans	628	Salt marsh/floodplain/terrestrial
	Developed – WWTWs	24	Salt marsh/floodplain
	Developed – roads & railways	65	Salt marsh/floodplain
Swartlintjies	Developed – roads	1.4	Salt marsh/terrestrial
Swartvlei	Developed – residential	141.6	Salt marsh/floodplain/reeds
Touw/Wilderness	Developed – residential	143.5	Reeds and sedges/terrestrial
Uilkraals	Developed – residential	21.8	Terrestrial
	Developed – roads	4.2	Terrestrial
uMgababa	Developed – residential/ industrial	6.2	Reeds and sedges

ESTUARY NAME	TYPE OF DEVELOPMENT	AREA (HA)	HABITAT LOST
uMgobezeleni	Developed – residential	0.9	Reeds and sedges/terrestrial
	Developed – beach shacks	0.2	Terrestrial
	Developed – housing	10.2	Terrestrial
	Developed – roads	3.4	Floodplain/reeds
uMhlali	Developed – roads	0.5	Terrestrial
uMlalazi	Developed – aquaculture	43.5	Floodplain
	Developed – roads/railway	17.42	Floodplain/terrestrial
uMthavuna	Developed – residential	6.4	Floodplain
Verlorenvlei	Developed – residential	247.6	Floodplain/terrestrial
Wadrift	Developed – railways	18	Terrestrial
Wildevoëlvlei	Developed – residential (Lake Michelle)	47.07	Salt marsh – pans
	Developed – residential	18.2	Salt marsh – pans
Zand	Developed – marina	473	Reeds/terrestrial
	Developed – recreational	82.3	Reeds/terrestrial

APPENDIX V:

DISTRIBUTION AND AREA COVER (HA) FOR SUBMERGED MACROPHYTES AND *ZOSTERA CAPENSIS* IN DIFFERENT ESTUARY TYPES ALONG THE SOUTH AFRICAN COASTLINE AS REPORTED IN THE 2018 NBA AND THE NATIONAL BLUE CARBON MAP METADATA. ESTUARY MANAGEMENT PLANS (EMP) FOR EACH ESTUARY ARE NOTED (Y – YES, N – NO). DASHES (–) INDICATE PRESENCE OF *Z. CAPENSIS* BUT UNKNOWN AREA COVERAGE, WHILE ZERO (0) INDICATES ABSENCE OF *Z. CAPENSIS*. ADAPTED FROM ADAMS ET AL. (2016) WITH UPDATES FROM ADAMS ET AL. (2019).

ESTUARY	NBA 2018 TYPE	EMP	SUBMERGED MACROPHYTE AREA	ZOSTERA CAPENSIS AREA 2021
Olifants	Predominantly Open	Y	47.7	47.7
Groot Berg	Predominantly Open	Y	206.0	206.0
Langebaan	Estuarine Lagoon	Y	85.8	85.8
Bot/Kleinmond	Estuarine Lake	Y	46.1	–
Klein	Estuarine Lake	Y	202.5	202.5
Uilkraals	Predominantly Open	Y	1.4	–
Heuningnes	Predominantly Open	Y	10.17	–
Breede	Predominantly Open	Y	40.6	40.6
Goukou	Predominantly Open	Y	5.0	4.2
Klein Brak	Large Temporarily Closed	Y	3.0	0.5
Touw/Wilderness	Estuarine Lake	Y	4.0	–
Swartvlei	Estuarine Lake	Y	219.4	23.0
Knysna	Estuarine Bay	Y	447.3	447.3
Keurbooms	Predominantly Open	Y	88.8	64
Sout (Oos)	Predominantly Open	N	0.1	0.1

ESTUARY	NBA 2018 TYPE	EMP	SUBMERGED MACROPHYTE AREA	ZOSTERA CAPENSIS AREA 2021
Kromme	Predominantly Open	N	34.0	10.8–34.0
Seekoei	Large Temporarily Closed	N	18.5	0.1
Kabeljous	Large Temporarily Closed	N	21.5	2
Gamtoos	Predominantly Open	Y	5.14	0.1
Swartkops	Predominantly Open	Y	81.9	81.9
Bushmans	Predominantly Open	N	39.8	15.7
Kariega	Predominantly Open	N	17.5	17.5
Kowie	Predominantly Open	N	8.2	4.6
West Kleinemonde	Large Temporarily Closed	N	8.2	1.0
East Kleinemonde	Large Temporarily Closed	N	14.5	1.0
Keiskamma	Predominantly Open	N	12.0	8.0
Nahoon	Predominantly Open	Y	2.3	2.3
Gqunube	Predominantly Open	N	6.33	6.33
Kwelera (Kwelerha)	Predominantly Open	N	2.3	2.3
Bulura (Bulurha)	Large Temporarily Closed	N	0.4	–
Kobonqaba (Khobonqaba)	Predominantly Open	N	2.6	2.6
Nxaxo/Ngqusi	Large Temporarily Closed	N	0.3	0.3
Gqunqe	Large Temporarily Closed	N	6.63	6.63
Qora (Qhorha)	Predominantly Open	N	8.5	8.5
Jujura (Jujurha)	Small Temporarily Closed	N	0.05	0.05
Nqabara/Nqabarana	Predominantly Open	N	1.2	1.2
Mbashe	Large Fluvially Dominated	N	1.5	1.5

ESTUARY	NBA 2018 TYPE	EMP	SUBMERGED MACROPHYTE AREA	ZOSTERA CAPENSIS AREA 2021
Xora	Predominantly Open	N	2.6	0.1
Mtakatye	Predominantly Open	N	1.8	1.8
Mngazana	Predominantly Open	N	7.6	7.6
Mnyameni	Large Temporarily Closed	N	1.9	1.9
Durban Bay	Estuarine Bay	Y	8.0	0
aMatigulu/iNyoni	Predominantly Open	Y	0.5	0.5
uMlalazi	Predominantly Open	Y	0.5	0.1
uMhlathuze	Estuarine Lake	N	28.5	28.5
St Lucia	Estuarine Lake	Y	431.5	0
Kosi	Estuarine Lake	Y	652.0	10.0

APPENDIX VI:

ESTUARIES WITH MEDIUM, HIGH AND VERY HIGH SCORES FOR PRESSURES FROM LAND – USE CHANGE AND DEVELOPMENT IDENTIFIED FROM THE 2018 NBA (VAN NIEKERK ET AL. 2019) AND THE RESPECTIVE AREA (HA) OF BLUE CARBON ECOSYSTEMS. ONLY ESTUARIES WITH BLUE CARBON ECOSYSTEM AREA > 20 HA ARE REPORTED BELOW.

ESTUARY NAME	PRESSURE SCORE	MANGROVE	SALT MARSH	SUBMERGED MACROPHYTES	TOTAL BLUE CARBON
Groot Berg	H		●	●	4 043.9
St Lucia	M	●	●	●	1 754.5
uMhlathuze	VH	●	●	●	1 125.8
Olifants	H		●	●	1 026.8
Orange	H		●	●	773.7
Swartkops	VH		●	●	605.1
Keurbooms	M		●	●	464.8
Klein	M		●	●	410.1
Keiskamma	M		●	●	398.0
Verlorenvlei	H		●		372.5
Klein Brak	H		●	●	336.1
Swartvlei	M		●	●	310.8
Heuningnes	H		●	●	298.2
Richards Bay	VH	●	●		249.4
Gamtoos	H		●	●	182.1
Mngazana	M	●	●	●	166.0

ESTUARY NAME	PRESSURE SCORE	MANGROVE	SALT MARSH	SUBMERGED MACROPHYTES	TOTAL BLUE CARBON
Diep/Rietvlei	VH		●		158.9
Sout (Noord)	VH		●		141.0
uMlalazi	M	●	●	●	127.5
Wadrift	VH		●		127.3
Bushmans	M		●	●	118.4
Kabeljous	M		●	●	106.8
Kariega	M		●	●	90.5
iMfolozi/uMsunduze	VH	●			78.2
Uilkraals	H		●	●	76.3
Mtata	M	●	●		57.3
Wildevoëlvlei	H		●		49.2
Kowie	H		●	●	47.6
Swartlintjies	M		●		45.6
Goukou	M		●	●	43.2
Jakkals	H		●		40.1
Groot Brak	VH		●		39.2
Duiwenhoks	H		●		35.1
uMngeni	VH	●	●	●	34.6
Hartenbos	H		●		32.2
Nxaxo/Ngqusi	M	●	●	●	28.7
Seekoei	VH		●	●	27.0
Gouritz	VH		●		22.5

APPENDIX VII:

ESTUARIES WITH MEDIUM, HIGH AND VERY HIGH SCORES FOR PRESSURES FROM FRESHWATER REDUCTION/FLOW MODIFICATION IDENTIFIED FROM THE 2018 NBA (VAN NIEKERK ET AL. 2019) AND THE RESPECTIVE AREA (HA) OF BLUE CARBON ECOSYSTEMS. ONLY ESTUARIES WITH BLUE CARBON ECOSYSTEM AREA > 20 HA ARE REPORTED BELOW.

ESTUARY NAME	PRESSURE SCORE	MANGROVE	SALT MARSH	SUBMERGED MACROPHYTES	TOTAL BLUE CARBON ECOSYSTEMS
Groot Berg	M		●	●	4 043.9
Olifants	M		●	●	1 026.8
Orange	VH		●	●	773.7
Swartkops	VH		●	●	605.1
Verlorenvlei	VH		●		372.5
Klein Brak	H		●	●	336.1
Heuningnes	M		●	●	298.2
Richards Bay	H	●	●		249.4
Bot/Kleinmond	M		●	●	242.6
Gamtoos	M		●	●	182.1
Diep/Rietvlei	M		●		158.9
Sout (Noord)	VH		●		141.0
uMlalazi	M	●	●	●	127.5
Wadrift	VH		●		127.3
Kabeljous	M		●	●	106.8
Kariega	VH		●	●	90.5

Breede	M		●	●	90.0
Uilkraals	VH		●	●	76.3
Mtata	M	●	●		57.3
Wildevoëlvlei	M		●		49.2
Goukou	H		●	●	43.2
Jakkals	VH		●		40.1
Groot Brak	M		●		39.2
Duiwenhoks	H		●		35.1
uMngeni	VH	●	●	●	34.6
Hartenbos	M		●		32.2
Spoeg	M		●		31.3
Mtati (Mthathi)	M		●	●	29.4
Seekoei	H		●	●	27.0
Gouritz	VH		●		22.5
Mgwalana	M		●	●	20.5

APPENDIX VIII:

ESTUARIES WITH MEDIUM, HIGH AND VERY HIGH SCORES FOR PRESSURES FROM WATER QUALITY/EUTROPHICATION IDENTIFIED FROM THE 2018 NBA (VAN NIEKERK ET AL. 2019) AND THE RESPECTIVE AREA (HA) OF BLUE CARBON ECOSYSTEMS. ONLY ESTUARIES WITH BLUE CARBON ECOSYSTEM AREA > 20 HA ARE REPORTED BELOW.

ESTUARY NAME	PRESSURE SCORE	MANGROVE	SALT MARSH	SUBMERGED MACROPHYTES	TOTAL BLUE CARBON ECOSYSTEMS
Groot Berg	VH		●	●	4 043.9
St Lucia	M	●	●	●	1 754.5
uMhlathuze	VH	●	●	●	1 125.8
Olifants	H		●	●	1 026.8
Knysna	H		●	●	963.3
Orange	H		●	●	773.7
Swartkops	VH		●	●	605.1
Klein	H		●	●	410.1
Keiskamma	M		●	●	398.0
Verlorenvlei	VH		●		372.5
Klein Brak	M		●	●	336.1
Heuningnes	M		●	●	298.2
Richards Bay	H	●	●		249.4
Bot/Kleinmond	H		●	●	242.6
Great Fish	H		●		194.0
Gamtoos	M		●	●	182.1

Diep/Rietvlei	VH		●		158.9
Wadrift	H		●		127.3
Kabeljous	M		●	●	106.8
iMfolozi/uMsunduze	VH	●			78.2
Uilkraals	VH		●	●	76.3
Mtata	H	●	●		57.3
Wildevoëlvlei	VH		●		49.2
Goukou	H		●	●	43.2
Jakkals	H		●		40.1
Groot Brak	H		●		39.2
Duiwenhoks	M		●		35.1
uMngeni	VH	●	●	●	34.6
Hartenbos	VH		●		32.2
Seekoei	H		●	●	27.0
East Kleinemonde	M		●	●	25.2
Gouritz	M		●		22.5

APPENDIX IX:

ESTUARIES WITH MEDIUM, HIGH AND VERY HIGH SCORES FOR PRESSURES FROM WATER QUALITY/EUTROPHICATION IDENTIFIED FROM THE 2018 NBA (VAN NIEKERK ET AL. 2019) AND THE RESPECTIVE AREA (HA) OF BLUE CARBON ECOSYSTEMS. ONLY ESTUARIES WITH BLUE CARBON ECOSYSTEM AREA > 20 HA ARE REPORTED BELOW.

ESTUARY NAME	PRESSURE SCORE	MANGROVE	SALT MARSH	SUBMERGED MACROPHYTES	TOTAL BLUE CARBON ECOSYSTEMS
St Lucia	VH	●	●	●	1 754.5
Orange	M		●	●	773.7
Klein	M		●	●	410.1
Verlorenvlei	H		●		372.5
Swartvlei	M		●	●	310.8
Heuningnes	H		●	●	298.2
Bot/Kleinmond	H		●	●	242.6
iMfolozi/uMsunduze	H	●			78.2
Uilkraals	M		●	●	76.3
Touw/Wilderness	M		●	●	46.3
Groot Brak	H		●		39.2
Hartenbos	H		●		32.2
Seekoei	VH		●	●	27.0
uMgobezeleni	M	●		●	22.7
Zand	VH		●		11.6

APPENDIX X:

LIST OF PROTECTED AREAS AND THE BLUE CARBON ECOSYSTEMS THAT ARE REPRESENTED WITHIN THESE PROTECTED AREAS (DOT = PRESENCE). THE PROTECTED AREAS INFORMATION WAS OBTAINED FROM THE PROTECTED AREAS DATASET FROM SANBI. SG = SUBMERGED MACROPHYTES, ISM = INTERTIDAL SALT MARSH, SSM = SUPRATIDAL SALT MARSH, FSM = FLOODPLAIN SALT MARSH, MN = MANGROVES.

				BLUE CARBON ECOSYSTEM				
Estuary Name	**Type**	**Legal Status**	**Protected Area Name**	**SG**	**ISM**	**SSM**	**FSM**	**MN**
aMatigulu/ Nyoni	Nature Reserve	Designated	Amatikulu Nature Reserve		•	•		
	Nature Reserve	Degazetted	Talmage Pan Nature Reserve			•		
Bot/ Kleinmond	Nature Reserve	Not in SAPAD	Rooisand (Botrivier) Nature Reserve			•		
	Nature Reserve	Designated	Rooisand Provincial Nature Reserve			•		
Breede	Nature Reserve	Designated	Witsand Local Nature Reserve	•				
Bushmans	Protected Environment	Designated	Indalo Protected Environment	•	•			
Duiwenhoks	Nature Reserve	Designated	Duiwenhoksriviermond Private Nature Reserve			•		
Goukamma	Nature Reserve	Designated	Goukamma Provincial Nature Reserve			•		
Goukou	Marine Protected Area	Designated	Stilbaai Marine Protected Area	•	•	•	•	
Great Fish	Nature Reserve	Not in SAPAD	Kap River Nature Reserve				•	
	Nature Reserve	Designated	Great Fish River Mouth Wetland Nature Reserve				•	
	De facto PA	Not in SAPAD	Sunshine Coast: Fish River Camp Site			•		
Groen	National Park	Designated	Namaqua National Park			•	•	

				BLUE CARBON ECOSYSTEM				
Estuary Name	**Type**	**Legal Status**	**Protected Area Name**	**SG**	**ISM**	**SSM**	**FSM**	**MN**
Groot (Wes)	National Park	Designated	Garden Route National Park			•		
	National Park	Not in SAPAD	Garden Route National Park			•		
Gxulu	De facto PA	Not in SAPAD	East London Nature Reserve: Gulu Nature Reserve		•	•		
Heuningnes	Forest Nature Reserve	Designated	De Mond Nature Reserve	•	•	•	•	
Kabeljous	Nature Reserve	Not in SAPAD	Kabeljouwsriver Nature Reserve		•	•		
Kariega	Protected Environment	Designated	Indalo Protected Environment	•	•	•	•	
Keiskamma	De facto PA	Not in SAPAD	Hamburg Coastal Reserve		•	•		
	De facto PA	Not in SAPAD	Hamburg Coastal Forest	•				
Keurbooms	Nature Reserve	Designated	Wadrift Private Nature Reserve	•	•	•		
	Nature Reserve	Not in SAPAD	Keurbooms River Nature Reserve - Seagull Colony	•	•	•		
Klein	Nature Reserve	Designated	Fernklood Nature Reserve			•		
	Nature Reserve	Designated	Oude Bosch Private Nature Reserve	•		•		
	Nature Reserve	Not in SAPAD	Walker Bay Nature Reserve		•	•		
	Nature Reserve	Designated	Coppull Private Nature Reserve	•				
Knysna	Protected Environment	Designated	Knysna National Lake Area	•	•	•	•	
Kosi	Nature Reserve	Proclaimed	Coastal Forest Reserve	•		•		•
Kowie	De facto PA	Not in SAPAD	Kowie Nature Reserve			•		
Kromme (Oos)	Protected Environment	Designated	Kromme Geelhout Protected Environment	•				
	Nature Reserve	Designated	Eastcot Private Nature Reserve	•				
Kwelera	Nature Reserve	Designated	Kwelera Island Local Nature Reserve	•				

				BLUE CARBON ECOSYSTEM				
Estuary Name	**Type**	**Legal Status**	**Protected Area Name**	**SG**	**ISM**	**SSM**	**FSM**	**MN**
Langebaan	National Park	Not in SAPAD	West Coast National Parl	●	●	●		
	Marine Protected Area	Designated	Langebaan Lagoon Marine Protected Area	●	●	●		
	Nature Reserve	Degazetted	Langebaan Nature Area	●	●	●		
Mbashe	Marine Protected Area	Designated	Dwesa-Cwebe Marine Protected Area					●
	Nature Reserve	Designated	Dwesa-Cwebe Nature Reserve					●
Mpekweni	De facto PA	Not in SAPAD	Hamburg Coastal Reserve: Mpekweni		●	●		
Mtati	De facto PA	Not in SAPAD	Hamburg Coastal Reserve: Mtazi Forest Reserve	●	●	●		
Mtentu	Nature Reserve	Not in SAPAD	Mkhambathi Nature Reserve: Mkambathi					●
Nahoon	Nature Reserve	Not in SAPAD	Nahoon Nature Reserve		●	●		
Orange	Nature Reserve	Designated	Orange River Mouth Nature Reserve			●		
Palmiet	Nature Reserve	Not in SAPAD	Kleinmond Coast and Mountain			●		
Quinira	Nature Reserve	Designated	Quenera Nature Reserve	●	●			
	Nature Reserve	Not in SAPAD	Quenera Nature Reserve	●	●			
Riet	De facto PA	Not in SAPAD	Sunshine Coast: Riet River Camp Site			●		
	Nature Reserve	Designated	Tharfield Private Nature Reserve			●		
Rietvlei/Diep	Nature Reserve	Designated	Rietvlei Nature Area			●	●	
	Nature Reserve	Not in SAPAD	Table Bay - Rietvlei Section			●	●	

				BLUE CARBON ECOSYSTEM				
Estuary Name	**Type**	**Legal Status**	**Protected Area Name**	**SG**	**ISM**	**SSM**	**FSM**	**MN**
Rooiels	World Heritage Site	Designated	Cape Floral Regional Protected Areas			•		
Seekoei	Nature Reserve	Designated	Seekoei Nature Reserve	•		•		
	Nature Reserve	Not in SAPAD	Seekoei Nature Reserve	•		•		
Spoeg	National Park	Designated	Namaqua National Park			•	•	
St Lucia	Nature Reserve	Designated	False Bay Park			•	•	
	De facto PA	Designated	iSimangaliso Wetland Park			•	•	•
	Nature Reserve	Designated	St Lucia Game Park	•		•	•	•
	Nature Reserve	Designated	St Lucia Park	•		•	•	•
	Nature Reserve	Not in SAPAD	iSimangaliso Wetland Park				•	•
Sundays	National Park	Designated	Addo Elephant National Park		•	•		
Swartkops	Nature Reserve	Designated	Zwartkops Valley Nature Reserve	•	•	•	•	
	Nature Reserve	Not in SAPAD	Zwartkops Valley Nature Reserve			•		
Swartvlei	National Park	Designated	Garden Route National Park			•		
	National Park	Not in SAPAD	Garden Route National Park			•		
Uilkraals	Nature Reserve	Not in SAPAD	Uilkraalsmond Nature Reserve		•	•		
uMngeni	Nature Reserve							
Designated	Beachwood Mangroves Nature Reserve			•	•	•		
uMgobezeleni	Nature Reserve	Designated	Sodwana Bay National Park	•				
	Nature Reserve	Designated	Coastal Forest Reserve	•				

				BLUE CARBON ECOSYSTEM				
Estuary Name	**Type**	**Legal Status**	**Protected Area Name**	**SG**	**ISM**	**SSM**	**FSM**	**MN**
	Marine Protected Area	Designated	iSimangaliso Marine Protected Area					
uMhlathuze	Nature Reserve	Designated	Richards Bay Game Reserve	•				•
uMlalazi	Nature Reserve	Designated	Umlalazi Nature Reserve		•	•	•	•
uMthavuna	Nature Reserve	Designated	Red Desert Nature Reserve					•
	Nature Reserve	Designated	Umtamvuna Nature Reserve			•		
Wadrift	Nature Reserve	Designated	Steenboksfontein Private Nature Reserve			•		
West Kleinemonde	Nature Reserve	Designated	Tharfield Private Nature Reserve	•	•	•	•	
Wildevoelvlei	World Heritage Site	Designated	Cape Floral Region Protected Areas			•		
	National Park	Designated	Table Mountain National Park			•		

APPENDIX XI:
ACTIONS FOR THE WEM AND WAM SCENARIOS WERE SCORED (1–3) BASED ON OVERALL EFFECT ON BLUE CARBON ECOSYSTEMS. ACTIONS WITH HIGHER SCORES ARE MORE HEAVILY WEIGHTED, AND WILL HAVE A GREATER IMPACT ON THE PREDICTED PERCENTAGE CHANGE IN ECOSYSTEM AREA IF THE ACTION IS CARRIED OUT. ACTIONS WERE IDENTIFIED AND LINKED TO RELEVANT POLICIES IN SECTION 3.

ACTIONS RELATED TO PRESSURE FROM REDUCED FRESHWATER INFLOW/FLOW MODIFICATION

WEM ACTIONS	SCORE	WAM ACTIONS	SCORE
Establish and maintain freshwater flow allocations.	3	Protect/maintain sediment transport processes.	1
Prevent over – abstraction and lowering of groundwater table.	1	Do not allow new commercial forest plantations within a 2 km buffer of EFZ.	1
Clear invasive alien plants in catchments to restore critical base flows.	1	Avoid all new mining activities.	1
Improve freshwater inflow and tidal exchange.	3	Develop medium – to high – confidence ‘Reserves’, including drought allocations.	1
		Develop a land – exchange programme so that blue carbon ecosystems can migrate landwards.	3

ACTIONS RELATED TO PRESSURE FROM REDUCED WATER QUALITY/EUTROPHICATION

WEM ACTIONS	SCORE	WAM ACTIONS	SCORE
Limit and reduce the volume of effluent from WWTWs.	1	Control and reduce urban stormwater runoff into estuaries.	1
Improve water quality of WWTW effluents.	1	No agriculture return flows or use of herbicide and pesticide in and around estuaries.	1
Improve water quality of return flow from agriculture in catchments.	1		

ACTIONS RELATED TO PRESSURE FROM ARTIFICIAL BREACHING

WEM ACTIONS	SCORE	WAM ACTIONS	SCORE
Prohibit artificial breaching of estuaries for unnecessary or invalid reasons.	1		
Prohibit development of new infrastructure in low-lying areas.	1		
Remove poorly planned, low-lying infrastructure and access routes where possible.	1		

ACTIONS RELATED TO PRESSURE FROM TRANSFORMATION/LAND – USE CHANGE

WEM ACTIONS	SCORE	WAM ACTIONS	SCORE
Avoid clearing or infilling of estuarine habitat and soil disturbance within EFZ.	3	Avoid all mining-related activities within EFZs.	1
Develop and enforce conservative setback lines – floodlines (1:100 year)/setback/ management lines to maintain blue carbon ecosystems.	3	Restore degraded blue carbon ecosystems.	3
Reduce the impact of boating activities – boating policy that considers impacts on blue carbon ecosystems such as destruction and erosion of habitat.	1	Develop a land-exchange programme to reclaim accommodation space and facilitate blue carbon ecosystems persistence under rising sea level conditions.	3
		Develop and enforce conservative setback lines – ecosystems under threat of coastal squeeze are identified.	1
		Reduce the impact of boating activities – zonation plans that protect blue carbon ecosystems from boating.	1

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