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Blue Carbon Opportunities: seagrass carbon storage and accumulation rates at Roxas, Palawan, The Philippines

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TECHNICAL REPORT

For the IKI Seagrass Ecosystem Services Project

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Report prepared as a contribution to the IKI Project "Conservation of biodiversity, seagrass ecosystems and their services – safeguarding food security and resilience in vulnerable coastal communities in a changing climate"

The IKI Project is a partnership between the CMS, Edith Cowan University, Project Seagrass, Seagrass Watch, Murdoch University, MRS, Blue Ventures, SAN, C3, ZSL, MareCet and Yapeka. The collaboration enhances the understanding of seagrass ecosystem services and the capacity to develop and deliver science-based policy solutions in seagrass conservation. It brings together scientists, policy experts, business development experts and conservation NGOs across the globe to provide expert and independent advice on seagrass ecosystems services and how these might be relevant to policy and financial solutions to marine conservation issues. This report deals specifically with the assessment of seagrass blue carbon ecosystem services.

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GLOSSARY

Above ground storage/stock	Carbon stored in above-ground biomass (e.g. trunks, stems, leaves) or other above-ground carbon sinks.
Accumulation rate	The rate at which atmospheric CO_2 is sequestered. Usually reported as a mass per unit area per year.
Activity	An action undertaken to reduce anthropogenic GHG emissions; or an action undertaken to increase anthropogenic GHG removals by sinks.
Additional/Additionality	The effect of a project activity to reduce anthropogenic GHG emissions below the level that would have occurred in the absence of the project activity; or The effect of a project activity to increase net GHG removals by sinks above that would have occurred in the absence of the activity.
Allochthonous carbon	Carbon (organic or inorganic) formed at a site distant to that where it is found.
Autochthonous carbon	Carbon (organic and inorganic) formed at the site where it is found.
Below ground storage	Carbon stored below ground level as biomass (e.g. roots and rhizomes) or sedimentary/soil carbon.
Biomass	The total quantity (usually weight) of organisms in a given area or volume.
Blue Carbon	The carbon stored and sequestered in coastal ecosystems such as mangrove forests, seagrass meadows or tidal marshes.
Carbon pools	Above-ground biomass, below-ground biomass, litter, dead wood and soil/sediment organic carbon.
C_{org}	Organic carbon (i.e. the carbon contained within living and dead organic matter)
CO_2	Carbon dioxide, a gas composed of one carbon and two oxygen atoms. It is a major component of the global carbon cycle and a key greenhouse gas
$CO_{2\text{-}eq}$	a measure of the environmental impact of one tonne of any greenhouse gases in comparison to that of one tonne of CO_2.
Dating methods	The various methods used to age sediments/soils or carbon within sediments/soils, thereby allowing the accumulation rate to be determined. The most common methods involve the use of the radioisotopes Carbon-14 or Lead-210.
Emissions	An amount of a substance (usually a gas) that is released into the environment (usually the atmosphere). The commonly considered emissions are CO_2, CH_4, N_20.
GHG (greenhouse gas)	A greenhouse gas listed in Annex A to the Kyoto Protocol, unless otherwise specified in a particular methodology. With respect to blue carbon ecosystems, the commonly considered GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)
Organic carbon	Carbon, both particulate and dissolved, found in an organic compound, including living organisms, detritus, litter, and dissolved compounds

Project	An action by a private or public entity which coordinates and implements any policy/measure or stated goal that leads to GHG emission reductions or net anthropogenic GHG removals by sinks that are additional to any that would occur in the absence of the action.
Remineralization	The process in which organic carbon is transformed into inorganic forms, such as carbon dioxide (CO_2)
SAR	Sediment accumulation rate – the net rate of vertical accumulation of sediment at a site.
Sediment	Naturally occurring material broken down by weathering and erosion, and subsequently transported to a place where it accumulates. In contrast to solids, sediments are relatively unstructured and are not formed by interaction of biological, physical and chemical processes.
Sedimentary carbon	Organic and inorganic carbon stored within sediments
Sequestration	The capture and long-term storage of atmospheric carbon dioxide.
Sink	a reservoir that accumulates and stores carbon-containing chemical compounds. Use of the term sink usually implies that the storage is long-term (or semi-permanent).
Soil	A complex, structured mixture of organic matter, minerals gases, liquids and living organisms formed by the interaction of the parent material, organisms, climate and relief.
Soil carbon	Organic and inorganic carbon stored within soils
Stocks (of carbon)	The total amount of, in this case, carbon stored in an area or volume. Used interchangeably with 'store'.
Verification	The periodic, independent evaluation and retrospective determination of monitored GHG emission reductions that have occurred as a result of a project activity.

Units used this this report.

kg	Kilogram	1,000 grams
t	Metric tonne	1,000 kg
Mt	Megatonne	10^6 (or 1 million) tonnes
Mg	Megagrams	10^6 (or 1 million) grams = 1 tonne
ha	Hectare	10,000 m^2 = 0.01 km^2
km^2	Square kilometre	10^6 (1 million) m^2 = 100 ha
Mg ha^{-1}	Megagrams per hectare	10^6 (1 million) g per ha = 0.1 kg m^{-2}

1 EXECUTIVE SUMMARY

1.1 Background and Objectives

Seagrasses provide many ecosystem services, including carbon sequestration, yet they are frequently neglected in decision-making. Seagrass meadows of the Indo-Pacific support up to one billion people through their provision of inshore fisheries. They also provide critical habitat for many marine species, including the Dugong (*Dugong dugong*), which is listed a vulnerable on the IUCN Red List. At the same time, seagrasses in the region are declining because of coastal development, deforestation, unsustainable resource extraction, and environmental degradation. Limited data exists on seagrass status, their ecosystem services and value in the region, information that can incentivise effective seagrass conservation.

The Seagrass Ecosystem Services Project (SES project) was established to provide critical data on the state and condition of seagrass ecosystems and to promote the integration of Seagrass Ecosystem Services (SES) into evidence-based decision-making and business models to ensure the sustainability of seagrasses across the Indo-Pacific. The project focused on five priority sites in SE Asia, including the Johor and Penang regions in Malaysia, and addressed a range of seagrass ecosystem services, including carbon sequestration (or Blue Carbon; BC). The Philippines NGO, C3, implemented the BC assessment, supported with training and expert advice from Edith Cowan University (ECU).

This technical report presents the outcomes of the assessment of BC function in seagrass meadows at the priority sites of Roxas, in Palawan, Philippines. The assessment was implemented with the following goals:

- Obtain information that can be used to inform decision makers of the value of seagrasses for CO_2 capture and storage, and to inform the design of BC projects;
- Build the capacity of local NGO and communities to undertake BC SES assessments;
- Collect data to undertake a Seagrass BC assessment at the priority sites; and
- Build capacity within the NGO to integrate the BC Assessment into policy guideline development, decision-making and management.

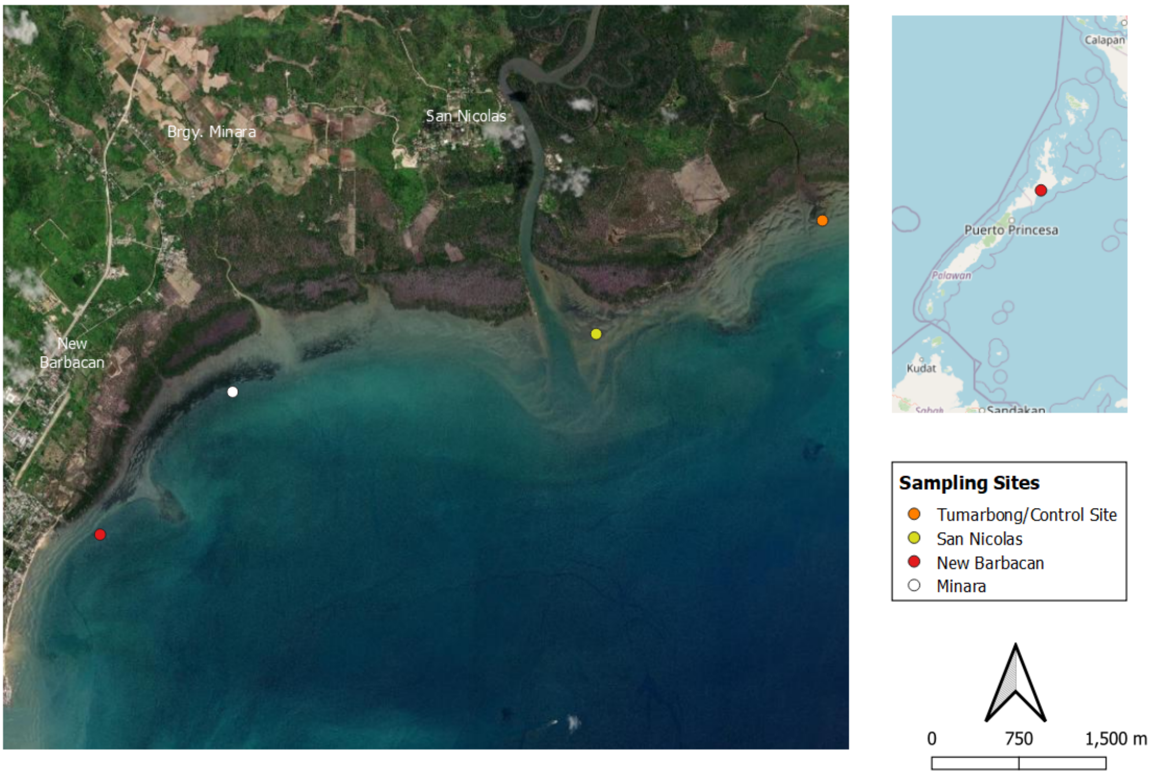
1.2 Assessment design

The BC assessment was undertaken by C3 in the Roxas, NE Palawan province (**Error! Reference source not found.**), and included the following sites:

- one Reference sites (Tumarbong);
- three Impacted sites. New Barbacan, impacted by fishing and boating activities, Minara, impacted by sedimentation and river run-off, and San Nicolas, impacted by higher sedimentation and river run-off compared to Minara.

At each site, four seagrass cores were collected to determine the carbon characteristics for comparison of undisturbed and disturbed sites. The methods used followed published protocols, modified to suit the local circumstances of the National Partner while providing scientifically robust estimates of the stocks and accumulation rates. Unfortunately, due to export permit constraints, it was not possible to directly analyse the C_{org} content in the seagrass soils, as had been planned.

Instead, the carbon content had to be estimated indirectly, apply a global relationship between organic carbon organic matter content.



ES Figure 1. The location of the four sampling sites used by C3 in the BC assessment for the Roxas region in NE Palawan. See **Table 2** for details of site characteristics and location coordinates.

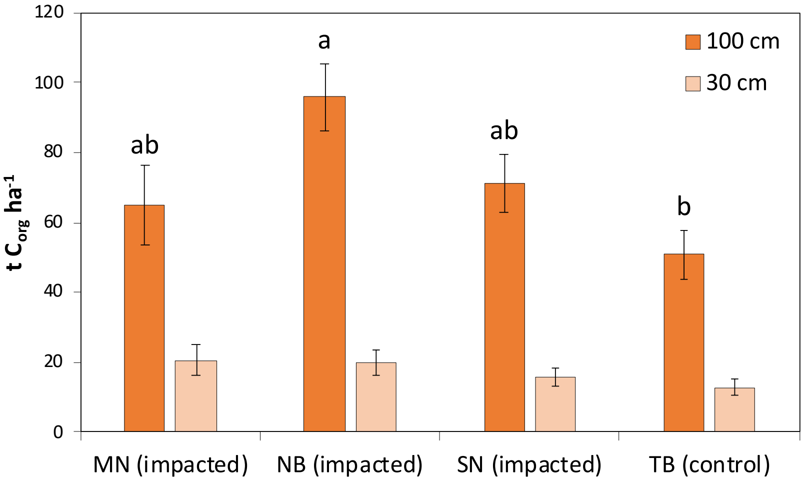
1.3 Soil C_{org} Stocks

The mean soil C_{org} stocks in the top 100 cm showed significant differences among sites (ES Figure 1). The C_{org} stock at New Barbacan (impacted by fishing and boating) was 95.9 ± 9.6 t C_{org} ha^{-1}, significantly greater than at Tumarbong (reference site), where the stock was 50.9 ± 7.0 t C_{org} ha^{-1}. The higher stock found in New Barbacan suggests that the degree of fishing and boating activities happening at the site are not sufficient to affect the C_{org} sequestration capacity of the seagrasses. The high C_{org} stock may also reflect terrestrial soil inputs and/or discharges of organic waste into the bay from the village. Stable isotopes analyses of the sediments would help to confirm this.

The control site (Tumarbong) was characterized by seagrass patches which, even if dense, are unlikely to have the same capacity to accumulating C_{org} as a continuous meadow, resulting in a general lower C_{org} stock than other sites, including the two sites impacted by sedimentation. Other site-specific characteristics could have influenced the C_{org} sequestration capacity of this site and they would need to be further investigated.

The C_{org} stock in San Nicolas and Minara were intermediate to those of New Barbacan and Tumarbong. San Nicolas and Minara sites are both affected by sediment deposition from the San Nicolas River but to different degrees; San Nicolas receives more sediment input than Minara.

However, this difference in sediment input did was not reflected in the C_{org} stocks which were similar (71.3 ± 8.4 and 61.1 ± 11.4 t C_{org} ha^{-1}, respectively).



ES Figure 2. Mean (± SE) organic carbon (C_{org}) stocks in 30 cm and 100 cm-thick soil seagrass deposits collected in The Philippines. MN: Minara, NB: New Barbacan, SN: San Nicolas, TB: Tumarbong. Different letters indicate significant differences in C_{org} stocks among sites. When letters are not reported significant differences were not detected.

1.4 C_{org} accumulation rates

Comparing stocks is not always the appropriate approach for understand differences in C_{org} sequestration capacity among seagrass sites; data on C_{org} accumulation rates are essential to provide a full BC assessment. Neither short-term nor long-term C_{org} accumulation rates could be estimated for The Philippines sites. Site conditions prevented application of radio-isotope methods (i.e., ^{210}Pb) to determine short-term rates (i.e., last 100 years) which typically are higher than long-term accumulation rates, and reflect the contemporary conditions at a site. Due to a delay in obtaining the relevant export permits and subsequent time constrain, it was not possible to analyse radiocarbon (^{14}C) in any of the cores collected in The Philippines. ^{14}C could have provided long-term soil and C_{org} accumulation rates (i.e., thousands of years). Comparing C_{org} accumulation rates could provide a better understanding of the C_{org} sequestration capacity of seagrasses in the Roxas region and so it is recommended that efforts be made to analyse the existing samples for ^{14}C concentrations to determine long-term accumulation rates, once the appropriate permits are obtained.

1.5 Potential for carbon abatement

The potential for avoided emissions was estimated by taking the total stock of C_{org} in the top 100 cm of soil at a site and applying a number of assumptions which are detailed in the main body of the report. It was estimated that the potential emissions would range from 13 to 38 t C_{org} ha^{-1} (or 47 – 140 t $CO_{2\text{-}e}$ ha^{-1}) for the control site Tumarbong.

For illustrative purposes, we have provided a first-order estimate of the potential stocks in The Philippines's seagrass meadows and the potential annual emissions associated with seagrass loss. Seagrass extent in The Philippines has been reported to be 14,923 km^2 (Fortes 2022). Using assumptions detailed in the main report, we estimated that The Philippines seagrass meadows contain between 79 and 119 Mt of C_{org} in the top 1 m of their soils, equivalent to 279 to 438 Mt of CO_{2-eq} (ES Table 1). The losses of seagrass meadow, estimated at 2.62% or 391 km^2 yr^{-1} (Fortes 2022), could potentially result in an emission of 6.8 to 10.6 Mt per year of CO_2 (ES Table 2).

ES Table 1 Illustrative estimates of potential soil C_{org} stocks for Philippines's seagrass meadows. Estimates are based on reported extent of Philippines's seagrass meadows and the C_{org} stocks reported here. * from Fortes (2021); # from data in Tables 1 and 5**.**

Seagrass Area* (km^2)	Stock[#] (kg C_{org} m^{-2})	Total Stock (Mt C_{org})		Total Stock (Mt CO_{2-eq})	
		Min	Max	Min	Max
14,923	5.1 – 8.0	76	119	279	438

ES Table 2 Potential annual emissions from Philippines's seagrass meadows based on available reported losses and assuming 50% to 100% of lost C_{org} is remineralised. * From DMCR (2019); [#]from **Table 1** and **Error! Reference source not found.**

Habitat loss* (km^2 y^{-1})	Stock[#] (kg C_{org} m^{-2})	C_{org} at risk of remineralisation (Mt C_{org} y^{-1})		Potential CO_2 emissions (Mt CO_{2-eq} y^{-1})			
				50% remineralisation		100% remineralisation	
		Min	Max	Min	Max	Min	Max
361	5.1 - 8.0	1.8	2.9	3.4	5.3	6.8	10.6

1.6 Lessons learnt

The four SES case studies, including that undertaken in The Philippines, have provided valuable insights into methodological and logistical issues that could affect the capacity to implement BC projects by NGOs working in the region. These included:

Determining Carbon Accumulation Rates

Most carbon crediting schemes and inventories require estimates of Carbon Accumulation Rates (CAR), however, there is a paucity of CAR measurements for SE Asia, especially short-term CAR which are critical to BC projects. Determining CARs typically involves either dating the soil using radioisotope techniques or directly measuring accumulation using surface elevation tables (SET). Generally, there was little success in using radioisotope techniques to establish short-term CARs. In Malaysia this was due to the local environmental conditions at the study sites, a problem not uncommon in seagrass sites. Efforts to establish SETs were also unsuccessful, at least in some sites, due to the theft of the measuring rods but offers the most promising way forward.

Methodological issues with determining %C_{org} using %LOI

It is common in BC studies to use the relationship between organic matter (LOI) and organic carbon (C_{org}) to estimate the C_{org} content of a soil when financial constraints limit the number of C_{org} analyses that can be performed. We attempted that approach here and we were successful only for the Malaysian sites. In the other countries it was generally unsuccessful due to:

1. the relationship being weak and with significant uncertainties for the C_{org} data; or
2. being unable to analyse the samples for C_{org} content due to legal constraints on exporting the samples for analysis.

Overcoming these two barriers will be an important step for allowing NGO and community groups in the region to undertake carbon sequestration assessments.

Permits

Some of the SES project sites experienced difficulty obtaining permits needed to undertake the BC assessments. These issues related either to:

1. Processing system to obtain the supporting documents for the project implementation
2. Permits to undertake field sampling; or
3. Permits to export soil samples for chemical analysis.

The permitting system in the case of Palawan, Philippines is bound by the Strategic Environmental Plan for Palawan (Republic Act 7611), a lengthy process that has to pass by several government units to obtain the necessary consent/endorsements. In addition, the limited services of the Bureau of Soils in the Provinces added to the delays as the samples are subject for inspection and the export permit can only be issued by the central office located in Metro Manila, Philippines.

In some cases, the lack of permit severely compromised to outcomes of the project. The lesson here is that it is critical to understand the permitting requirements in countries before commencing a BC assessment and that sufficient time needs to be allowed for obtaining those permits.

Training delivery

The SES Project was initially structured around in-country, face-to-face training sessions, for the technical partners to build capacity among the NGO partners. COVID-19 travel restrictions prevented face-to-face training and necessitated a shift to on-line training resources, which were useful in allowing the NGO partners to implement the assessments. However, the impact of no face-to-face training became apparent as the project developed: what could effectively be explained face-to-face in a two- or three-hours discussion proved almost impossible to convey using other approaches. The lack of opportunity to hold the planned in-person workshops had a detrimental effect on the efficiency and the quality of the outcomes of the BC assessments. While the outcomes are still valuable, there is no doubt that any future capacity building should prioritise in-person training.

1.7 Conclusions and Recommendations

- Healthy seagrass meadows in Roxas, Palawan region were found to have soil C_{org} stocks of about 51 ± 7 t C_{org} ha^{-1}, though other meadows, considered to be disturbed had higher stocks, up to about 96±10 t C_{org} ha^{-1} .
- Sediment deposition, at the range of intensities present across the two disturbed sites, did not seem to affect the C_{org} stocks of the affected sites (Minara and San Nicolas). Disturbance by fishing in New Barbacan does not seem to have reduce C_{org} stock.
- As ^{210}Pb analyses suggested negligible net sedimentation, a short-term C_{org} accumulation rate could not be provided for The Philippines' sites and, as ^{14}C could not be analysed, a long-term accumulation rate could not be reported either.

- The potential abatement associated with conservation of seagrass meadows in the region was estimated to be 47 – 140 t $CO_{2\text{-eq}}$ ha^{-1}.
- Reported losses of 361 km^2 of seagrass meadows per year in The Philippines were estimated to represent a potential emission of about 6.8 – 10.6 Mt $CO_{2\text{-eq}}$ y^{-1}.
- The SES Project has successfully achieved the key objectives of:
    - Building capacity to undertake BC assessments,
    - Generating data for application in policy and future BC projects,
    - Identification of partner organisations to assist in future BC projects.
- The BC assessment saw the following activities completed as parts of Work Packages I, II, III and IV of the SES Project:
    - **Activity I.1:** Modify or develop new methodological tools for monitoring seagrass ecosystem services (carbon sequestration);
    - **Activity I.2:** Four trainings (one per site) provided to local stakeholders on assessment of seagrass status (BC status) – through on-line instructional videos and a face-to-face workshop which all five National partners participated in;
    - **Activity I.4**: Data collection at four sites, with community participation, to build on and integrate with any existing data concerning the location, extent, conservation, and SES of seagrass meadows and megafauna;
    - **Activity II.1**: SES (BC) data collection, analysis, and assessment at four sites to determine the different ways in which seagrass is providing value and what the loss of these services would cost;
    - **Activity II.2**: Five workshops (one per site) provided to local stakeholders on understanding assessment and valuation of key SES. Total of ≥50 community members. Due to COVID travel restrictions, the five workshops (one per site) were replaced with a single workshop to which all six of the project's NGOs participated;
    - **Activity IV.1**: Training to build capacity of stakeholders (decision-makers, Protected Area managers and NGOs) to utilise SES assessment and valuation. Training for the BC component was provided through a face-to-face workshop (Bogor, 2023) for all six project National Partners.

Recommendations

- **It is recommended that** the findings of this assessment be used to inform policy and seagrass restoration efforts in The Philippines.
    - The information generated in this assessment should be used to inform decision makers and the broader community about the value of seagrasses in carbon abatement, to argue for the inclusion of seagrass ecosystems in the NDC and for the inclusion of seagrass projects in government strategies for the conservation of vegetated habitats. The data generated in this assessment can also provide an initial indication of the carbon credit potential of seagrass BC projects in voluntary carbon trading market operating in The Philippines.

- **It is recommended that** the CMS assist C3 in completing the analysis of the seagrass soil samples collected during the SES for C_{org} for:

  - C_{org} content and carbon stable isotopes, to: 1) improve estimates of carbon stocks; 2) provide future capacity for local NGOs to apply a robust C_{org}: LoI relationship based on locally-derived data; and 3) to identify potential organic carbon inputs from villages which may account for the relatively high carbon stocks at these sites; and
  - Radio-carbon (^{14}C) dating of the cores, to estimate Carbon Accumulation Rates

  Both sets of analyses will place the National Partner in a better position to estimate BC opportunities, and develop BC projects under current verification schemes. The un-analysed samples held by C3 and ECU represent an extremely valuable opportunity to fill several key knowledge gaps regarding Philippines BC resources, with benefit beyond the SES Project. The cost of implementing this recommendation would be modest compared to the investment already made in obtaining high-quality samples but would yield highly significant data for Philippines.

- **It is recommended that future efforts to undertake seagrass blue carbon assessment use the approaches, based on the experience gained during the SES Project:**
  - Further effort be applied to generate more robust Organic Carbon: Organic Matter relationships for seagrass meadows;
  - The National Partner work collaboratively with local university/research partners to implement assessments, in particular the LoI and organic carbon analyses;
  - Direct measurement of soil accumulation rates be made using surface elevation rods, horizon markers or rSETs, rather than relying solely on radio-isotopic approaches; and
  - Future efforts to build capacity in seagrass ecosystem service (blue carbon) assessment prioritise the inclusion of face-to-face field and laboratory techniques training.

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2 Introduction and Aims

This report summarises the activities and findings of a Blue Carbon (BC) assessment undertaken by C3 Philippines (C3) with technical assistance from Edith Cowan University (ECU). The assessment was undertaken as part of a broader assessment of seagrasses at selected seagrass sites in Roxas, Palawan, Philippines, as part of the IKI- funded project "Conservation of biodiversity, seagrass ecosystems and their services – safeguarding food security and resilience in vulnerable coastal communities in a changing climate", hereafter referred to as the SES (Seagrass Ecosystem Services) project'. The full SES project was a collaboration among six National Partners (NGOs based in five SE Asian Countries) supported by four Technical Partners and two Implementing Partners collaboration. The project was designed to enhance the understanding of seagrass ecosystem services and the capacity of the National Partners to develop and deliver science-based policy solutions in seagrass conservation. It brings together scientists, policy experts, business development experts and conservation NGOs across the globe to provide expert and independent advice on seagrass ecosystems services and how these might be relevant to policy and financial solutions to marine conservation issues.

Seagrasses provide many ecosystem services, including the provision of human food, biogeochemical cycling (including carbon sequestration), biodiversity protection and coastal protection. Yet they are frequently neglected in decision-making, leading to alarming rates of loss – 29% of global seagrass meadows have been lost and, at the end of the last century, the remaining beds were declining at a rate of 110 km^2 per year. Seagrass meadows of the Indo-Pacific support up to one billion people through their provision of inshore fisheries. They also provide critical habitat for many marine species, supporting biodiversity including the Dugong (*Dugong dugon*), which is listed as Vulnerable on the IUCN Red List of Threatened Species. At the same time, seagrasses in the region are declining because of coastal development, deforestation, unsustainable resource extraction, and environmental degradation. Limited data exist on seagrass status, their ecosystem services (including carbon storage capacity) and economic value in the region. This information is essential to inform and incentivise effective seagrass conservation. Beyond a better understanding of the role and value of seagrass to tropical marine ecosystems, a coordinated research and decision-making response is needed if effective seagrass management is to occur in the Indo-Pacific region.

The SES project was established to provide critical data on the state and condition of seagrass ecosystems. It also aimed to promote the integration of Seagrass Ecosystem Services (SES) into evidence-based decision-making and business models to ensure the productivity and sustainability of seagrasses across the Indo-Pacific. The project focused on five priority sites in SE Asia, one in each of five partner countries, and applied a 'bottom-up' approach designed to empower local communities to collect and provide the data needed to inform decision-makers and to develop sustainable financing for the conservation of seagrasses and associated biodiversity that are tailored to the specific environmental and economic contexts of the country and community. Consistent with that approach, it was intended that each National Partner would implement the program, supported with training and expert advice from the Technical Partners.

In each of the five priority sites, the project was implemented via five work packages:

WP1. Assessment: primary data collection using biological SES assessments and participatory approaches with local communities.

WP2. Integration: build capacity for integration, develop policy guidelines and integrate SES into decision-making and management.

WP3. Business models: conceptualise 3 models for 5 pilot sites and build community capacity to implement them.

WP4. Communications: develop a strategy and tools for the promotion of SES services and biodiversity.

WP5. Project Management and Coordination.

This technical report presents the outcomes of components of the SES assessment (WP1) and Integration (WP2), specifically, the assessment of BC function in seagrass meadows at the priority sites in The Philippines. The assessment was implemented by C3, supported by technical experts at Edith Cowan University (ECU). The goals were to:

- Build the capacity of local NGO and communities to undertake BC SES assessments;
- Collect data necessary to undertake a Seagrass BC assessment at priority sites identified by the NGO (WP1);
- Build capacity within the NGO to integrate the BC Assessment into policy guideline development, decision-making and management (WP2).

Before describing the activities undertaken (Section 3) and the outcomes of the BC Assessment (Section 4), the following section of the report provides some relevant background on BC, seagrasses and the concept of 'blue carbon projects'.

2.1 What is Blue Carbon?

Blue carbon, also known as coastal carbon, refers to the atmospheric CO_2 which is captured and stored in coastal vegetated ecosystems, either as plant biomass or in the soils, referred to as sedimentary organic carbon. Seagrass, mangrove and tidal marsh ecosystems are recognised as making a significant contribution to the global carbon cycle (Nellemann et al. 2009), due to their ability to bury organic carbon (C_{org}) in their soils at rates, and for storage periods, that are orders of magnitude higher than in many terrestrial ecosystems (McLeod et al. 2011). Interest in BC intensified following the release of two reports in 2009 (Laffoley & Grimsditch 2009, Nellemann et al. 2009), which highlighted the exceptional capacity of these ecosystems to sequester atmospheric carbon, and the subsequent efforts of governments to embed BC into their climate change mitigation and/or adaptation policies (Martin et al. 2016). This, together with the high rates of loss of BC ecosystems globally, make them of significant interest for national and regional climate change mitigation strategies. The conservation, restoration and creation of BC ecosystems have the potential to increase carbon capture and storage, mitigate climate change, support carbon crediting systems and provide numerous co-benefits, including the provision of habitat for endangered species such as the dugong (*Dugong dugon*). Globally, seagrasses occupy about 600,000 km^2 and account for 12% of total carbon stored in ocean sediments. However, significant ongoing losses of seagrasses result in a reduced capacity to mitigate climate change as well as losses to economic sectors dependent on the extensive ecosystem services that seagrass meadows provide.

Seagrass Blue Carbon

BC ecosystems store C_{org} in two main pools: the above-ground pool, mainly comprising living biomass and litter; and the below-ground pool, comprising roots and rhizomes, dead below-ground plant organs, buried litter and soil (or sedimentary) C_{org}. The majority of the C_{org} stocks in BC ecosystems are found in this below-ground pool (Duarte et al. 2013), typically more than 90% of total C_{org} stocks in tidal marshes and seagrasses and in the order of 65-75% in mangroves (Nellemann et al. 2009, Alongi 2014, Serrano et al. 2019). This predominant storage of C_{org} within the below-ground pool (hereafter referred to as soil C_{org}) makes this the pool of primary interest in many BC initiatives (Sutton-Grier et al. 2014), especially in seagrass ecosystems.

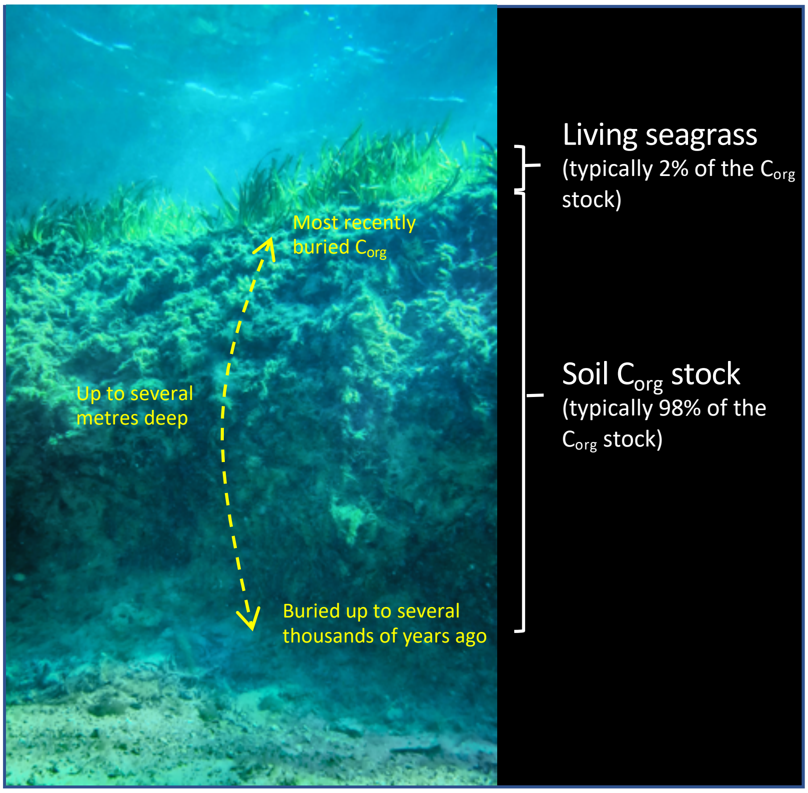

Figure 1. A profile through a seagrass meadow made possible by the erosion of an escarpment wall and revealing the large amount of organic carbon-rich soil below the relatively thin living layer. Numbers in the figure are based on Serrano et al. (2019) for Australian seagrass ecosystems

The capacity of different seagrass ecosystems to trap and store carbon in their soils varies. Up to 45-fold differences in soil organic carbon stocks have been reported among seagrass habitats, while their annual carbon accumulation rates can vary by up to 70-fold (Lavery et al. 2013, Serrano et al. 2019, Mazarrasa et al. 2021). This variation is driven by many factors, including species composition, geomorphological settings, soil characteristics, and biological features which interact to control the capture and storage of C_{org} in seagrass ecosystems (Adame et al. 2013, Ouyang & Lee 2014, Serrano et al. 2016). Understanding this variability and the factors that control the stocks and accumulation rates is key to identifying opportunities to enhance C_{org} stocks or avoid emissions of GHG, thereby contributing to the mitigation of GHG emissions and forming the basis for potential inclusion of BC activities within carbon crediting programs.

How do seagrass capture and store carbon?

Seagrass meadows trap and accumulate two types of carbon – autochthonous and allochthonous carbon. Autochthonous carbon is carbon which the seagrass plants, and other primary producers in the meadow, have produced through photosynthesis and turned into plant biomass. This biomass can then experience several fates. It may be consumed by herbivores, such as dugongs or be exported, in the form of dead leaves shed by the plant. Through the process of remineralisation, this carbon is likely to be turned back in inorganic forms, such as carbon dioxide and, potentially, re-enter the atmosphere as gaseous emissions (Figure 2). However, some of the biomass be buried in the sediments, where it can accumulate and be isolated from the atmosphere for millennia. Most of this buried carbon comes from the below-ground biomass of the seagrass (rhizomes and roots) which are incorporated into the sediments when the tissues die. Allochthonous carbon refers to organic carbon which originated in a different place but has accumulated in the seagrass meadow, largely dead plants and animals which drifts into a meadow. The seagrass canopy slows the water movement and facilitates the trapping of the material, where it falls into the sediment and is buried. Most of the organic carbon accumulated in seagrass meadows is found in the sediments – typically more than 95%. This is because the sediments have characteristics which assist the accumulation and preservation of the carbon, while in the seagrass canopy conditions favour remineralisation. The vertical growth of the seagrass plants and the trapping of particles by the canopy results in vertical accumulation of the sediment and burial of material in it. Once buried, the carbon is isolated from oxygen, which slows down its remineralisation. Furthermore, because the sediments are permanently wet (even inter-tidal sediments) they are not subjected to fires. The constant burial, lack of oxygen and absence of fire all promote the accumulation and preservation of carbon in seagrass sediments. In contrast, the seagrass canopy (and terrestrial soils) is exposed to high levels of oxygen and physical disturbance which work against the accumulation and preservation of carbon, and terrestrial soils also experience fire which rapidly remineralises the stored organic carbon to carbon dioxide. For these reasons, seagrasses and other BC ecosystems tend to have much higher rates of carbon accumulation in their soils than terrestrial ecosystems.

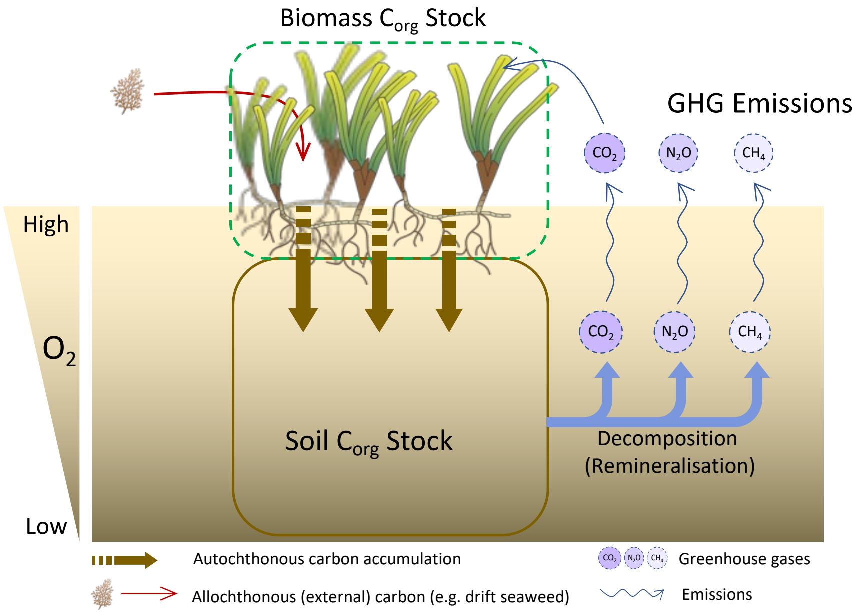

Figure 2. Carbon stocks, accumulation, and greenhouse gas emissions in seagrass meadows

What is a Seagrass Blue Carbon Project?

A seagrass BC Project refers to any action which is designed to maintain or enhance the capture and storage of carbon by seagrass ecosystems. These actions (or projects) can take many forms, ranging from the conservation of existing, healthy seagrass meadows through to the restoration of degraded seagrass meadows or even the creation of seagrass meadows in places that did not previously support them. The motivations for these actions are also quite varied. In some instances, the goal is to conserve habitat for the range of ecosystem services it provides, carbon capture being just one of these. In other cases, actions may contribute to regional or national goals to mitigate climate change, contributing to Nationally Determined Contributions (NDCs), a national plan for climate change mitigation under the United Nations Framework Convention on Climate Change (UNFCCC). In yet other instances the goal may be to generate income through carbon credits which can be used for a variety of purposes, including funding of conservation initiatives. Of course, these motivations are not mutually exclusive.

In most instances, any seagrass BC project will need to demonstrate the potential or actual effectiveness in carbon capture. Where the actions are feeding into Greenhouse Gas (GHG) inventories, NDCs or Crediting projects, then a formal estimation or verification of the carbon capture will likely be required. Such assessments require information on how much carbon the seagrass site captures each year (i.e., the **sequestration** rate or **Carbon Accumulation Rate**, CAR), the total amount they have buried in their soils (the soil **C_{org} stock**) and the **emissions** of GHGs from the meadow (Figure 2). For seagrasses, and many other ecosystems, this information will likely be incomplete, requiring estimates to be made with some degree of uncertainty. The IPCC has classified their methods for estimating GHG emissions into three tiers based on their complexity and data requirements (IPCC 2006, 2019). Tier 1 is the most basic method, Tier 2 intermediate and Tier 3 most demanding, with Tiers 2 and 3 generally considered to be more accurate. In the absence of locally-derived information on seagrass C_{org} stocks, CAR and GHG emissions, global default values could be used to estimate the amount and rate of C_{org} capture at a specific site, providing a tier 1 estimate. Determining region-specific values for C_{org} stocks and sequestration rates will allow tier 2 or tier 3 estimates (i.e., estimates based on regional data or modelling) to be applied. The benefit of deriving tier 2 or 3 estimates is that they provide a more accurate estimate of carbon capture, or possible carbon emissions following disturbance, for use in nationally determine contributions, and the greater certainty may be rewarded in the size of carbon credits that might be derived in a BC project.

There is a paucity of case studies to inform the potential enhancement of carbon capture and storage following specific management actions such as seagrass restoration projects. The potential opportunities for seagrass ecosystems in carbon mitigation strategies is based on the presumption that restoration can return the C_{org} sequestration rates to those of undisturbed ecosystems, yet this remains to be tested. The 'SES Project' was designed to generate data to fill critical knowledge gaps around BC in the study region, thus supporting the ability to demonstrate one of the values of seagrasses to local communities and decision-makers and to assist in any future efforts to develop seagrass BC projects by providing data to underpin tier 2 or tier 3 estimates of GHG inventories.

Blue Carbon Projects and data requirements

The specific information requirements for any BC assessment will depend on the purpose of the assessment. Broadly, assessment can be undertaken to:

a) provide an understanding of the function and value of a seagrass ecosystem, which might educate stakeholders (such as local communities through to regional or national governments) and, thereby, influence policy or decision-making;
b) to provide data that can underpin carbon accounting activities, such as those needed for GHG accounting or measuring performance against NDCs; or
c) to provide the information required as part of the verification process for a BC crediting project. Sometimes, the assessment may need to meet more than one of these objectives.

The data requirements and methods for a baseline survey (a, above) will be for the assessment team to decide, and there is comprehensive guidance available on this (e.g., Howard et al. 2014, Rahmawati et al. 2019). For assessments which feed into formal GHG accounting or crediting schemes, it is likely that the data requirements and methods will be specified by national or international governance bodies (e.g., the IPCC) or by a verification agency (e.g., VERRA:

www.verra.org/programs/verified-carbon-standard). In all these cases, there is usually a requirement to assess the carbon characteristics of an undisturbed meadow and a disturbed meadow. The undisturbed meadow defines the baseline condition and provides insights into the ecosystem service being provided by existing seagrass meadows, in terms of carbon capture. The disturbed meadow provides insights into the impact humans can have on carbon emissions if a meadow is disturbed or if a disturbed meadow is rehabilitated.

For GHG inventories and general information for influencing policy, the undisturbed condition demonstrates how much carbon a healthy seagrass meadow can sequester each year – i.e., the ecosystem service being provided. It also provides insight into how much carbon could be released to the atmosphere (i.e., an emission) if the meadow was disturbed. The difference between the healthy and disturbed meadow provides further insight into the potential emission from a seagrass meadow if it were disturbed. Conversely, it can be used to demonstrate how much additional carbon would be captured if the disturbed meadow were restored to a healthy condition.

For BC crediting project, measurements of healthy and disturbed meadows can be critical in estimating its carbon abatement potential. Most project verification schemes require the project to demonstrate two features of any carbon capture: additionality and permanence. Additionality implies that the carbon which a project captures is additional to that which would have been captured in the absence of the project. For example, if the project was restoration of a seagrass meadow, the only carbon eligible to receive credits is that which can be shown to have accumulated because of the restoration; any carbon that would have accumulated in the absence of the restoration would not be eligible. In this situation it is necessary to define the baseline condition (or the condition before any project is implemented – often referred to as the Business as Usual (or BAU) condition – as this indicates the amount of carbon that would accumulate without the project. The BAU case is often estimated by measuring the disturbed area. It is then necessary to estimate how much carbon will be sequestered by the project. This can be done in many ways, but one way is to measure the sequestration in a healthy meadow and assume that the project will result in similar characteristics. The difference between the Project estimate and the BAU estimate represents the additionality and is the amount of carbon potentially eligible for credits.

Additionality can be achieved in two ways, by:

1) **Enhanced sequestration** – in this case, the project occurs on a disturbed site and results in an improvement in the seagrass such that more carbon is being accumulated (sequestered) each year. An example of this is a seagrass restoration project on a disturbed site; and
2) **Avoided Emissions** – in this case, the project acts to conserve an area that would otherwise have been disturbed. By avoiding the disturbance, the project is also ensuring that the emissions associated with the disturbance are also avoided. An example of this might be declaring a marine Protected Area on a site that would otherwise have been dredged for development.

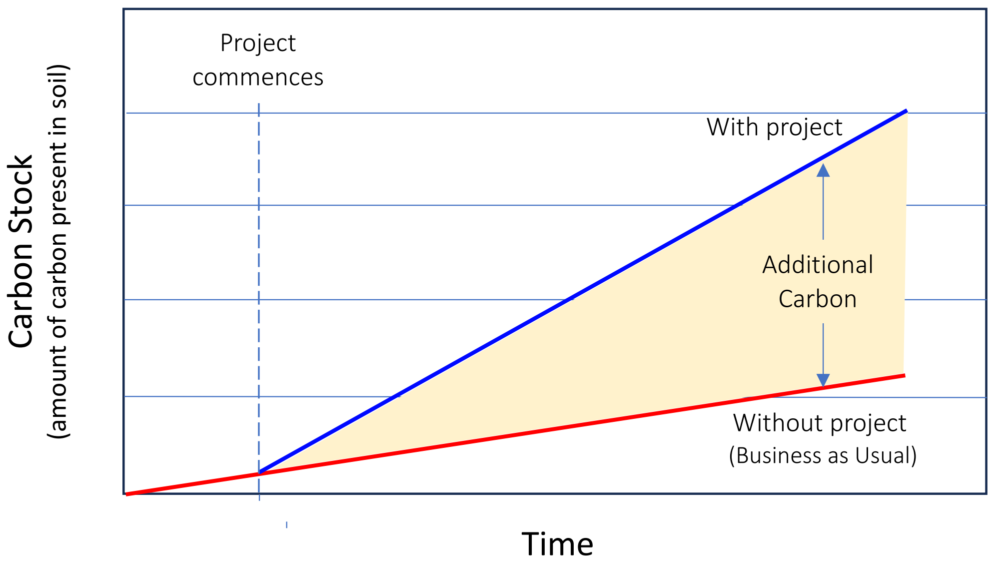

Figure 3. Additionality in BC projects. The diagram shows the amount of carbon which might accumulate at a site over time under two scenarios: at a site with no management action (i.e., Business as Usual (red line); and at the same site following implementation of a BC project (blue line). The difference between the two lines represents the additionality – i.e. the additional carbon sequestered as a result of the management action

The second important requirement for any crediting project is that permanence can be demonstrated. Permanence refers to the length of time that the captured carbon will be retained on the site. Many verification schemes require the carbon to be captured for 20 or 100 years, and the number of credits awarded will reflect the level of confidence and the duration of the permanence; project with a high level of certainty of capturing carbon for a long period of time may receive more credits. Demonstrating permanence requires ongoing monitoring of a project site to show that carbon has been captured and retained. However, it is also possible to gain insights into permanence by measuring healthy sites and determining the age of carbon in those sites.

It is apparent from the above that any BC assessment will generate the most versatile outcomes for future application when both healthy and disturbed meadows are assessed. Ideally, the disturbed meadow will be very similar to the healthy meadow in all respects except for the disturbance or interest – e.g., dredging, boat moorings, eutrophication, sediment deposition, fishing.

2.2 National Partner-identified objectives for BC assessment

In late 2019, at the SES Project Inception meeting held in Manado, each National partner was asked to clarify their objective(s) in undertaking a BC assessment. All the National Partners indicated that their primary objective was to:

- Build capacity for the National Partner to independently undertake BC assessments; and
- Provide data which would demonstrate to policy makers and the broader community the capacity of local seagrasses to sequester and store carbon.

There was less focus on undertaking the assessments to subsequently develop BC projects that could generate financial returns through crediting or any other approach.

Following the Manado meeting, ECU worked closely with the National Partners to develop a BC assessment which would meet their stated objectives. This required the sampling of healthy meadows which could be used to demonstrate the ecosystems service currently being provided. It also required the sampling of disturbed meadows which could, be used to demonstrate any negative effect of those impacts on the ecosystem service. This approach also provided an opportunity to generate baseline data that could inform any future BC project seeking carbon credits.

This report presents the findings of the BC assessment in Johor and Penang Island, Malaysia, undertaken as part of Work package 1. The assessment incorporated sampling of relatively undisturbed and degraded seagrass ecosystems, focused on C_{org} storage and sequestration. Because the collection of these data added to the database on C_{org} stocks and sequestration rates in Malaysia seagrass ecosystems, a review of known information on seagrass BC in Malaysia's coastal ecosystems is included.

3 Seagrass Blue Carbon and Blue Carbon Policy in The Philippines

Only two studies, which have been summarised in some review papers on the topic (e.g., Stankovic et al. 2023), have been conducted in The Philippines and report seagrass soil C_{org} stocks data, while no studies are available for seagrass C_{org} accumulation rates (Table 1). Those studies have mostly been conducted in the northern part of The Philippines (e.g., Luzon region) and none of them reported data from Palawan Island, where the sites used in this assessment are located. The available literature reports seagrass C_{org} soil stocks ranging between 15.5 and 80 ± 15 t C_{org} ha^{-1} (Table 1), with a mean value of 40 ± 22 t C_{org} ha^{-1}, indicating high variability among sites.

Reyes et al. (2022) reported C_{org} stock for the top 30 cm of sediment of both mixed and monospecific (i.e., *Enhalus acoroides*) meadows in the North West of The Philippines (Zambales). Cores were collected in the intertidal area of the protected environment of Oyon Bay, one of the MPA with the highest biodiversity in the country but where disturbances, such as aquaculture and coastal development, have caused a significant reduction in seagrass meadows cover. The authors only reported dry bulk density and % C_{org}, therefore the C_{org} stocks were calculated for this report. Mean C_{org} stock of the mixed healthy meadows (39 ± 14 t C_{org} ha^{-1}) was 2.5-fold higher than the mean value of the disturbed *E. acaroides* C_{org} stock (16 ± 16 t C_{org} ha^{-1}), highlighting how disturbances can affect the C_{org} sequestration capacity of seagrass meadows.

The review paper by Corcino et al. (2023) reported an average C_{org} sediment stock equal to 80 ± 15 t C_{org} ha^{-1}. Data on C_{org} stocks presented in this review have been standardized to 100 cm depth, and therefore it is not surprising that they are higher than those reported by Reyes et al. (2022). Three studies were included in Corcino et al.'s (2023), but original documents, probably published in local journals, could not be found and therefore details on type of sites, meadows and methodology are unknown.

Table 1. Published seagrass soil C_{org} stocks and C_{org} accumulation rates (CAR) for coastal sites in The Philippines. CAR = Carbon Accumulation Rate. References: [1]Reyes et al. 2021; [2]Corcino et al. 2023.

SITE	HABITAT	Sediment depth (cm)	STOCK ($t\ C_{org}\ ha^{-1}$) Mean ± s.d.	CAR ($kg\ C_{org}\ ha^{-1}\ y^{-1}$) Mean ± s.d.	Ref
Oyon Bay, Masinloc, Zambales	mixed meadows (intertidal)	30	36.3	-	1
	mixed meadows (intertidal)	30	25.9	-	1
	mixed meadows (intertidal)	30	54.5	-	1
	E. acoroides (intertidal)	30	45.9	-	1
	E. acoroides (intertidal)	30	20.6	-	1
	E. acoroides (intertidal)	30	15.5	-	1
Visayan Sea and West Philippine Sea	unknown	100*	80 ± 15	-	2

3.1 Seagrass blue carbon policy

The Philippines per capita greenhouse gas (GHG) emissions including land use were recorded to be 1.18 t CO_{2e}/capita last 2017 (Enerdata 2020, United Nations Department of Economic and Social Affairs Population Division 2020), and last 2020, The Philippines emits an average of 1.98 t CO_{2e}/capita in 2020, well below the global average of 4 metric tons per capita. In relation to this, The Philippines is one of the signatory countries to the Paris Agreement on Climate Change and pledged to reduce its carbon emissions of up to 75% by 2030 relative to the business-as-usual (BAU). The Philippines has committed to a projected GHG emissions reduction and avoidance of 75%, of which 2.71% is unconditional and 72.29% is conditional, representing the country's ambition for GHG mitigation for the period 2020 to 2030 for the sectors of agriculture, wastes, industry, transport, and energy. This commitment is referenced against a projected business-as-usual cumulative economy-wide emission of 3,340.3 Mt $CO_{2\text{-}eq}$ for the same period.

The National Framework Strategy on Climate Change (NFSCC) of the country has explicitly stated that two of the key underlying risk drivers of climate change are the loss of forest cover and degradation of coastal and marine resources and it is committed to protect its people and the environment. The State has high regard to the capability of the coastal and marine ecosystems and biodiversity and the role that it can play in the adaptation strategies and measures.

The country recognizes the importance of addressing climate change due to its vulnerability to the impacts of climate-related events such as typhoons, sea-level rise, and extreme weather conditions. Some of the key components of The Philippines' approach to climate change include:

- Article II, Section 16 of the Philippine Constitution of 1987 states that it is the policy of the state to ensure the sustainable use, development, management, protection, and conservation of the country's environment and natural resources and cultural heritage for the benefit of the present and future generations.
- Republic Act No. 9729, also known as the "Climate Change Act of 2009", serves as the legal framework for The Philippines' climate change policy. It established the Climate Change Commission (CCC) as the lead agency responsible for coordinating, monitoring, and evaluating climate change-related programs and actions.
- Republic Act No. 10174, which is an amendment to the Climate Change Act, established a People's Survival Fund (PSF) to support and fund climate change adaptation activities of local governments and communities. It also paved the way towards the integration of disaster risk reduction into climate initiatives and programs and provides policy framework support for funding climate change adaptation at the local level.
- Republic Act No. 10121 or the "Philippine Disaster Risk Reduction and Management Act of 2010", provided for the development and implementation of a National Disaster Risk Reduction and Management Plan (NDRRMP) and for Local Government Units LGUs to formulate and implement their Local Disaster Risk Reduction and Management Plan (LDRRMP). It also established the National Disaster Risk Reduction and Management Council (NDRRMC) to coordinate and manage all disaster risk management interventions of the government.
- General Welfare Clause under Sections 16 and Sec. 17 (b) of Republic Act 7160, also known as the Local Government Code, further provide for the establishment of tree parks, greenbelts zones, and similar forest development projects and promote passage of legislations or

ordinances with support from the Department of Environment and Natural Resources (DENR) regional offices.

- Executive Order No. 174, s. 2014 institutionalized the Philippine Greenhouse Gas Inventory Management and Reporting System (PGHGIMRS) and designated the CCC as the overall lead implementer to provide direction and guidance in the accounting and reporting of GHG emissions.
- The Philippine National REDD+ Strategy (PNPRS).
- Executive Order 881- 2010 (EO 881) where REDD+ was defined as follow: “Reducing Emissions from Deforestation and Forest Degradation-Plus (REDD+) is a set of steps designed to use market/financial incentives to reduce the emissions of greenhouse gases from deforestation and forest degradation. The objective is to reduce greenhouse gases, but it can deliver “co-benefits” such as biodiversity conservation and poverty alleviation.”
- National Climate Change Action Plan (NCCAP) is The Philippines' national strategy for addressing climate change. It outlines the country's goals, priorities, and actions to mitigate greenhouse gas emissions and adapt to the impacts of climate change. The NCCAP covers various sectors such as agriculture, water resources, energy, health, and more.
- National Framework Strategy on Climate Change (NFSCC) outlines the strategic directions and principles for addressing climate change in The Philippines. It emphasizes the importance of mainstreaming climate change concerns into development planning and decision-making processes.
- Senate Bill No. 1992. An Act Promoting a Low Carbon Economy established an Emission Trading system and implementation mechanism to achieve National Climate Targets.
- A comprehensive Climate Policy agenda was adopted and integrated into the Philippine Development Plan, including the National Framework Strategy on Climate Change (2010-2022), the National Climate Change Action Plan (2011-2028), the Philippine Development Plan (2017-2022), the Philippine Energy Plan (2018-2040), the Philippine National Security Policy (2017-2022), the National Climate Risk Management Framework of 2019, and the Sustainable Finance Policy Framework of 2020.
- Philippine Development Plan (PDP) includes climate change as a cross-cutting issue, integrating climate change adaptation and mitigation measures across different sectors and development goals.

There are also a range of other initiatives that embed climate change aspects within them, including Climate Finance Initiatives, the National Disaster Risk Reduction and Management Plan (NDRRMP) Enactment of Republic Act 10771 of 2016 , and a number of joint memoranda or partnerships to advance low emission technology or reduce emissions, including with Japan, The United Kingdom and the World Bank.

NDC Approach and Commitment of The Philippines

The specific policies, measures, and strategies to achieve The Philippines’ stated INDC are outlined in the country's National Climate Change Action Plan (NCCAP) and related documents. The NCCAP outlines a range of actions and strategies aimed to achieving its GHG reduction targets. These actions encompass both mitigation in terms of reducing emissions and adaptation by building resilience to climate impacts. Some of the key actions and strategies outlined in the NCCAP are:

1. Mitigation Actions:

- Promotion of Renewable Energy.
- Energy Efficiency Enhancement
- Afforestation and Reforestation: (primarily dealing with terrestrial forests).
- Sustainable Transport.
- Waste Management Improvements.

2. Adaptation Actions:

- Climate-Resilient Agriculture.
- Ecosystem-based Adaptation: this includes protecting and restoring ecosystems such as mangroves and coral reefs that provide natural buffers against climate-related impacts like storms and sea-level rise.
- Water Resource Management.
- Community-based Adaptation.
- Climate-Resilient Infrastructure.
- Health and Disaster Risk Reduction.

These actions are designed to align with The Philippines' commitment to reducing greenhouse gas emissions and enhancing resilience, as outlined in its intended nationally determined contributions (INDC) under the Paris Agreement. As can be seen, some of these, and specifically the Ecosystem-based Adaptation actions, could relate directly to seagrass ecosystems.

Economic value of Seagrass

Despite the importance of the seagrass ecosystem has been widely recognized, seagrasses are still poorly represented and of least priority in conservation and protection in SE Asia. The total blue carbon economic value of seagrasses in SE Asia has been estimated to be around $15,745 ± 4,109 ($10^6$ USD) (Stankovic et al. 2021), as about 1574 ± 42 Tg of CO_2 is stored within these seagrasses. In fact, seagrasses alone in SE Asia could offset 1.43% of the total CO_2 emissions by 2030, however, only Indonesia, Vietnam, and Myanmar have included nature-based solutions in their NDCs nature-based solutions adaptation and mitigation component, unlike The Philippines where they are only recognized as mitigation or adaptation components (Seddon et al. 2020). The Philippines, has not yet included coastal and marine habitats in its NDC (Francis & Wilkman 2022) though while not mentioned or included specifically, some of the actions outlined in The Philippines' NCCAP may potentially involve coastal ecosystems such as seagrasses and mangroves. Some of these action and how they are relevant to the above-mentioned actions are:

- Afforestation and Reforestation: mangrove reforestation and conservation are key components of the NCCAP. Mangroves sequester carbon and provide natural coastal buffers against storm surges and sea-level rise.

- Coastal Planning: integrating coastal ecosystems into urban planning can help protect them from negative impacts of transportation infrastructure. Proper planning can also ensure that transportation projects do not harm sensitive coastal habitats.
- Waste Management Improvements in terms of Coastal Health: proper waste management prevents pollution that can harm coastal ecosystems, including seagrasses and mangroves.
- Climate-Resilient Agriculture in terms of Coastal Agriculture: coastal agriculture practices that incorporate sustainable land use techniques can prevent sediment runoff and pollution that can affect nearby seagrass beds and mangroves.
- Ecosystem-based Adaptations: protecting and restoring mangrove ecosystems provides coastal protection against storm surges and sea-level rise and preserve and enhance mangroves carbon sequestration.
- Water Resource Management/Coastal Watershed Management: protecting and restoring coastal watersheds helps maintain water quality and sediment balance, benefiting seagrass and mangrove ecosystems.
- Community-based Adaptation: many coastal communities depend on seagrasses and mangroves for their livelihoods. Community-based adaptation efforts can include sustainable resource management to protect these ecosystems.
- Climate-Resilient Infrastructure: integrating natural coastal features like mangroves into infrastructure design can enhance resilience to coastal hazards. Incorporating blue carbon ecosystems into climate change strategies recognizes their ecological value and potential contributions to mitigation and adaptation efforts. However, it is important to note that the specific actions and strategies may vary based on local conditions and priorities.

Carbon trading

The Philippines lacks both a clearly defined carbon tax and a CO_2 emissions trading system. Nevertheless, it does gather revenue through energy-related taxes, which encompass excise taxes imposed on fuels and electricity consumption. Though The Philippines does not have any carbon pricing policy, there are initiatives in the legislative branch and other agencies that aim to pursue a carbon tax and a carbon credit system. The Department of Environment and Natural Resources (DENR) is advocating for the establishment of a legal framework to formalize carbon credit systems, with the aim of enhancing the country's climate change efforts.

Conclusion

At present, most of the climate change mitigation related policies are focused on the forest and the energy sectors, while the coastal and marine habitats are still a work in progress, especially recognition of the role of the seagrass ecosystem in carbon sequestration and climate change mitigation. Most of the existing policies for coastal and marine habitats are general and none of them specifically focus on seagrasses. The data that will be generated from the SES Project can complement the many research studies on seagrass cover and the roles and function it can play in carbon sequestration and its economic contribution in coastal fisheries such as fishing and nursery grounds. This will be a powerful argument in favour of conservation of our blue carbon ecosystems. The biggest challenge is communicating the importance of the seagrasses and the consequences their loss to the decision-makers, including stakeholders, for them to acknowledge and consider the seagrass ecosystem services as nature-based solution(s) to climate change.

4 Blue Carbon Assessment

4.1 Assessment design

The Blue Carbon (BC) Assessment was designed to meet the following objectives:

- Build capacity for the NPs to undertake BC assessments;
- Provide data to demonstrate to policy makers and the broader community the capacity of local seagrasses to sequester and store carbon; and
- Provide data which could inform the development of potential BC Projects for financial benefit.

The BC assessment was undertaken by C3 in the Roxas, NE Palawan province. To assess the BC potential of the area, C3 assessed four sites (Figure 4; Table 2):

- Tumarbong – a reference site. This site is characterized by healthy seagrass beds.
- Minara – an impacted site. The site is characterized by seagrass meadows heavily affected by river run-off and sediment deposition.
- New Barbacan – an impacted site. The site is characterized by seagrass meadows impacted by fishing and boating activities; and
- San Nicolas – a meadow impacted by high fishing activity, sediment deposition, and river run-off, and is classified as a high-priority area due to a very high fishing intensity.

All impacted sites were previously more vegetated than the current condition of the area.

All four sites had similar geo-morphological settings and water depth. The study locations were all occupied by mixed species of *Thalassia hemprichii, Cymodocea serrulata, Halodule uninervis, C. rotundata, H. pinifolia, Syringodium isoetifolium, Halophila spinulosa, Halophila ovalis*, and are dominated by *Enhalus acoroides.* At each site, four replicates cores were collected, each, located at 50 meters apart and along a line parallel to the shore to remove any confounding effect of depth.

The data for undisturbed meadows can inform the government and other decision-makers of the value of seagrasses for CO_2 capture and storage. It is also relevant data for the design of BC projects, since these data can identify the 'baseline' or Business as Usual conditions and are relevant to both Avoided Emission and Enhanced Sequestration projects. The data from the disturbed meadows are essential for indicating the extent of carbon which might be lost following disturbance of a meadow and, therefore, the potential amount of carbon loss which could be avoided by conserving this habitat (Avoided Emission) or the additional carbon capture which might be achieved by restoring the meadow (Enhanced Sequestration), by comparison to the undisturbed sites.

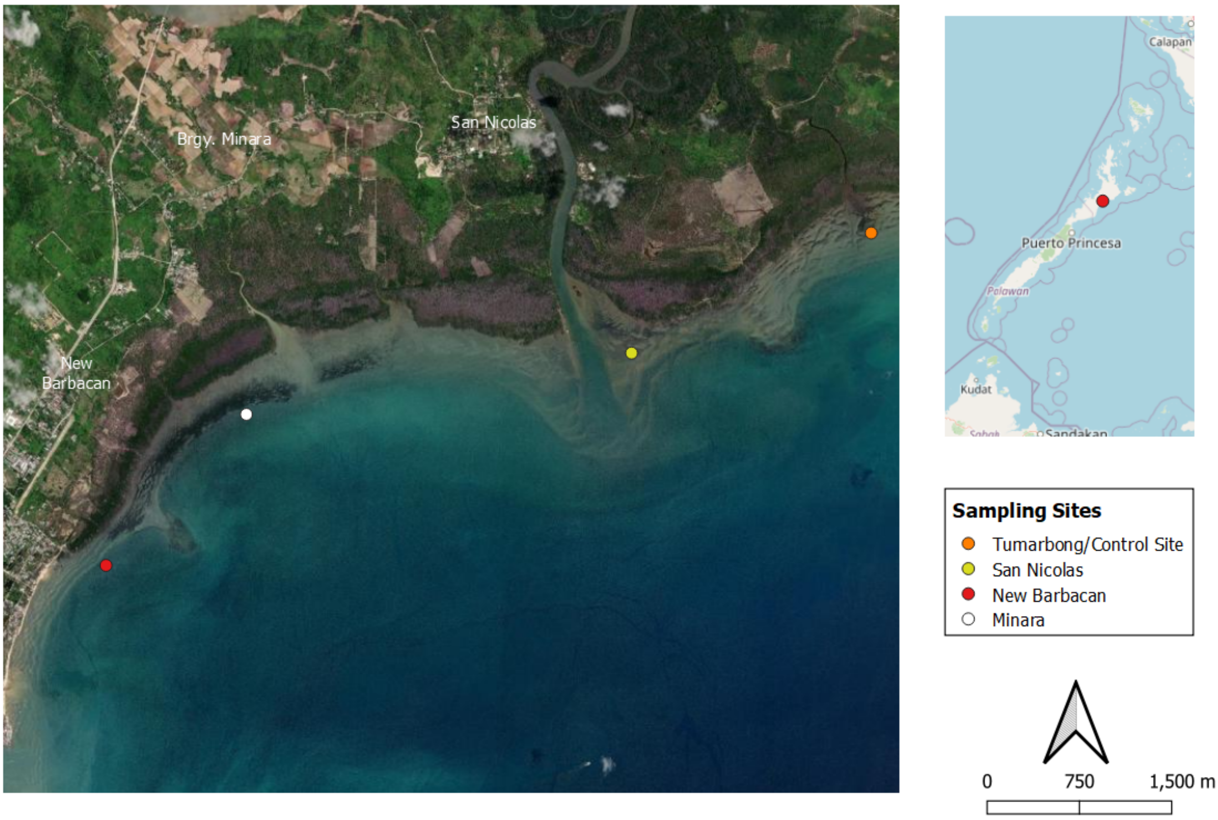

Figure 4. The location of the four sampling sites used by C3 in the Blue Carbon assessment for the Roxas region in NE Palawan, Philippines. See Table 2 for details of site characteristics and location coordinates.

Table 2. Site details for the blue carbon assessment of seagrass meadows in Roxas, Palawan, Philippines.

SITE	DESCRIPTION	Latitude (N)	Longitude (E)
Minara	Mildly impacted site (intertidal). The site has mixed species of *Enhalus acoroides, Cymodocea serrulata, Syringodium isoetifolium, C. rotundata, Halodule pinifolia* and *Halophila ovalis* in a healthy condition but with disturbance due to river run-off and sedimentation.	10.3433	119.3765
San Nicolas	Highly impacted site (intertidal). This site is affected by sediment run-off and fishing activity. The site is unvegetated but was previously vegetated with the dominant species, *C. rotundata* as well as *C. serrulata, H. pinifolia, E. acoroides*.	10.3447	119.3985
New Barbacan	Impacted site (intertidal). The site comprises patchy seagrass meadows of mixed species and is impacted by fishing and boating activities by local fishermen.	10.3321	119.3622
Tumarbong	Reference site (intertidal). No activities are known to cause any significant disturbance. The site is characterized by mixed seagrass meadows dominated by *E. acoroides* occurring in patches.	10.3539	119.4169

4.2 Site Descriptions

Roxas is a coastal municipality located in the northern portion of the island province of Palawan. and it is bounded by the Municipalities of Taytay and San Vicente on the north, the town of Dumaran on the northeast, and the City of Puerto Princesa on the south (Coastal Environmental Profile 2005). It is about 134 km north-northeast of Puerto Princesa City, the Provincial Capital of Palawan, and the 4th largest municipality out of the 23 municipalities of Palawan province. It is classified as a first-class municipality with 31 barangays and 13 islands, with 18 coastal barangays under its jurisdiction.

During the site selection, the local community, MPA managers and fisheries technicians from the local government unit were consulted and approved sample collection from: Barangay Minara, New Barbacan, San Nicolas, and Tumarbong, all distributed along ~6 km coastline in Roxas, Palawan.

4.2.1 BARANGAY MINARA

The Barangay Minara site was ~3 km west of the San Nicolas River (Figure 4) and is impacted by runoff from the river, which causes sedimentation. There is no published data on the status of seagrass beds in the area. The site was characterized by mixed species dominated by *Enhalus acoroides*. In December 2021, Northern Palawan was hit by super typhoon Odette (typhoon Rai), resulting into seagrass loss which was still apparent during sampling in November 2022. Additionally, it has been reported that human-related activities in areas such as trawling could have caused some seagrass loss. The sampling sites were previously used to install fishnets and bamboo poles for the collection of lobster.

Figure 5. A healthy *Enhalus acoroides* seagrass meadow in a vegetated site in Minara

4.2.1 SAN NICOLAS

San Nicolas in Roxas, Palawan is located at the mouth of the San Nicolas River (Figure 4) and it is highly impacted due to run-off, and high fishing activity. As observed, the study site was sandy and was previously vegetated with the dominant species, *Cymodocea rotundata*, as it had experienced seagrass loss. Six species of seagrass were recorded in the area, namely *C. rotundata, Halodule uninervis, Thalassia hemprichii, C. serrulata, Halodule pinifolia and Enhalus acoroides.* The *E. acoroides* growth and bare sand patches span a vertical length of 48 cm observed in the area. As reported, 10 -15 years previously, the San Nicolas was used as site for mangrove plantations. The sediment cores were collected in bare areas which were previously vegetated.

Figure 6. Patches of disturbed seagrass in San Nicolas, Roxas, Palawan

4.2.1 BARANGAY NEW BARBACAN

Barangay New Barbacan study site is located in front of the small village in the area. It is typically composed of areas with sediments characterized as fine-grained particles, such as clay or silt, that settle out of suspension water. During the core sampling, disturbed seagrass species were observed in the study area. This site is impacted by fishing and boating activities by local fishermen.

Figure 7. Mixed seagrass species dominated by *E. acoroides* in muddy sediment at New Barbacan, Roxas, Palawan

4.2.2 TUMARBONG

The Tumarbong site is located ~2 km east of the San Nicolas River mouth, away from sediment run-off coming from the river and was chosen as a reference site, even though some small disturbances are still present. The site is intertidal and dominated by *Enhalus acoroides*, while nearby areas supported *Cymodocea serrulata, C. rotundata, and Halodule pinifolia.* Cores were collected in healthy seagrass meadows.

Figure 8. Healthy seagrass meadow dominated *by E. acoroides* in Tumarbong, Roxas, Palawan

4.3 Core collection, processing, laboratory analysis and numerical procedures

Prior to core collection, the National Partner received training on field techniques for core collection and laboratory techniques for core processing. Initially, it was intended to deliver this training as on-site workshops, but COVID-19 travel restrictions prevented this. Instead, ECU prepared instructional videos on the process of collecting seagrass soil cores for BC assessment and the laboratory techniques for their subsequent processing. The videos can be accessed at (www.dugongseagrass.org/resources-impact/tools/seagrass-blue-carbon-toolkit/). ECU ensured the NPs had all the necessary sampling equipment and were available via video connection during the sampling event to provide technical support.

At each site, four seagrass cores were collected to determine the carbon characteristics and allow comparison of undisturbed, disturbed and revegetated sites. The methods used for the collection and processing of the cores and the numerical procedures use to determine C_{org} stocks and accumulation rates followed published protocols, modified to suit the local circumstances of the national partner. While the protocols were modified, they were designed to provide scientifically robust estimates of C_{org} stocks and accumulation rates which could be applied in existing carbon verification schemes. Full details of the methods are provided in Appendix A.

5 Blue Carbon Stocks and Accumulation Rates

5.1 Relationship between %OM and %C_{org}

A key objective of the BC assessment was to apply a cost-effective means for NGOs and communities to estimate the carbon stocks in their seagrass soils. The two most common ways to estimate the C_{org} content of seagrass soils are by direct measurement, using an elemental analyser, and indirect estimation by applying a conversion factor to 'Loss on Ignition' (LoI) measurements made on the soils (Fourqurean et al. 2012, Howard et al. 2014). Elemental analysis is costly and requires access to an analyser, which is not always available. The SES project used a combination of the two approaches, providing a method to estimate the soil C_{org} content which is less expensive and can be performed using readily available laboratory equipment. Globally, a strong relationship has been reported between Soil C_{org} and soil organic matter (OM) content, with OM explaining about 96% of the variability in C_{org} (Fourqurean et al. 2012). Furthermore, OM is relatively inexpensive to measure using the LoI) method. The goal was to analyse all soil samples for LoI and a subset for both LoI and C_{org}. The sub-set samples were then to be used to develop a relationship between the two variable which could be applied to all the samples.

In the case of The Philippines, it was not possible to develop a regional relationship between seagrass soil OM and soil C_{org}, for a number of reasons. Samples were successfully collected from all sites and were analysed for soil organic matter (LoI). Despite considerable effort, it was not possible to locate a laboratory within The Philippines which could perform the analyses. It seems that a laboratory needed for this type of analyses is not present at all in the country. The alternative was to export the samples to ECU where the analyses could be performed. Unfortunately, the export permit required to send the samples out of the country for analysis could not be obtained until July 2023, leaving insufficient time to perform the analyses before the end of the SES project's implementation phase. Consequently, it was not possible to develop a %LOI – % C_{org} relationship for the Roxas region and, instead, the seagrass global relationship (Fourqurean et al. 2012) was used to calculate %C_{org} in all samples, which were only analysed for %LOI.

Nonetheless, the samples remain available for analysis should C3 have the opportunity to analyse them in the future. Given the low number of seagrass BC studies in The Philippines that provide data on soil C_{org} stocks but the extensive seagrass BC habitat that exists in the country, it is recommended that the sample are analysed in the future should the resources be available, as they will be a significant addition to the national dataset.

Due to the absence of a region-specific conversion factor, the global conversion factor developed by (Fourqurean et al. 2012) for seagrass soils was used to convert the OM data into estimates of soil organic carbon content (%), where:

$$C_{org} = (0.0678. OM) + 0.5528$$

Where C_{org} is soil organic carbon content (%), and OM is the soil organic matter content, estimated from the Loss on Ignition (%).

The full (Fourqurean et al. 2012) data set was used rather than data only for The Philippines region sub-set of data since the full relationship was stronger. Consequently, these C_{org} estimates, and the stock estimates which are based on them, should be considered Tier 1 estimates.

5.2 Soil C_{org} stocks and accumulation rates in The Philippines seagrass ecosystems

Soil C_{org} Stocks

The mean soil C_{org} stocks showed significant differences among sites, but only in the top 100 cm (Figure 9, Table 3). The C_{org} stock in New Barbacan, which was impacted by fishing and boating activities was 95.9 ± 9.6 t C_{org} ha^{-1}, significantly higher than Tumarbong (50.9 ± 7.0 t C_{org} ha^{-1}). New Barbacan has the highest dry bulk density among all sites (Figure 12) possibly contributing to the high C_{org} stock value in the top 100 cm of sediment. The higher stock found in New Barbacan could indicated that the degree of fishing and boating activities happening at the site are not strong enough to affect the C_{org} sequestration capacity of the seagrasses. Finally, the high C_{org} stock may reflect terrestrial soil inputs and/or discharges of organic waste into the bay from the adjacent village. Stable isotopes have been used to estimate the proportion of allochthonous carbon in seagrass soils (Kennedy et al. 2010), and could be used to help to confirm the source of carbon at Barbacan. While originally planned to be part of the study, stable isotopes analyses could not be analysed due to the inability to export the samples in a timely manner because of the difficulties in obtaining the appropriate export permit.

On the other hand, the control site (Tumarbong) is characterized by seagrass patches which, even if dense, could not have the same capacity of accumulating C_{org} than a continuous meadow, resulting in a general lower C_{org} stock than other sites, including the two sites impacted by sedimentation. As several factors can affect the C_{org} sequestration capacity of the seagrasses (Mazarrasa et al. 2018), reasons for the lower stocks found in the reference site could be related to site-specific characteristics (e.g., unknown impact, higher hydrodynamics, lower amount of fine particles at the site) that would need to be further investigated.

The C_{org} stock in San Nicolas and Minara were not significantly different to either of the other sites. San Nicolas and Minara sites are both affected by sediment deposition coming from the San Nicolas River but to different degrees, with San Nicolas receiving more sediment input than Minara. However, this difference in sediment input was not reflected in the C_{org} stocks, which were similar (71.3 ± 8.4 and 61.1 ± 11.4 t C_{org} ha^{-1}, respectively), indicating that the difference in sediment deposition were not affecting the C_{org} store capacity of the sites. While in Minara cores were collected within the seagrass meadow, in San Nicolas, where seagrasses have been lost, the cores were collected in the bare sediment, which used to be previously vegetated. The high degree of sediment deposition at this site may compensate for the absence of the seagrass meadows allowing a similar amount of C_{org} to be stored in the sediment.

The C_{org} stocks reported in this report for the top 30 cm are in the range of those reported in the literature (Table 1), except for the reference site (Tumarbong) C_{org} stock which is lower than previously reported healthy and disturbed seagrass soils. C_{org} stocks for the top 100 cm in Roxas (71 ± 19 t C_{org} ha^{-1}; Table 3) were more variable than the only other mean value provided in the literature for 1 m stocks (80 ± 15 t C_{org} ha^{-1}; Table 1). However, all data on soil C_{org} 1 m stock available at the moment are below the global mean reported for seagrasses of about 140 t C_{org} ha^{-1} (Duarte et al. 2013). As data have been reported only for few areas in The Philippines it is possible that the C_{org} stock variability in the country has not been fully described yet. More studies on seagrass C_{org} soil stock are needed to fill this gap.

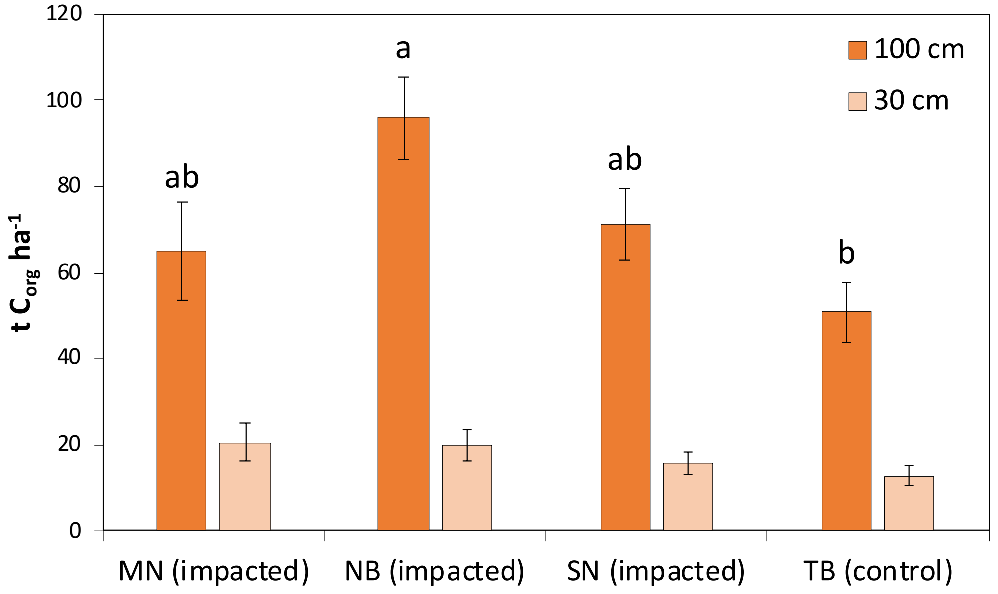

Figure 9. Mean (± SE) organic carbon (C_{org}) stocks in 30 cm and 100 cm-thick soil seagrass deposits collected in The Philippines. The organic carbon values were estimated from the Loss on Ignition data by applying the correlation equation reported in Fourquearan et al. (2012). MN: Minara, NB: New Barbacan, SN: San Nicolas, TB: Tumarbong. Different letters indicate significant differences in C_{org} stocks among sites. When letters are not reported significant differences were not detected

Table 3. Soil C_{org} stocks in Roxas seagrass ecosystems. MN: Minara, NB: New Barbacan, SN: San Nicolas, TB: Tumarbong

Ecosystem	Location	Species	**Soil C_{org} stock** (t C_{org} ha^{-1}) 30 cm Mean	30 cm SE	100 cm Mean	100 cm SE
Disturbed (fishing and boating)	MIN	Mixed species dominated by *E. acoroides*	20.6	4.6	65.1	11.4
Disturbed (low sedimentation)	NB	Mixed species dominated by *E. acoroides*	19.7	3.7	95.9	9.6
Disturbed (high sedimentation)	SN	Bare sediment (once vegetated)	15.6	2.7	71.3	8.4
Reference	TB	Mixed species dominated by *E. acoroides*	12.8	2.2	50.9	7.0

C_{org} accumulation rates

Comparing soil C_{org} stocks over comparable depths is not always the most appropriate approach for understanding differences in C_{org} sequestration capacity among seagrass sites. Ideally, comparisons of C_{org} accumulation should be made over comparable periods of time, providing an understanding of the rate at which carbon is being accumulated at a site. Comparison of stocks over depth do provide important information, particularly the amount of C_{org} that could be lost if disturbance of the sedimentary deposit to a certain depth would happen. However, data on C_{org} accumulation rates are essential to provide a full BC assessment and data which are typically essential for carbon verification schemes.

Unfortunately, for the seagrass cores analysed from each of the four study sites, short-term soil accumulation rates (based on ^{210}Pb) could not be determined as there was an absence of excess ^{210}Pb, suggesting a lack of soil accumulation at the sites or the sediment which is accumulating is remobilised, older sediments. Detailed results of the ^{210}Pb analyses are presented in Appendix B. ^{14}C data can provide long-term soil and carbon accumulation rates (i.e., thousands of years), which are typically lower than short-term (i.e., last 100 years) accumulation rates. Short-term accumulation rates, reflect the contemporary conditions at a site and, therefore, are more appropriate when estimating current carbon accumulation rates. However, in the absence of short-term accumulation rate a long-term accumulation rate can still provide valuable information on carbon accumulation at the sites, even if on a different time scale. However, in this case, the delay in obtaining the appropriate export permits prevented the analysis of radiocarbon (^{14}C) in the cores so that neither short-term norr long-term accumulation rates could be determined. On a ore positive note, the samples collected by C3 are still available for ^{14}C analysis should the relevant export permit be obtained. Given the absence of any other seagrass carbon accumulation rates or The Philippines, and the critical nature of these rates for carbon project verification purposes, it is strongly recommended that the samples be retained and analysed if and when the opportunity arises. The carbon accumulation estimates would eb a significant value well beyond the SES project.

The difficulty in obtaining reliable age-depth models from seagrass soils using radionuclide methods is not uncommon (Lafratta et al. 2020), though under appropriate conditions can be successfully applied with the significant benefit of providing immediate rates of soil accumulation that integrate over decades or centuries periods (Arias-Ortiz et al. 2018). Where the method cannot be applied, an alternative approach is to directly measure soil accumulation using surface elevation tables or elevation rods. While elevation rods have the advantage of providing a direct measure of soil accumulation rates, they have some disadvantages: it may take several years to obtain a reliable estimate of soil accumulation; they are prone to being disturbed; and they can be difficult to establish and to re-sample in sub-tidal seagrass meadows. For these reasons, elevation rods are not commonly applied in seagrass BC studies. Nonetheless, the outcomes of the Roxas case study suggests that this approach should be pursued for future BC assessments in the region, with pilot studies to address some of the concerns with the method. Surface elevation rods were not established at the Roxas study sites due to logistical constraints on the National Partner. Installing and measuring the rods over time should be a priority for future activities at the sites, with measurements to be taken on a 6-monthly to one-year cycle. Carbon accumulation rate has never been reported for seagrasses in The Philippines and therefore pursuing the application of alternative methods and additional analyses (e.g., ^{14}C) would be extremely valuable.

5.3 Potential for carbon abatement

The C_{org} stocks for the Roxas seagrass sites have been reported for both the top 1 m and the top 30 cm of soil. For this study, the top 1 m stocks was used to assess the potential for abatement of CO_2 emissions through management of seagrass habitat. The top 1 m has been used globally as a reference depth to report BC stocks and assess abatement potential on the basis that this captures the depth of soil likely to be disturbed following seagrass canopy loss.

The differences in soil C_{org} stocks between the sites indicates a potential for avoided greenhouse gas (GHG) emissions in the seagrass ecosystems. Due to the absence of any C_{org} accumulation rates, it is not possible to estimate the potential abatement through enhanced sequestration (e.g. restoration or creation of a seagrass site). The potential for avoided emissions can be estimated in different ways. We took the total stock of C_{org} in the top 100 cm of soil at a site and assumed that any disturbance causing this C_{org} to be lost from the site would result in its exposure to oxygen and a portion of it would be remineralised. This approach has been used previously and is heavily dependent on the assumed proportion of carbon which is remineralised, which typically has been estimated to range between 0 and 100% (Pendleton et al. 2012, Arias-Ortiz et al. 2018, Serrano et al. 2019, Salinas et al. 2020). Here, to be conservative, we assumed that 25% and 75% of the carbon is ultimately remineralised and present the potential emissions as a range. Another approach could have been to compare the stocks at an undisturbed site and an appropriate disturbed comparison site, assuming that the undisturbed site was representative of the original condition of the disturbed site. However, as the C_{org} stock in the reference site was lower than any of the stocks in the disturbed site, this approach could not be used for the Roxas region.

Using the first approach, the undisturbed sites Tumarbong had mean soil C_{org} stock of 51 t C_{org} ha^{-1}. Assuming all this stock was lost due to disturbance and subsequent soil erosion, and that 25 – 75% of the lost C_{org} was then remineralised, the potential emissions would range from 13 to 38 t C_{org} ha^{-1} (or 47 – 140 t CO_{2-e} ha^{-1}).

The data generated through this study, together with published estimates of C_{org} stocks in The Philippines's seagrass meadows, can be applied to illustrate the potential C_{org} stocks and abatement opportunities at a national scale. For illustrative purposes, we provide a first-order estimate of the potential stocks in The Philippines's seagrass and the potential annual emissions associated with seagrass loss. In 2020, the estimated extent of seagrass in The Philippines was 14,923 km^2 (Fortes 2022). Assuming (rather boldly) that the stocks for undisturbed meadows reported in this assessment of Roxas, and those summarised in Table 1, are representative of good condition meadow, then the seagrass meadows of The Philippines are estimated to contain between 76 and 119 Mt of C_{org} in the top 1 m of their soils, equivalent to 279 to 438 Mt of CO_{2-eq} (Table 4). Conservation of these meadows will ensure this carbon is not emitted to the atmosphere and will continue to assimilate additional CO_2 over the years. In contrast, the losses of seagrass meadow estimated at 2.62% or 391 km^2 yr^{-1}, could potentially have resulted in an emission of 6.8 to 10.6 Mt per year of CO_2, assuming all the carbon in those meadows were remineralised (
Table 5). These estimates clearly indicate the significantly higher abatement gains to be made by avoiding losses of seagrasses meadows through effective management, including conservation, rather than attempting to restore them.

Table 4. Illustrative estimates of potential soil C_{org} stocks for Philippines's seagrass meadows. Estimates are based on reported extent of Philippines's seagrass meadows and the C_{org} stocks reported here. * from Fortes (2021); # from data in Tables 1 and 5**.**

Seagrass Area* (km^2)	Stock# (kg C_{org} m^{-2})	Total Stock ($Mt\ C_{org}$)		Total Stock (Mt CO_{2-eq})	
		Min	Max	Min	Max
14,923	5.1 – 8.0	76	119	279	438

Table 5. Potential annual emissions from Philippines's seagrass meadows based on available reported losses. * From DMCR (2019); #from **Table 1** and **Error! Reference source not found.**.

Habitat loss* (km^2 y^{-1})	Stock# (kg C_{org} m^{-2})	C_{org} at risk of remineralisation (Mt C_{org} y^{-1})		Potential CO_2 emissions (Mt CO_{2-eq} y^{-1})			
				50% remineralisation		100% remineralisation	
		Min	Max	Min	Max	Min	Max

361	5.1 - 8.0	1.8	2.9	3.4	5.3	6.8	10.6

The national-scale estimate presented above necessarily uses values for C_{org} stocks and seagrass extent which have significant uncertainty associated with them, given the limited knowledge on all these variables. Furthermore, the above estimates are based on the C_{org} stocks measured at a limited number of locations in The Philippines and it is therefore unclear how representative these are of other seagrass meadows in the region or The Philippines as a whole. Therefore, the estimated potential abatement should be taken as first-order estimates provided here for illustrative purposes. As more data are collected for Philippines' seagrasses, these estimates can be improved.

5.4 Methodological issues for BC assessments and methods (Lessons learnt)

The four SES case studies, including that undertaken in The Philippines, have provided valuable insights into two methodological issues associated with determining C_{org} stocks and accumulation rates (CAR), which could affect the capacity to implement future BC projects by NGOs working in the region. These relate to the determination of sediment, and therefore, carbon, accumulation rates using either radioisotope methods or SETs, and the second relates to the use of organic matter as a proxy for determining the organic carbon content of soils. Below is an outline of the findings and consideration of their implications for future BC assessments and method development.

Determining Carbon Accumulation Rates

Most carbon crediting schemes and inventories require a measure of the change in C_{org} content of a soil (and/or biomass) over time. This typically involves either dating the soil using radioisotope techniques (Arias-Ortiz et al. 2018) or directly measuring accumulation using surface elevation tables (SET) or a similar method (Cahoon & Turner 1989, Webb et al. 2013). Radioisotope dating methods (e.g. ^{210}Pb and ^{14}C) allow relatively rapid assessment of the carbon accumulation rate with a one-off sampling. However, the successful application of these methods depends on the accumulation of radioisotopes within the soil and lack of subsequent mixing of the soil, which does not always occur in dynamic coastal environment. SETs or horizon marker rods are used to directly measure the change in soil height relative to a fixed depth marker. These have the advantage on no dependence of radioisotope accumulation or lack of mixing. On the other hand, it may require years or decades to gain a reliable estimate of the soil accumulation rates using SETs. Furthermore, they are rarely applied in seagrass habitats where it is difficult for divers to take measurements without themselves disturbing the surface.

This study attempted to apply radio-isotope (^{210}Pb or ^{14}C) methods to determine soil accumulation rates. Application of the ^{210}Pb method to determine accumulation rates over the past 100 or so years was unsuccessful. This poor return on an expensive and time-consuming investment is not uncommon in seagrass ecosystems (Lafratta et al. 2020) and argues for the wider use of direct measurement of sediment elevation. Due to the limited duration of the SES project, it was not possible to determine accumulation rates from the elevation rods which were deployed in Malaysia, Indonesia and Thailand, but this is something that can be evaluated by the National Partners in the future, following a period of 6-monthly rod measurements. An important finding of the assessment was that, in many of the intertidal sites, the surface elevation rods were removed by locals who saw value in the metal rods (stainless steel or brass). Finding ways to work with the communities to protect the rods will be critical if this approach is to be used in the future. In The Philippines it was not possible to install the rods but we highly recommend the C3 to plan this for the future.

Findings from this study lead to three important conclusions:

1. not all sites are suited to the use of radioisotope techniques for estimating carbon sequestration rates;
2. further trials are required to assess the reliability of using elevation rods to make direct measurements of net sediment accumulation; and
3. current carbon accounting and crediting methods (Hiraishi et al. 2013, Verra 2023) require demonstration that the GHG emission reductions are real, measurable and permanent, and the inability to calculate rates of carbon accumulation or to date soils can make it difficult to show this. Consequently, careful assessment of potential sites should include an assessment of the soil accumulation dynamics to determine whether the site is suitable for the intended project method and thereby, management actions can result in carbon abatement.

Methodological issues with determining %C_{org} using %LOI

Loss on Ignition (LOI) is commonly used to estimate the organic content of a soil. It is not uncommon in BC studies to use the relationship between LOI and C_{org} (Fourqurean et al. 2012, Howard et al. 2014) to estimate the C_{org} content of a soil when only LOI data are available, when financial constraints limit the number of C_{org} analyses that can be performed, or when there is no access to an elemental analyser. This is exactly what happened in The Philippines, where no facility to analyse C_{org} was available in the country forcing C3 to seek approval to export the samples overseas. Unfortunately this process took longer than expected and when samples reached the analytical facilities it was too late to analyse them within the time frame of the project and forcing the use of global relationship to calculated C_{org}. In other countries within this project, to estimate soil C_{org} content in the cores based on LOI, this study attempted to generate site-specific relationships between LOI and C_{org}. While in Malaysia a relatively strong relationship was found, in Thailand the relationship was weak and there were significant uncertainties for the C_{org} data, forcing the project to rely on the relationship in Fourqurean et al. 2012) in several instances.

The poor relationships (i.e., Thailand) could be due to errors in the sample analysis or highly unusual soil characteristics which introduce artefacts into the analyses of LoI, C_{org}, or both, for example: 1) the loss of acid-soluble organic matter and the heat generated during carbonate reaction with acid, i.e. hydrolysing organic matter, during acidification can lead to an underestimation of C_{org} content (Roberts et al. 1973, Heath et al. 1977, Froelich 1980); and 2) the loss of inorganic compounds (e.g. carbonates) during the LOI combustion can lead to an overestimation of organic matter, hence C_{org} content (Wang & Li 2011).

Findings from this study indicate that:

- the inclusion of LOI–C_{org} correlations in a BC methodology should be done with caution. The appropriateness of using such relationships should be determined on a site-by-site basis;
- Despite the relatively simple techniques involved in estimating LoI, some National Partners had difficulty performing these, either through difficulty in accessing appropriate facilities, or in misunderstanding of the protocol (not helped by the inability to provide face-to-face training due to COVID travel restrictions); and
- Some of the laboratories used to conduct elemental analysis of C_{org} returned quite variable results, suggesting some quality assurance issues.

This emphasises the need to use appropriate laboratory facilities to support NGOs for undertaking soil carbon analyses, rather than relying on the NGOs to undertake these analyses themselves. Despite the laudable goal of building capacity within the NGOs, it was clear that none of the partners had the expertise or facilities necessary to undertake the full range of analyses and, in some instances, those facilities were not available within their country to outsource the analyses.

The generation of reliable soil C_{org} data is central to the BC assessment and the uncertainties regarding the data from some of the sites reduces confidence on the assessments. In future, a more efficient approach will be for NGOs to collect and process the samples but use appropriate laboratories to undertake the chemical analyses and provide the results to the NGO for interpretation.

Permits

Several of the SES Project case study sites experienced significant difficulty in implementing the assessments because of permitting issues. These related either to:

- Processing system to obtain the supporting documents for the project implementation
- Permits to undertake field work to collect soil samples; or
- Permits to export soil samples for chemical analysis.

The first issue was typically resolvable but in once instance required several months to gain the permits despite vigorous efforts on the part of the NGO partner. By the time the permit was issued, the field sampling season had been missed, causing about a one-year delay in the assessment. The second issue was more problematic, in that some governments (e.g., Indonesia) required permits to export either samples or data for analysis. If those countries have analytical facilities that NGOs can use on a collaboration or fee-for-service basis, then this is not a significant issue as the samples can simply be analysed in-country. However, as in the case of Indonesia, there were no facilities within the country to conducted either the elemental carbon analyses or the ^{210}Pb analyses. While the samples could easily have been analysed by the Technical Partners, it took almost 3 years to work through the permitting process and, ultimately, this was not resolved by the end of the implementation phase of the project. Consequently, there was a much-reduced data set for some countries, including The Philippines, despite the significant efforts of the NGO partner.
The permitting system in the case of Palawan, Philippines is bound by the Strategic Environmental Plan for Palawan (Republic Act 7611), a lengthy process that has to pass by several government units to obtain the necessary consent/endorsements. In addition, the limited services of the Bureau of Soils in the Provinces added to the delays as the samples are subject for inspection and the export permit can only be issued by the central office located in Metro Manila, Philippines.

The lesson here is that it is critical to understand the permitting in-country requirements before commencing a BC assessment and that sufficient time needs to be allowed for obtaining those permits. In some countries this is not an issue. In others it can be an almost insurmountable obstacle and, in those cases, establishing relationships with agencies or other NGOs which have the necessary permits may be an effective strategy.

Training delivery

The SES Project was initially structured around in-country, face-to-face training sessions, for the Technical Partners to build capacity among the NGO partners. COVID-19 travel restrictions prevented several Technical Partners travelling during 2020-2022, requiring a shift in approach. For the BC assessments, training was provided through a combination of training videos which produced specifically for the project, and are now available as an online resources through the CMS's project webpage, and on-line instruction during sampling and laboratory activities.

The online training resources proved useful in allowing the NGO partners to collect the necessary samples and to undertake initial processing in the laboratory. However, the impact of no face-to-face training became apparent as the project developed: many small issues that arose in the field or laboratory were difficult to predict in advance and so were not covered in the instructional videos; other problems were not recognised by the NGOs and so errors were introduced into the various protocols. An illustration of this was the LoI protocol, which relies on accurate measurement of weight loss in sugar standards; several of the laboratories did not take this measurement, instead making a visual assessment that all the sugar was gone, which unfortunately is often misleading. Later in the project, it became apparent that the interpretation of the findings, and considering how the BC data can be applied in the policy or business context was a significant hurdle for some NGO. What could effectively be explained face-to-face in a two- or three-hours discussion proved almost impossible to convey using other approaches.

In short, the experience of the BC Technical Partners and all the NGO National Partners was that the lack of opportunity to hold the planned in-person workshops had a detrimental effect on both the efficiency and the quality of the outcomes of the BC assessments. While the outcomes are still valuable, there is no doubt that any future capacity building should prioritise in-person training.

6 Conclusions and Recommendations

- Healthy seagrass meadows in Roxas, Palawan region were found to have soil C_{org} stocks of about 51 ± 7 t C_{org} ha^{-1}, though other meadows, considered to be disturbed had higher stocks, up to about 96±10 t C_{org} ha^{-1} .
- Sediment deposition, at the range of intensities present across the two disturbed sites, did not seem to affect the C_{org} stocks of the affected sites (Minara and San Nicolas). Disturbance by fishing in New Barbacan does not seem to have reduce C_{org} stock.
- As ^{210}Pb analyses suggested negligible net sedimentation, a short-term C_{org} accumulation rate could not be provided for The Philippines' sites and, as ^{14}C could not be analysed, a long-term accumulation rate could not be reported either.
- The potential abatement associated with conservation of seagrass meadows in the region was estimated to be 47 – 140 t $CO_{2\text{-eq}}$ ha^{-1}.
- Reported losses of 361 km^2 of seagrass meadows per year in The Philippines were estimated to represent a potential emission of about 6.8 – 10.6 Mt $CO_{2\text{-eq}}$ y^{-1}.
- The values generated in this assessment for seagrass carbon stocks and potential carbon abatement through management, can inform decision makers and the broader community about the value of seagrasses, and can be used to make first order estimates of the potential abatement opportunity for seagrass BC projects in The Philippines, including those seeking carbon credits.
- The SES Project has successfully achieved the key objectives of:
  - Building capacity in the National Partners to undertake BC assessments,
  - Generating local data for application in policy contexts and to strengthen any future carbon crediting verification projects, including development of Tier 2 and Tier 3 carbon abatement projects; and
  - Identification of local partner organisations to assist the NGO partners in any future projects.
- The BC assessment saw the following activities completed as parts of Work Packages I, II, III and IV of the SES Project:
  - **Activity I.1:** Modify or develop new methodological tools for monitoring seagrass ecosystem services (carbon sequestration);
  - **Activity I.2:** Five trainings (one per site) provided to local stakeholders on assessment of seagrass status (BC status) – the trainings were provided through online instructional videos and a face-to-face workshop which all five National partners participated in;
  - **Activity I.4**: Data collection (BC) at all five sites, with community participation, to build on and integrate with any existing data concerning the location, extent, conservation, and SES of seagrass meadows and megafauna;
  - **Activity II.1**: SES (BC) data collection, analysis, and assessment at four sites to determine the different ways in which seagrass is providing value and what the loss of these services would cost;

  - **Activity II.2**: Five workshops (one per site) provided to local stakeholders on understanding assessment and valuation of key SES. Total of ≥50 community members. Due to COVID travel restrictions, the five workshops (one per site) were replaced with a single workshop to which all six of the project's NGOs participated;
  - **Activity IV.1**: Training to build capacity of stakeholders (decision-makers, Protected Area managers and NGOs) to utilise SES assessment and valuation. Training for the BC component was provided through a face-to-face workshop (Bogor, 2023) for all six project National Partners.

Recommendations

- **It is recommended that** the findings of this assessment be used to inform policy and seagrass restoration efforts in The Philippines.
  - The values generated in this assessment for seagrass carbon stocks, carbon accumulation rates and potential carbon abatement through management, can be used to inform decision makers and the broader community about the value of seagrasses, in particular their role in carbon abatement. This can be used to argue for the inclusion of seagrass ecosystems in the NDC, specifically the LULUCF sector. It can also be used to argue for the inclusion of seagrass projects in a range of government strategies that involve the conservation or restoration of marine and other vegetated habitats, particularly mangroves, for climate change mitigation. The data generated in this assessment can also provide an initial indication of the carbon credit potential of seagrass BC projects in the voluntary carbon trading market operating in The Philippines.
  - Achieving the above will be made far more possible if the NGO partners in the SES Project are provided ongoing support to consider the outcomes of the BC assessment in the policy context of their countries, and if they are able to work with partners experienced in the formulation and implementation of BC projects, due to the complexity of negotiating this emerging opportunity.

- **It is recommended that** the CMS assist C3 in completing the analysis of the seagrass soil samples collected during the SES for C_{org} for:
  - C_{org} content and carbon stable isotopes, to: 1) improve estimates of carbon stocks; 2) provide future capacity for local NGOs to apply a robust C_{org}: LoI relationship based on locally-derived data; and 3) to identify potential organic carbon inputs from villages which may account for the relatively high carbon stocks at these sites; and
  - Radio-carbon (^{14}C) dating of the cores, to estimate Carbon Accumulation Rates

  Both sets of analyses will place the National Partner in a better position to estimate BC opportunities, and develop BC projects under current verification schemes.

  The unanalysed samples held by C3 and ECU represent an extremely valuable opportunity to fill key knowledge gaps regarding Philippines' blue carbon resources, with benefit beyond the SES Project. The cost of implementing this recommendation would be modest compared to the investment already made in obtaining high-quality samples but would yield extremely valuable data.

- **It is recommended that future efforts to undertake seagrass BC assessment use the approaches, based on the experience gained during the SES Project:**
    - Further effort be applied to generate more robust Organic Carbon: Organic Matter relationships which can be applied to estimate carbon stocks from Loss on Ignition data;
    - NPs work collaboratively with local university/research partners to implement assessments, in particular the LoI and organic carbon analyses;
    - Effort should be made to equip the countries with suitable laboratories for analyses of organic carbon or additional training in the use of available equipment.
    - Direct measurement of soil accumulation rates be made using surface elevation rods, horizon markers or rSETs, rather than relying on radio-isotopic approaches. This will require pilot studies to overcome some of the difficulties associated with the use of rods such as removal by local communities; and
    - Future efforts to build capacity in seagrass ecosystem service (BC) assessment prioritise the inclusion of face-to-face field and laboratory techniques training.

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Appendix A. Methods - core collection, processing, and numerical procedure

Core collection and processing

At each site, four cores were collected using PVC pipes (7.5 cm inner diameter) by manual percussion and rotation. Compression during coring was assessed by measuring the length of the core protruding from the soil surface inside and outside the core (Glew et al. 2001). All results presented in this study refer to the decompressed depths (cm), unless indicated. Following retrieval, cores were sealed at both ends, transported vertically and stored at the C3 office until processing.

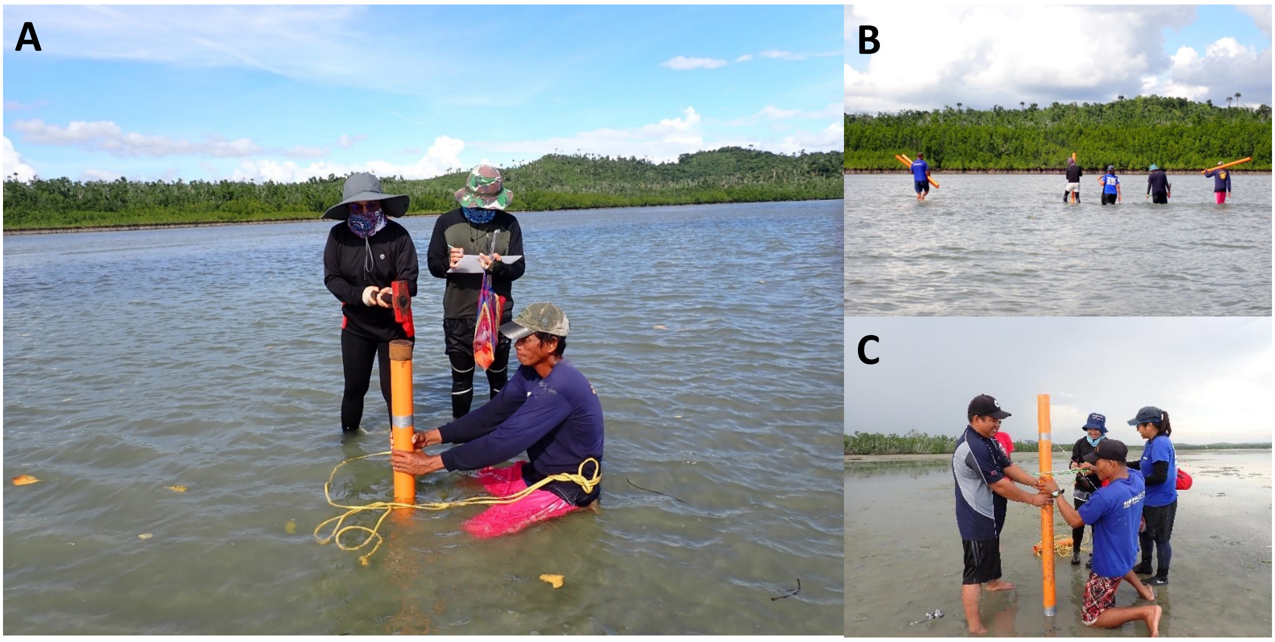


Figure 10. C3 team undertaking blue carbon core collection at the Minara (A) and Tumarbong (B and C) sites

The cores were sliced at 1 cm-thick resolution for the top 20 cm, and at 5 cm-thick intervals for the remainder (High Resolution, HR). For each soil slice, the wet weight (WW) was recorded prior to drying at 60°C until constant dry weight (DW) to estimate dry bulk density (DBD). The dried samples were homogenized and divided into sub-samples by quartering. The sub-samples were used for Organic Matter (OM) analyses as well as analysis for ^{210}Pb dating.

Organic Matter and Organic Carbon determination

Organic Matter (OM) was determined for every sediment slice on every core. This analysis was performed on one sub-sample of every soil slice which had been ground in a ball mill grinder. The OM of the ground soil samples was estimated in each slice of every core, with the intention of using the relationship between %OM and %C_{org} to interpolate the C_{org} values for slices along the core which had not been analysed for %C_{org} content, in order to calculate the accumulated C_{org} stocks (Fourqurean et al. 2012, Howard et al. 2014). OM content was estimated using the LOI method (Heiri et al. 2001, Kendrick & Lavery 2001) at Edith Cowan University (ECU) facilities by combusting 4 g of dry sample for 4 hours at 550 °C. All combustions included reference samples of pure glucose to correct for incomplete combustion of OM.

Age-depth chronology

To determine soil and C_{org} sequestration rates, one core from each site was dated by means of ^{210}Pb (short-term accumulation; last ~100 years) and radiocarbon (long-term). Concentrations of ^{210}Pb in the upper 20 cm were determined through the quantification of its granddaughter ^{210}Po activity by alpha spectrometry, assuming radioactive equilibrium between the two radionuclides (Sanchez-Cabeza et al. 1998). When sand content was high (in most seagrass scores), the soil samples were sieved (<63 µm), and <63 µm fraction was analysed for ^{210}Pb. 200 mg aliquots of each sample were spiked with a known amount of ^{209}Po and microwave digested with a mixture of concentrated HNO_3 and HF. Boric acid was then added to complex fluorides. The resulting solutions were evaporated and diluted to 100 mL with 1 M HCl, and polonium isotopes were auto-plated onto pure silver disks. Polonium emissions were measured by alpha spectrometry using Passivated Implanted Planar Silicon, PIPS detectors. Reagent blanks were run in parallel and found to be comparable to the detector backgrounds. Supported ^{210}Pb (^{226}Ra) was analysed by ultra-low background liquid scintillation counting (Masqué et al. 2002). The concentration profile of excess ^{210}Pb was determined by subtraction of ^{226}Ra from total ^{210}Pb concentrations along the core (Appleby & Oldfield 1978, Masqué et al. 2002).

Radiocarbon was not analysed in any of The Philippines cores, due to difficulties in obtaining the export permit in a time manner and subsequent delay in shipping the samples to external facilities.

Surface elevation tables (SETs)

Surface elevation rods were not deployed at any of the Roxas sites. However, we recommend installing them in the future. At each site, four stainless rods (5 mm-thick 1.8 m long) should be driven into the soils to a depth of 1.2 m, leaving 60 cm above the sediment surface. The rods should be located either along a single line or in circle, separated by 5 m from each other. The distance between the top of the rod and the sediment surface should be measured (60 cm for all rods on the first occasion). To avoid any influence of depression holes around the edge of the rod, a washer should be carefully lowered down around the rod and placed on the sediment surface to provide a flat platform for the rule to sit on.

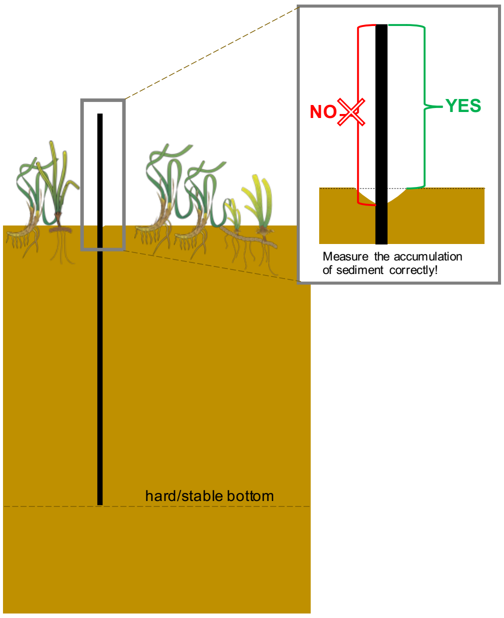


Figure 11. Schematic diagram shows how rods are installed and the measurement approach.

Numerical procedures.

The CF:CS model (Krishnaswamy et al. 1971) was used to estimate the average soil accumulation rates (SAR) for the last century, where possible (Appendix B for details). When good chronostratigraphy of both the radiocarbon-aged section of a core and the ^{210}Pb-derived ages were available , we combined the ages using the R package Bacon, which applies Bayesian statistics as an approach to age-depth modelling to reconstruct accumulation histories (Blaauw & Christen 2011). For cores where accumulation rates could not be determined (i.e., the core was mixed) we applied the accumulation rate of the replicate core, if available, or an average accumulation rate (Mean ± SE) for that specific habitat. When ^{210}Pb analyses revealed no net accumulation of soil (i.e., no excess ^{210}Pb) an accumulation rate was not applied to that particular core.

Accumulated soil C_{org} stocks in each core were calculated for 30 cm and 100 cm thick soil deposits using the DBD (g cm^{-3}) and the %C_{org}. Because C_{org} was not analysed in every sample along the depth of the cores, the missing C_{org} values were interpolated using the C_{org} content of the two adjacent analysed samples in order to calculate the accumulated soil C_{org} stocks. The relationship between %OM and %C_{org} was inconsistent among cores and, in some cases, among sections of the same cores (**Error! Reference source not found.**), therefore, we did not apply the relationship to estimate %C_{org}.

For cores shorter than 100 cm we extrapolated the soil C_{org} stock up to 100 cm-thick using a polynomial correlation between depth and C_{org} stock of the section of the core where the change in soil C_{org} stock with depth was constant. We validated this approach on a number of long (>1 m) cores; for these cores we used the data from the top 50 cm only and then extrapolated the carbon stocks to 1 m using the above approach. We then compared the measured (real) stocks to 1 m with those estimated by extrapolation. In all cases, the correlation between extrapolated and measured C_{org} stocks was significant ($p<0.001$; $r^2 = 0.96$).

Total soil C_{org} stocks in The Philippines were calculated by multiplying the average ± SD soil C_{org} stocks of the reference sites and undisturbed meadows reported in available literature by the ecosystem area.

We tested for statistically significant differences in %C_{org}, DBD and soil C_{org} stocks (in 30- and 100 cm-thick soil deposits) among BC ecosystems. Because the data were not normally distributed, had outliers and/or the sample size was not homogeneous among groups we applied a Kruskal–Wallis test followed by Dunn's multiple post-hoc test. To test for differences in the soil C_{org} stocks among disturbed and undisturbed sites, we applied a one-way ANOVA (one test for seagrass and a separate test for mangroves), because the data were normally distributed, outliers were absent, and the variances were homogeneous.

Appendix B. ^{210}Pb dating of sediment cores: IKI-funded SES Project - Philippines

^{210}Pb dating of sediment cores – IKI Project - Philippines

Prof Paul Lavery and Dr Anna Lafratta (Edith Cowan University)

by

Pere Masqué

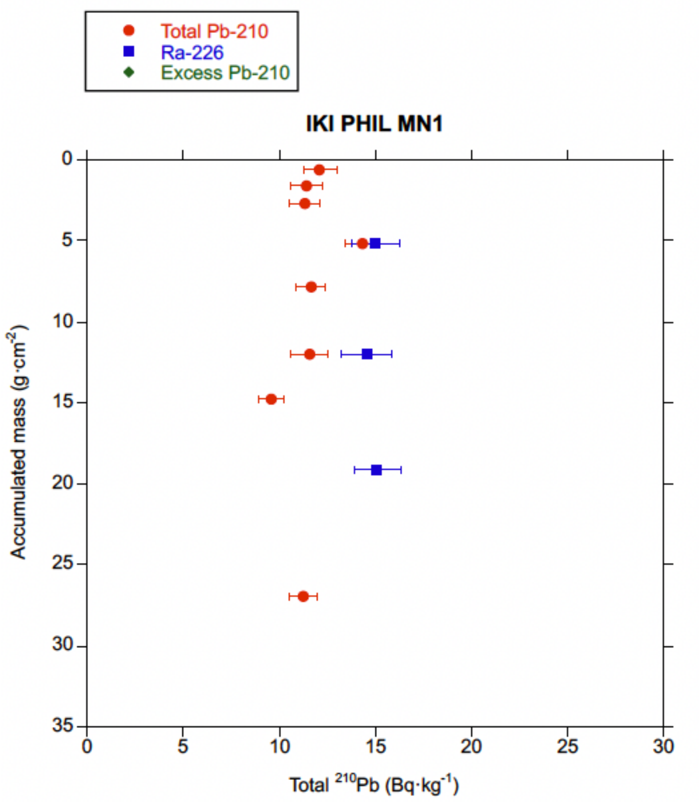
Edith Cowan University (Australia)

October 2023

- We received samples of 3 sediment cores collected in 2022 from several seagrass sites in The Philippines for the analysis of Pb-210 to determine the sediment accumulation rates during the last decades/century where possible.
- The sediment cores had been sliced every 1 cm (upper 20 cm) and 5 cm (below 20 cm) and dried.
- ^{210}Pb was determined through the analysis of ^{210}Po by alpha spectrometry after addition of ^{209}Po as an internal tracer and digestion in acid media using an analytical microwave[i]. Some samples from each core were gamma spectrometry to determine the concentrations of ^{226}Ra. The concentrations of ^{137}Cs were determined where detected. The concentrations of excess ^{210}Pb used to obtain the age models were determined as the difference between total ^{210}Po and ^{226}Ra (supported ^{210}Pb).
- No correction for compression is applied in the following.
- Main observations and estimates of sedimentation rates for each site are provided below. An accompanying file (Report Pb-210 dating IKI Philippines.xlsx) contains all relevant data.

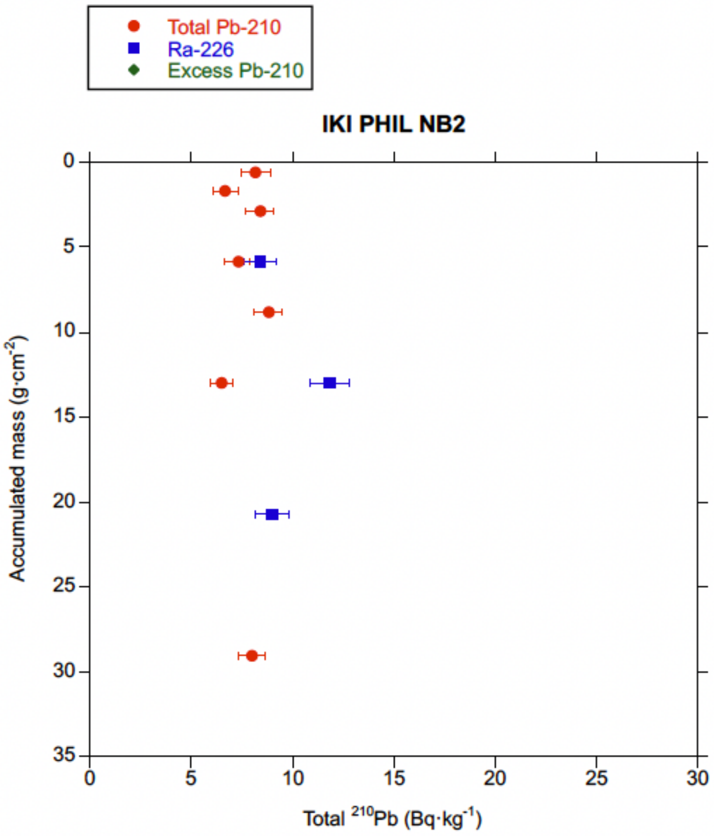
Minara – Core MN1 (impacted)

- The core was collected from an impacted site, described as "Colour is dark grey. Muddy/Silt in texture with very few/small shell fragments/small bivalve shell".
- Dry bulk density along the core was relatively high, between 1.4 and 1.8 g·cm^{-3}, although it was somewhat variable and lower in the upper layers. Fine contents (<63 µm) were 20-30% for most of the samples analysed. The analyses of ^{210}Pb were conducted on both the bulk and the finer fraction, while gamma spectrometry was carried out in the bulk only.
- The concentrations of total ^{210}Pb ranged from 10 to 14 Bq·kg^{-1} along the upper 20 cm, without any decreasing trend with depth. A similar pattern was obtained for the concentrations of total ^{210}Pb in the fines, with only slightly higher concentrations. The concentrations of ^{226}Ra measured at several depths averaged 14.9 ± 0.3 Bq·kg^{-1}. Therefore, there was no excess ^{210}Pb along the core, suggesting negligible net sedimentation during the last decades at this site.



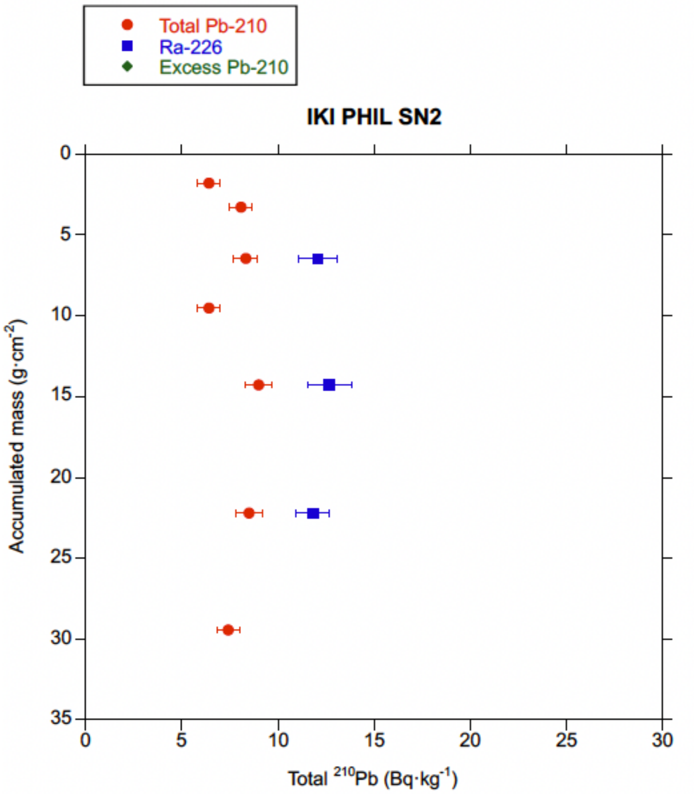
New Barbacan – Core NB2 (Impacted – fishing and boating)

- The core was collected from an impacted site, described as “fine sand and grey in colour”.
- Dry bulk density along the core was relatively high, of about 1.5 g·cm^{-3}. Fine contents (<125 µm) were >85% for most of the samples analysed. The analyses of ^{210}Pb were conducted on both the bulk and the finer fraction, while gamma spectrometry was carried out in the bulk only.
- The concentrations of total ^{210}Pb ranged from 7 to 9 Bq·kg^{-1} along the upper 20 cm, without any decreasing trend with depth. A similar pattern was obtained for the concentrations of total ^{210}Pb in the fines. The concentrations of ^{226}Ra measured at several depths averaged 9.7 ± 1.8 Bq·kg^{-1}. Therefore, there was no excess ^{210}Pb along the core, suggesting negligible net sedimentation during the last decades at this site.



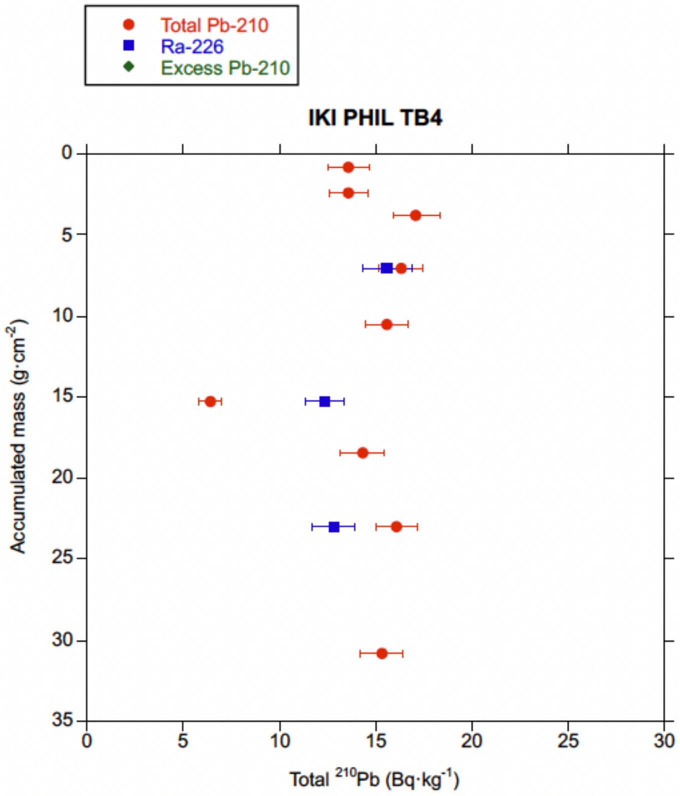
San Nicolas – Core SN2 (Heavily impacted)

- The core was collected from a heavily impacted site, described as "sandy, grey colour with small shells and fragments at a few layers".
- Dry bulk density along the core was relatively high, of about 1.6 g·cm^{-3}, with some variability in the upper 10 cm. Fine contents (<63 µm) were <10% for most of the samples analysed. The analyses of ^{210}Pb were conducted on both the bulk and the finer fraction, while gamma spectrometry was carried out in the bulk only.
- The concentrations of total ^{210}Pb ranged from 6 to 9 Bq·kg^{-1} along the upper 20 cm, without any decreasing trend with depth. A similar pattern was obtained for the concentrations of total ^{210}Pb in the fines, although with concentrations ranging from 18 to 21 Bq·kg^{-1}. The concentrations of ^{226}Ra (bulk) measured at several depths averaged 12.2 ± 0.4 Bq·kg^{-1}. Therefore, and while we couldn't measure the concentrations of ^{226}Ra in the fines because of the limited amount of sample available, we conclude that there was no excess ^{210}Pb along the core, suggesting negligible net sedimentation during the last decades at this site.



Tumarbong – Core TB4 (Control)

- The core was collected from a heavily impacted site, described as “Sandy-muddy, grey colour with shell fragments, bivalve shell, seagrass fiber”.
- Dry bulk density along the core was relatively high, of about 1.5 g·cm^{-3}, with some variability in the upper 20 cm. Fine contents (<63 µm) were <15% for most of the samples analysed. The analyses of ^{210}Pb were conducted on both the bulk and the finer fraction, while gamma spectrometry was carried out in the bulk only.
- The concentrations of total ^{210}Pb ranged from 6 to 9 Bq·kg^{-1} along the upper 20 cm, without any decreasing trend with depth. A similar pattern was obtained for the concentrations of total ^{210}Pb in the fines, although with concentrations slightly higher. The concentrations of ^{226}Ra (bulk) measured at several depths averaged 13.6 ± 1.8 Bq·kg^{-1}. Therefore, and while we couldn’t measure the concentrations of ^{226}Ra in the fines because of the limited amount of sample available, we conclude that there was no excess ^{210}Pb along the core, suggesting negligible net sedimentation during the last decades at this site.



References

Sanchez-Cabeza, J. A., Masqué, P. & Ani-Ragolta, I. ^{210}Pb and ^{210}Po analysis in sediments and soils by microwave acid digestion. (1998). Journal of Radioanalytical and Nuclear Chemistry, 227, 19-22.

Appendix D. Summary data for all seagrass cores sampled in The Philippines

Table 6. Summary of sampling location data, habitat type and soil C_{org} parameters for all cores collected in The Philippines seagrass habitat.

Core ID	Sampling date	Country	Site	Lat	Long	Type of site	Habitat	Species	max core depth	30 cm C_{org} stock	100 cm C_{org} stock
									cm dec	Mg C_{org} ha^{-1}	Mg C_{org} ha^{-1}
MN1	Nov-22	Philippines	Minara	119.3765	10.3433	impacted	seagrass	Mixed species dominated by *E. acoroides*	392	32.8	90.2
MN2	Nov-22	Philippines	Minara	119.3765	10.3433	impacted	seagrass	Mixed species dominated by *E. acoroides*	407	13.0	41.9
MN3	Nov-22	Philippines	Minara	119.3765	10.3433	impacted	seagrass	Mixed species dominated by *E. acoroides*	387	14.0	50.2
MN4	Nov-22	Philippines	Minara	119.3765	10.3433	impacted	seagrass	Mixed species dominated by *E. acoroides*	232	22.4	78.3
NB1	Nov-22	Philippines	New Barbacan	119.3622	10.3321	impacted	seagrass	Mixed species dominated by *E. acoroides*	266	14.0	97.7
NB2	Nov-22	Philippines	New Barbacan	119.3622	10.3321	impacted	seagrass	Mixed species dominated by *E. acoroides*	165	22.6	101.5
NB3	Nov-22	Philippines	New Barbacan	119.3622	10.3321	impacted	seagrass	Mixed species dominated by *E. acoroides*	180	13.4	69.5
NB4	Nov-22	Philippines	New Barbacan	119.3622	10.3321	impacted	seagrass	Mixed species dominated by *E. acoroides*	231	28.7	115.0
SN1	Nov-22	Philippines	San Nicolas	119.3985	10.3447	impacted	Bare (once vegetated)	-	322	7.9	64.8
SN2	Nov-22	Philippines	San Nicolas	119.3985	10.3447	impacted	Bare (once vegetated)	-	409	18.1	96.5
SN3	Nov-22	Philippines	San Nicolas	119.3985	10.3447	impacted	Bare (once vegetated)	-	396	19.9	62.5
SN4	Nov-22	Philippines	San Nicolas	119.3985	10.3447	impacted	Bare (once vegetated)	-	392	16.6	61.5
TB1	Nov-22	Philippines	Tumarbong	119.4169	10.3539	control	seagrass	Mixed species dominated by *E. acoroides*	429	14.4	48.7
TB2	Nov-22	Philippines	Tumarbong	119.4169	10.3539	control	seagrass	Mixed species dominated by *E. acoroides*	257	9.5	46.6
TB3	Nov-22	Philippines	Tumarbong	119.4169	10.3539	control	seagrass	Mixed species dominated by *E. acoroides*	417	8.9	37.7
TB4	Nov-22	Philippines	Tumarbong	119.4169	10.3539	control	seagrass	Mixed species dominated by *E. acoroides*	332	18.2	70.5

Appendix E. Statistical testing for difference in soil characteristics among Philippines seagrass sites

Table 7. Outcomes of statistical test for significant differences in soil carbon characteristics among the four seagrass BC ecosystems in Roxas, Philippines: soil C_{org} content (%), LoI, dry bulk density (DBD) (Kruskal-Wallis Test; A) and soil C_{org} stocks (ANOVA test; B) in the top 30- and 100- cm of soils.

A)

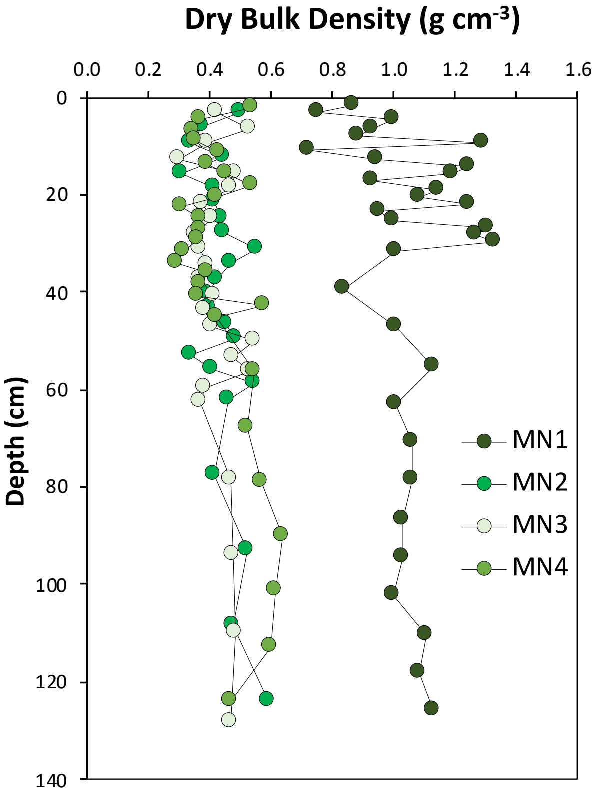
Parameter	K-W Test	Top 30 cm				Top 100 cm			
		SET	SIB JET	SIB TENG	PEN	SET	SIB JET	SIB TENG	PEN
DBD (g/cm³)	N	65	58	65	66	96	84	98	104
	Mean rank	157	40	178	125	200	66	273	208
	H-value	123				164.3			
	p-value	**0**				**0**			
LOI (%)	N	65	58	65	66	96	84	98	104
	Mean rank	180	134	69	128	290	200	92	188
	H-value	74				157			
	p-value	**0**				**0**			
Soil C_{org} content (%)	N	34	29	34	66	62	54	63	104
	Mean rank	130	113	20	76	236	186	34	128
	H-value	107				211			
	p-value	**0**				**0**			

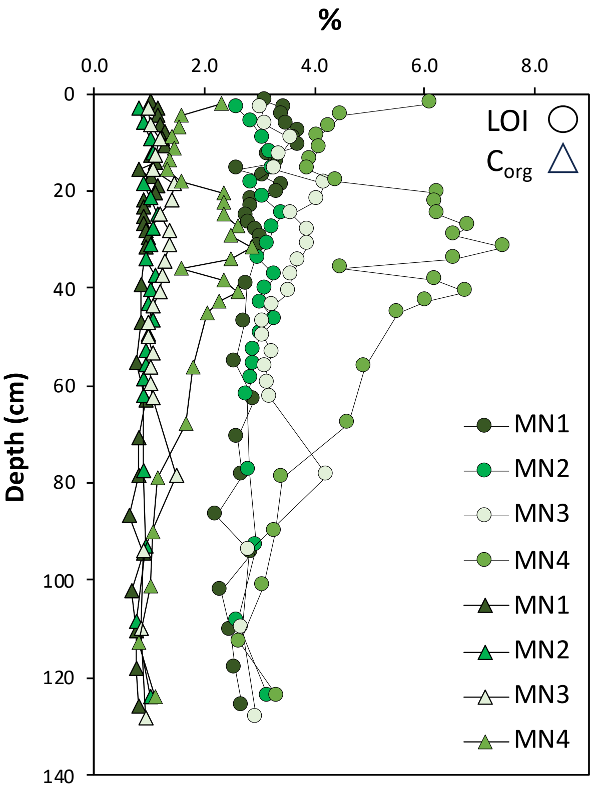
B)

Parameter	core section	one-way ANOVA				
		Sum of Square	df	Mean Square	F	*p* value
Soil C_{org} stock (Mg OC ha^{-1})	top 30 cm	38.878	3	12.959	30.243	< 0.00001
	top 100 cm	18.376	3	6.125	31.153	< 0.00001

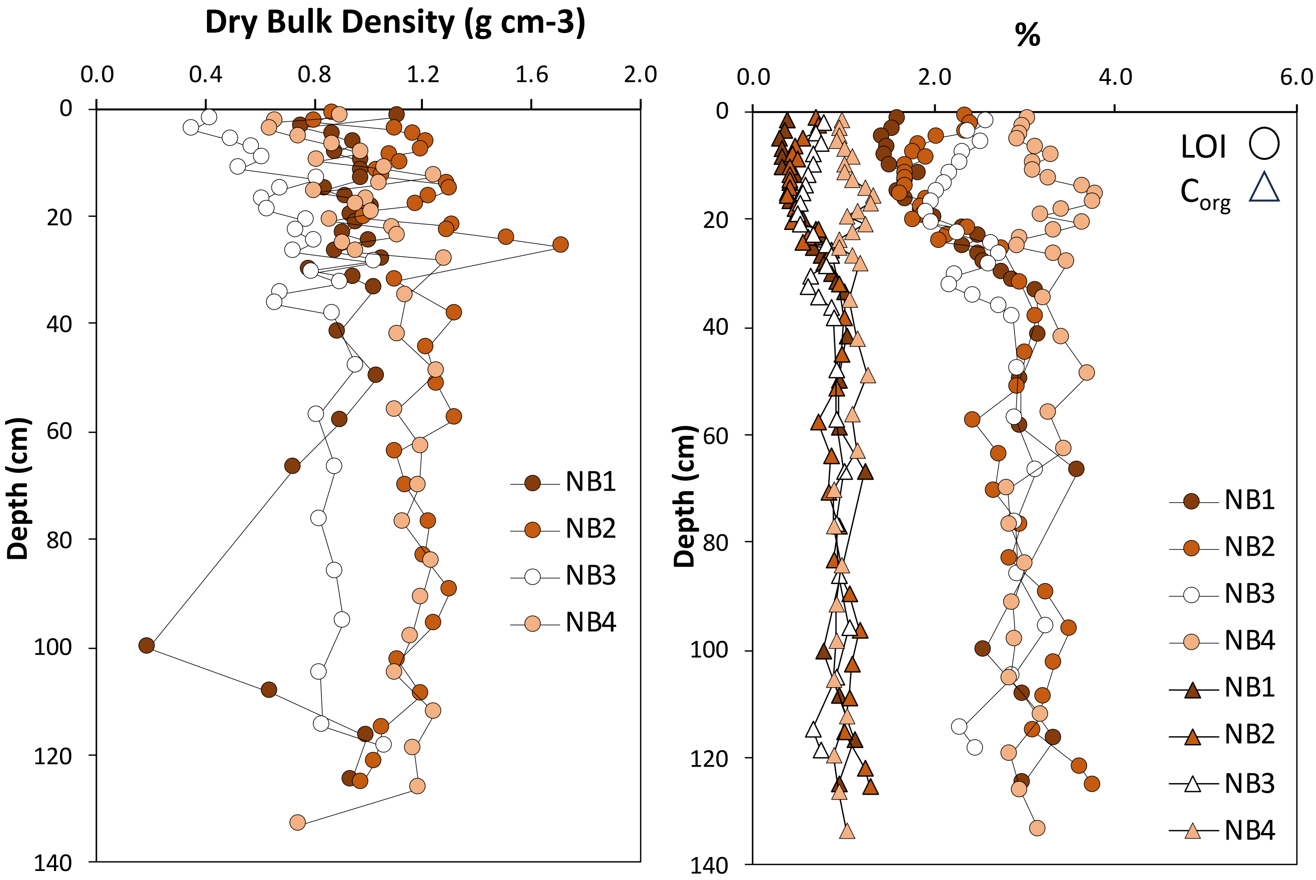
Appendix F. Seagrass soil characteristics profiles at the four Philippines sampling sites

a) Barangay Minara: impacted seagrass meadow

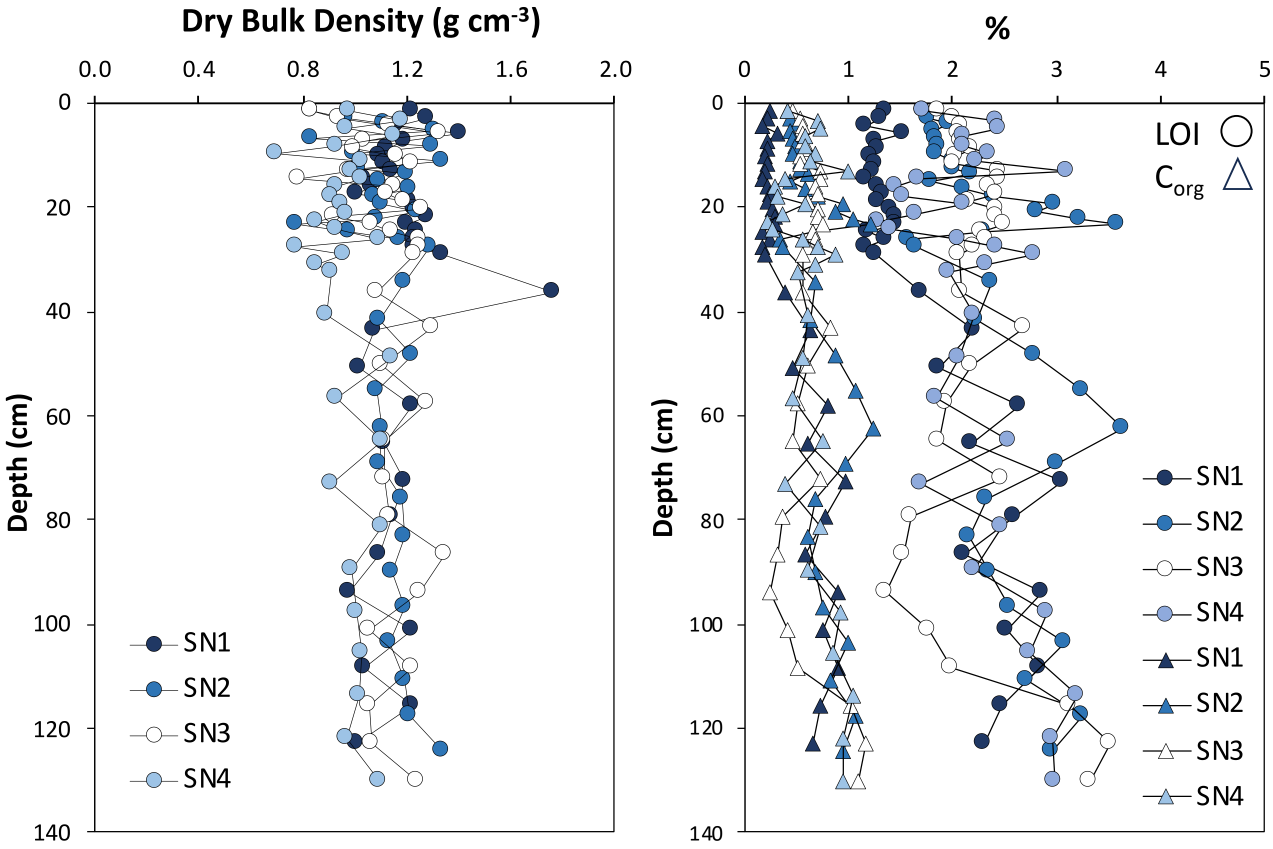




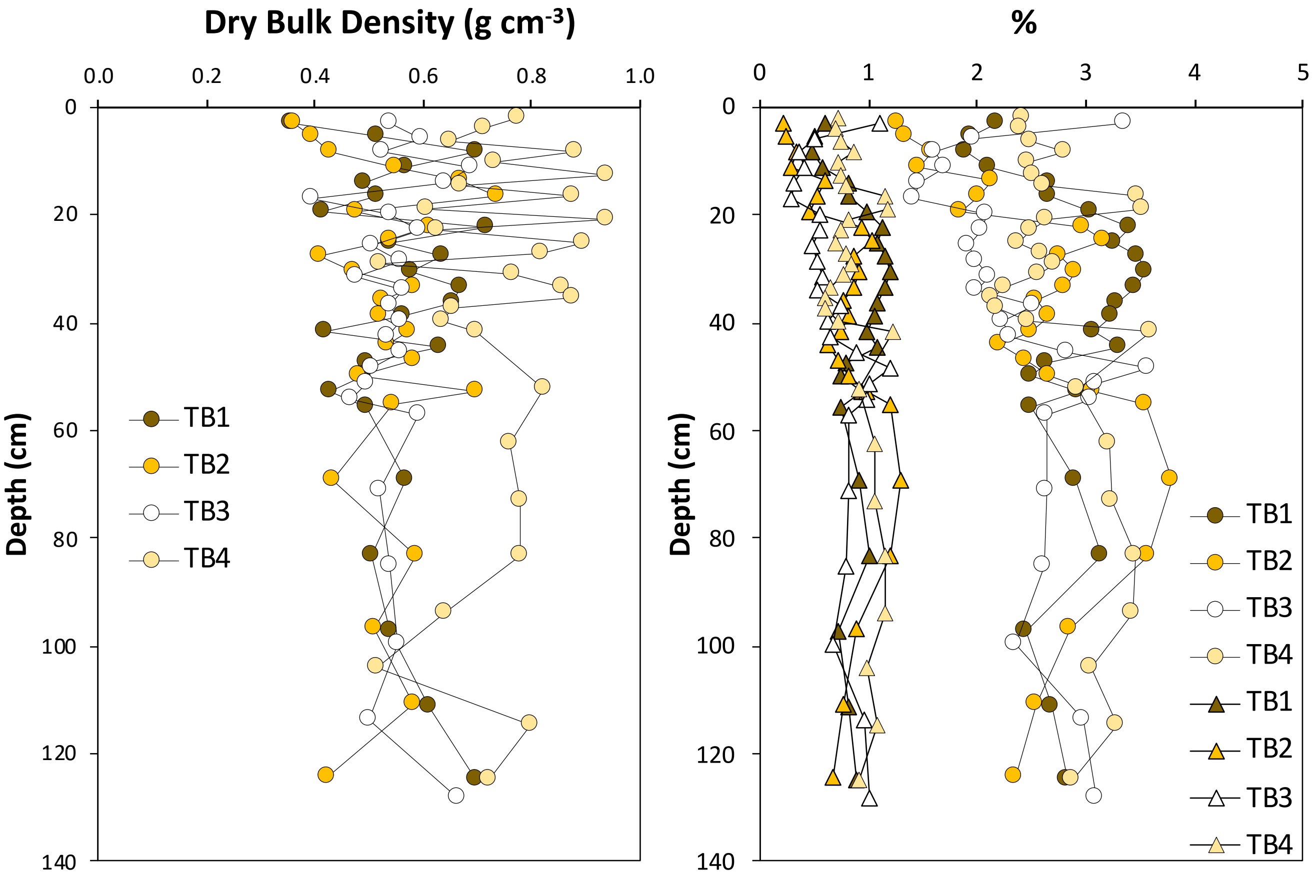
b) New Barbacan: impacted seagrass meadow



c) San Nicolas: impacted seagrass meadow



d) Tumarbong: non-impacted seagrass meadow



e) Mean data for the four Philippines sites

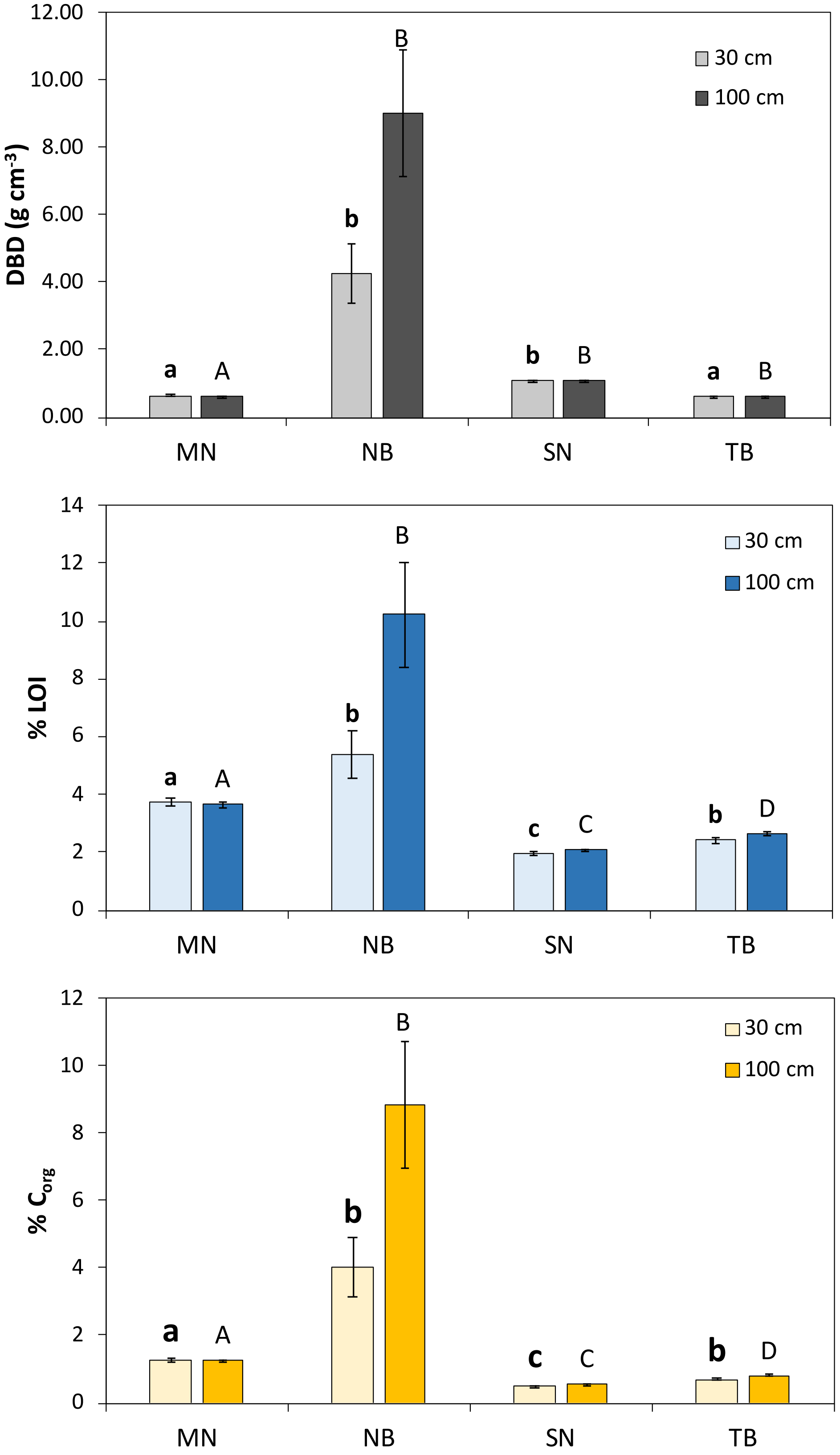


Figure 12. Mean (± s.e.) DBD, % LOI and % C_{org} in the top 30 and 100 cm of seagrass soil in The Philippines. MN= Minara; SIB NB= New Barbacan; SN= San Nicolas; TB= Tumarbong. Shared letters indicate no significant different ($p > 0.05$)

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