

ESTIMATION OF CARBON SEQUESTERED BY SEAGRASS TISSUES IN PASIL SANCTUARY, ILOILO, PHILIPPINES

Shella May A. Molicon, John Lester L. Bagaforo, Rogen A. Babiera, Dominic J. Leabres,
Johnbert L. Godio, Michelle B. Riego, Quin Y. Clarito and, Kyle F. Dalumpines*

College of Fisheries and Aquatic Fisheries, Iloilo State University of Fisheries Science and Technology

*Corresponding author: kyliechan76@gmail.com

Abstract

This study aimed to assess the carbon stock within the seagrass community of Pasil Seagrass Sanctuary, Barotac Nuevo, Iloilo. Key seagrass parameters measured included density, coverage, biomass, general health condition, and carbon stock. Biomass and carbon measurements were categorized into above-ground biomass (top) and below-ground biomass (bottom substrate). The carbon stock was quantified using the Loss on Ignition (LOI) method. The results revealed that the seagrass ecosystem in Pasil Seagrass Sanctuary was composed of five species: *Halodule uninervis*, *Halophila ovalis*, *Syringodium isoetifolium*, *Halophila spinulosa*, and *Halodule pinifolia*. Overall, the seagrass community was in a less healthy condition, with an average percentage cover of 43.06% and a density ranging from 253 to 1,539 shoots/m². The average above-ground biomass was 690.04 g/m², while the below-ground biomass averaged 893.49 g/m². Carbon stock measurements ranged from 8.96 to 48.91 g Corg/m² for above-ground carbon stock (AGCS) and 14.1 to 98.36 g Corg/m² for below-ground carbon stock (BGCS). These findings provide a valuable foundation for developing a database to analyze the potential of seagrass meadows as carbon dioxide (CO₂) repositories, contributing to efforts to adapt to and mitigate the effects of climate change.

Keywords: Biomass, Carbon stock, Climate change mitigation, Loss on Ignition (LOI), Seagrass community

INTRODUCTION

The seagrasses constitute a heterogeneous group of flowering plants angiosperms, adapted to grow and reproduce submerged in seawater, usually in shallow marine waters down to a depth where about 11% of surface light reaches the bottom (Duarte 1991; Orth *et al.*, 2006; Duarte and Gattuso, 2008).

They have reproductive organs (flowers and seeds, roots, rhizomes, stems and leaves as most terrestrial plants (Bjork *et al.*, 2008), and can be found on the coasts of every continent except Antarctica (Short *et al.*, 2007). The biodiversity of seagrasses, as well as their abundance and biomass increases towards the tropics (Short *et al.*, 2007), particularly in the Indo-Pacific region including the East African coast and islands of the WIO, where 14 seagrass species have been reported (Gullström *et al.*, 2002; Ochieng and Erftemeijer, 2003; Gullström *et al.*, 2006; Duarte *et al.*, 2012).

Seagrass occupies a relatively small area of the coastal oceans (~ 0.1- 0.2%) (Duarte 2002; Kennedy *et al.*, 2010; Fourqurean *et al.*, 2012) and yet, they play a large role in the coastal zone by providing several important ecosystem goods and services (Bjork *et al.*, 2008; Barbier *et al.*, 2011). Seagrass meadows supply food to mega-herbivores such as *dugongs*, sea turtles, sea urchins, manatees, water birds and herbivorous fish (Barbier *et al.*, 2011).

They provide breeding nurseries and feeding grounds to migratory and stationary fish and to other invertebrate organisms (Jackson *et al.*, 2001; Unsworth and Cullen, 2010). Seagrasses are

also ecosystem engineers, in the sense that they significantly modify the abiotic environment of their ecosystem (Jones *et al.*, 1996). For instance, seagrass leaves reduce hydrodynamic stress by attenuating currents and waves (van der Heide *et al.*, 2012), improve light conditions by trapping suspended sediment and nutrients (van der Heide *et al.*, 2007), and increase pH by absorbing CO₂ (Hendriks *et al.* 2014) creating favorable habitat to carbonate-associated organisms.

Like other plants, seagrasses utilize light energy and carbon dioxide to synthesize their own food, which allows them to grow and reproduce. Carbon fixation in seagrass leaves usually exceeds their immediate metabolic needs (Duarte and Cebrian, 1996), hence a large proportion of excess carbohydrate organic carbon is transported to the roots and rhizomes where it is stored, and eventually exuded in the sediment, forming anaerobic organic-rich soil (autochthonous). In addition, seagrass stems and leaves can trap and settle down suspended organic carbon from outside the meadows (allochthonous) from the water column (Mateo *et al.*, 2006; Fourqurean *et al.*, 2012; Howard *et al.*, 2016). This type of blue carbon can persist for millennia and can thus make seagrass meadows highly efficient in long-term carbon storage (Fourqurean *et al.*, 2012; Macreadie *et al.*, 2014; Howard *et al.*, 2016). The C_{org} accumulation in seagrass meadows is estimated to be 83 g C m⁻² yr⁻¹ (Duarte *et al.*, 2005). Its global carbon burial rates of 27–44 Tg C yr⁻¹ comprise 10–18% of the total carbon storage in the ocean (Kennedy and Björk, 2009; Kennedy *et al.*, 2010). However, the estimations of seagrass carbon budgets are highly variable as they depend on the species considered, the local environment and time of the year, as well as the associated epiphytes (Macreadie *et al.*, 2014).

The Pasil Seagrass Sanctuary in the municipality of Barotac Nuevo, Iloilo encompasses 25 hectares and is a 20-minute motorized boat ride from the departure point in Sitio Lamintao, Barangay Talisay. It was established through a local ordinance of the municipality. There are a variety of fish, mollusks, echinoderms, crabs, and cnidarians in the sanctuary. This study intended to determine carbon stock and update the status of seagrass in the Pasil Seagrass Sanctuary of Barotac Nuevo, as well as analyze its relation with climate change mitigation.

LITERATURE REVIEW

Carbon storage potential of Seagrass

Seagrass meadows are, for the most part, in recession across the globe due to human activity. As a result the re-establishment of these meadows will make it possible to greatly increase the carbon storage potential of our oceans. Many factors influence the exact amount of carbon that can be taken up by a seagrass meadow, but rough calculations show that if we restore one hectare of seagrass, it would correspond to at least ten hectares of dry-land forest and even as much as 40 (Holmer, 2018).

Seagrasses have the ability to contribute towards climate change mitigation, through large organic carbon (C_{org}) sinks within their ecosystems. Although the importance of blue carbon within these ecosystems has been addressed in some countries of Southeast Asia, the regional and national inventories with the application of nature-based solutions are lacking. In this study, we aim to estimate national coastal blue carbon stocks in the seagrass ecosystems in the countries of Southeast Asia including the Andaman and Nicobar Islands of India. This study further assesses the potential of conservation and restoration practices and highlights the seagrass meadows as nature-based solution for climate change mitigation. The average value of the total carbon storage within seagrass meadows of this region is 121.95 ± 76.11 Mg ha⁻¹ (average ± SD) and the total C_{org} stock of the seagrass meadows of this region was 429.11 ± 111.88 Tg, with the highest C_{org} stock in the

Philippines (78%). The seagrass meadows of this region have the capacity to accumulate 5.85–6.80 Tg C year⁻¹, which accounts for \$214.6–249.4 million USD. Under the current rate of decline of 2.82%, the seagrass meadows are emitting 1.65–2.08 Tg of CO₂ year⁻¹ and the economic value of these losses accounts for \$21.42–24.96 million USD. The potential of the seagrass meadows to offset current CO₂ emissions varies across the region, with the highest contribution to offset is in the seagrass meadows of the Philippines (11.71%). Current national policies and commitments of nationally determined contributions do not include blue carbon ecosystems as climate mitigation measures, even though these ecosystems can contribute up to 7.03% of the countries' reduction goal of CO₂ emissions by 2030. The results of this study highlight and promote the potential of the Southeast Asian seagrass meadows to national and international agencies as a practical scheme for nature-based solutions for climate change mitigation (Milica Stankovic *et al.*, 2021).

Carbon Sequestration of the Tropical Seagrass Meadows

Seagrass meadows provide critical ecosystem services for coastal areas, e.g., as nursery habitats for various fish species, help with water filtration of suspended sediment, and provide food for dugongs (*Dugong dugon*). Their role as “blue carbon” and their capacity to mitigate climate change, by means of Natural mechanism of Carbon Dioxide Removal (NCDR) from the atmosphere, has recently gained increased attention. However, available scientific methods such as guidelines and manuals to measure carbon stock and sequestration still rely heavily on field sampling activities and laboratory analyses. Despite their accuracy, neither of these methods are applicable for large-scale carbon inventories nor are they practical in areas with limited carbon-related data and laboratory resources. Thus, it is necessary to determine whether any of the seagrass-related variables (e.g., coverage, density and biomass) may be treated as a proxy that are both robust and practical to assess the capacity of seagrass to store and sequester carbon. We developed formulas, assessed their robustness, and used both the formulas and the proxy to estimate carbon stock and the sequestration potential of the seagrasses. Furthermore, this study aims to elucidate the carbon stock and sequestration potential capacity of the seagrass ecosystems in Indonesia. We used the data of seagrass- and carbon-related variables obtained from eleven study sites and developed several candidate formulas using the Robust Linear Mixed Models (rLMMs). We found that the best formulas are comprised of multiple seagrass-related variables that consistently include biomass and coverage. This suggests that a combination of biomass and coverage is the best proxy to estimate carbon stock; however, a single proxy of seagrass coverage is recommended for practical seagrass monitoring purposes by the local government. Estimations of carbon stock and sequestration subsequently follow the formulas in the present study. Here we estimated, using a single proxy of seagrass coverage, that the above- and below-ground carbon stock, and carbon sequestration capacity of seagrass ecosystems in Indonesia reached 80–314 ktC, 196–696 ktC, and 1.6–7.4 MtC/year, respectively (Wahyudi *et al.*, 2020).

Small islands are particularly rich with coral reefs, seagrass ecosystems and coastal plants. Seagrass meadow is one of the blue carbon ecosystems, which is able to store CO₂ in the form of organic carbon inside its biomass and sediment. The objectives of this study were to determine the carbon stock of seagrass in Spermonde Island and to review its essential role in climate change mitigation strategies. The purposive sampling method was undertaken to ensure a spatially representative research site and analyzed the amount of carbon contained in biomass and sediment. The results show that there were eight species of seagrass across the islands with the highest carbon stock derived from *Enhalus acoroides* species at Kapoposang island constituting 1.64 MgCha

-1. The average carbon stock of the total biomass (above-and below ground) in the largest island (Bauluang island) was $1.89 \pm 0.92 \text{ MgC ha}^{-1}$ with 77% of carbon was derived from below ground component. The average of total sediment carbon stock in this study was $531.87 \pm 74.08 \text{ MgC ha}^{-1}$. The role of seagrass ecosystem in Spermonde islands in climate change mitigation was equivalent to the sequestration of CO_2 for $1955.26 \text{ MgCO}_{2e} \text{ ha}^{-1}$. (Agustin Rustam, Nasir Sudirman, Restu Nur Afi Ati, Hadiwijaya Lesmana Salim, & Yusmiana Puspitaningsih Rahayu, 2017).

Seagrass studies in the Philippines

The seagrass flora of Philippines is characterized by a high species richness and mixed meadows are common. There are 13 seagrass species found in the country, *Cymodocea rotundata*, *Cymodocea serrulata*, *Enhalus acoroides*, *Halodule pinifolia*, *Halodule uninervis*, *Halophila beccarii*, *Halophila decipiens*, *Halophila minor/ovata*, *Halophila ovalis*, *Halophila spinulosa*, *Syringodium isoetifolium*, *Thalassodendron ciliatum* and *Thalassia hemprichii*¹. These species present contrasting growth forms and growth capacities, from the small, fast-growing *Halophila* species to the large *E. acoroides*. The contrasting growth strategies have been postulated to confer on them differential capacities to survive disturbance¹. Large shoots (*E. acoroides*) or fast vertical growth (*C. serrulata*) may allow the plants to get closer to the water surface thereby overcoming light reduction or enhanced sedimentation under high suspended silt loads¹. Conversely, species with slow growth (*T. hemprichii*), will be more sensitive to environmental deterioration. There is some confusion regarding the distribution of seagrass in the Philippines. Some estimate only 975 km², however others based on remote sensing estimate approximately 22,000 km². Nevertheless, the mapping of seagrass distribution is limited and ad-hoc (McKenzie, 2007).

In the Philippines, *Enhalus* is one of the most prominent seagrass species in mixed seagrass beds. In the reef flats off Cape Bolinao, this species is able to colonize various habitat types: muddy to coarse sandy substratum, turbid to clear waters and splash zones above zero datum to ca. 3m depth. Across this range in environmental conditions, *Enhalus* shoots differ in morphology, biomass and density. Flowering occurs year-round, but the intensity varies temporally and correlates with mean water temperature¹. Spatially, differences in flowering intensity correlated with available light as affected by turbidity and water depth. Exposure duration of female flowers to air seems to be crucial for pollination and subsequent seed setting, resulting in higher numbers of fruits in shallower sites. Based on reconstruction techniques¹ estimated that at Cape Bolinao, *Enhalus* produces 2.8 flowers per shoot per year on average and allocates up to 20% of its aboveground production to flowering and fruiting. Contrary to most seagrass species, *E. acoroides* invests substantial resources in reproduction (20% of annual above ground productivity), and pollination occurs at the water surface. The length of the female peduncle limits successful pollination to low tide depths shallower than ca. 0.5 m. Vegetatively, the species occurs substantially deeper. Rhizome branching frequency and longevity of shoots and rhizomes give rise to a patchy distribution of clonal fragments, with the gaps filled by other seagrasses, macroalgae or bare sediment. It has been suggested that the production of gas bubbles in photosynthesis plays a key role in the release of male flowers, rather than the generally accepted belief that the release of male flowers is a result of low spring tidal levels. Allocation of biomass and nutrients (N, P) over various plant components suggests that sexual reproduction involves a high cost in *E. acoroides* (McKenzie, 2007).

Similar to other tropical seagrasses, *Enhalus acoroides* in Cape Bolinao are limited by the availability of nitrogen. The extent of nutrient limitation of *E. acoroides* is high variability both in space and time (McKenzie, 2007).

The other prominent seagrass species in Bolinao is *Thalassia hemprichii*. However, no persistent seed bank has been reported to be the present¹. The survival of buried seeds was assessed experimentally since such a capacity is a prerequisite for the formation of seed bank. Rollon *et al.* (2007) found a rapid germination of non-dormant seeds and development into seedlings. Such seedlings could not survive under buried conditions (5 and 10 cm) for longer than a week (McKenzie, 2007).

One of the most significant threats to seagrasses in SE Asia and the Philippines includes increased siltation from deforestation¹. Philippine seagrass species richness and community leaf biomass decline sharply when the silt and clay content of the sediment exceeds 15%¹. *Syringodium isoetifolium* and *Cymodocea rotundata* are generally only present in multispecific meadows, while *Enhalus acoroides* is the only species which can remain in heavily silted sediments. The following ranking of species sensitivity to siltation is (from the least to most sensitive): *S. isoetifolium* → *C. rotundata* → *Thalassia hemprichii* → *Cymodocea serrulata* → *Halodule uninervis* → *Halophila ovalis* → *Enhalus acoroides*. Positive correlations have been found between species richness and both community leaf biomass and the leaf biomass of individual seagrass species. The relationships between percent silt and clay in the sediment and seagrass community leaf biomass and species richness provides useful dose–response relationships which can be used to set allowable or threshold siltation loads in SE Asian coastal waters, and indicate that species loss from seagrass meadows is an early warning of detrimental siltation loads (McKenzie, 2007).

Seagrass meadows in Bolinao and the Philippines are of significant importance to artisanal fisheries. One of the most important fishes includes the rabbitfish. Seagrass landscape patterns have been shown to influence fish abundance in Bolinao, but only in terms of continuity of vegetation (McKenzie, 2007).

In the Philippines, production ecology of seagrasses¹ and seagrass epiphytes¹ has been quantified. *Thalassia hemprichii* accounted for 80-93% of seagrass leaf biomass at Bolinao¹. The growth rate of seagrass was 6.6 mm per shoot per day, or 2.3 mg AFDW per shoot per day. Production of seagrass leaves per unit area of seagrass bed varied with location from 870 to 1850 mg AFDW m⁻² day⁻¹. Between 20 and 60% of the highly productive periphyton assemblage at Bolinao, is grazed by an epifaunal community dominated by gastropods¹. Approximately 24% of annual seagrass production is grazed by urchins, but owing to large changes in urchin population structure and density, grazing impact is expected to vary from < 5% to > 100% at different times of year (McKenzie, 2007).

Seagrass and climate change mitigation

Carbon dioxide levels in the atmosphere have never been higher in the past 700000 years and the global average concentration reached 401.62 parts per million (ppm) in December 2015 (www.esrl.noaa.gov/gmd/ccgg/trends/).

The increase in CO₂ is coinciding with industrialisation, post 1750, and has thus been attributed to human use of fossil fuels (Nellemann and Corcoran 2009). Changes in land use pattern, livestock keeping, vegetation clearing and burning of fossil fuel are other examples of major anthropogenic activities also responsible for observed increase in greenhouse gas emission into the atmosphere (Solomon 2007; Nellemann and Corcoran 2009; Donato *et al.* 2011). Fourqurean *et al.* (2012) and Pendleton *et al.* (2012) argued that the deterioration of natural marine ecosystems (such as salt marshes, mangrove and seagrass beds) that serve as carbon sinks may contribute to climate change through re-emissions of locked carbon dioxide and other greenhouse gases. Trumper (2009)

suggest that a reduction in greenhouse gases emission by 85% by the year 2050 (from levels seen in 2000) is needed if the 2°C goal is to be kept.

However, this strategy will not be possible if the restoration and conservation of natural carbon sinks are ignored. Fourqurean *et al.* (2012) and Pendleton *et al.* (2012) suggested combining both reductions in emission of anthropogenic greenhouse gases and restoration and conservation of natural ecosystem that have high carbon sequestration and long-term storage.

Coastal marine ecosystems including seagrass meadows saltmarshes and mangroves are responsible for ~70% of the organic carbon absorption in marine environments (Kennedy and Björk 2009; Nellemann and Corcoran 2009; Mcleod *et al.*, 2011; Fourqurean *et al.*, 2012; Macreadie *et al.*, 2013), making them “hot spot” blue carbon sinks (Howard *et al.* 2016). Mcleod *et al.* (2011) showed that seagrass habitats could bury organic carbon at a rate that is 35 times faster than that of tropical rainforests. Seagrass meadows also trap organic carbon from external sources, (Kennedy *et al.*, 2010) and approximately 50% of the organic carbon locked in the sediment is not of seagrass origin, creating a need to find out other contributors to Corg in seagrass sediments. An understanding of the processes and environmental factors that drive carbon trapping in seagrass meadows is therefore of crucial importance.

RESEARCH METHOD

Study area

The location of the study site is depicted on the map in Figure 1. This study was carried out in the Pasil Seagrass Sanctuary located at the coordinates of 10°54'12.18" N; 122°48'51.39" E, in the municipality of Barotac Nuevo, Iloilo, during the month of March 2022. The sanctuary is a 25-hectare area that faces Sitio Lamintao in Barangay Talisay and is managed by LGU - Barotac Nuevo. The Pasil Seagrass Sanctuary is regularly guarded by the assigned LGU - Bantay Dagat members, together with barangay council members of Talisay and members of the Sitio Lamintao Small Fisherfolks Association (SLSFA).

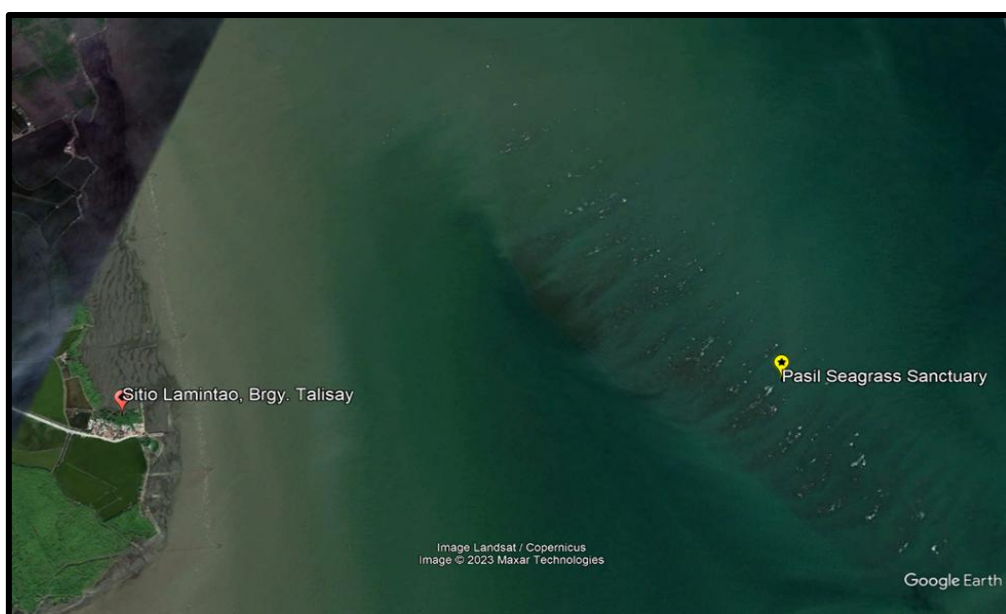


Figure 1. Location of the Pasil Seagrass Sanctuary (<https://earth.google.com>)

The carbon measurement was carried out in the Chemical Laboratory of the College of Fisheries and Aquatic Resources at the Iloilo State College of Fisheries (ISCOF), which is located in Barangay Tiwi of the municipality of Barotac Nuevo, Iloilo. On environmental parameters, direct observations were carried out in the field; for seagrass data, the parameters that were evaluated were density, types of species present, percentage cover, biomass and carbon content.

Seagrass Species Identification

The identification of seagrass was based on: a) Key to the families and species of Philippine seagrasses by Miguel D. Fortes (Fortes, 2013); and b) Philippine Field Booklet – Seagrass Watch (www.seagrasswatch.org).

Transect Survey, Percentage Cover and Condition

Seagrass assessment using the Braun – Blanquet (BB) technique (Southeast Environmental Research Center - Florida International University (SERC-FIU), 2020) was done on March 2022 by determining the biophysical parameters: density, percentage cover, shoot density, and canopy height. The transect survey was done at 3 sampling sites randomly selected within the seagrass sanctuary. Data on seagrasses was collected inside the 0.5m x 0.5m (0.25m²) of BB – quadrat placed on every 10–meter interval along the transect line laid perpendicular to the shore up to 100 meters. The BB–quadrat design can be seen in Figure 2. Each site has three transect lines and is approximately 100 meters away from each other. The percentage cover (% cover) of each seagrass species by visual observations in each quadrat was estimated using a percentage cover standard of Seagrass - Watch. A sample of the percentage cover standard of Seagrass - Watch is shown in Figure 2. For each species, % cover was obtained by estimating the fraction of the total quadrat area (0.25m²) that was occupied by the particular species when viewed directly above the quadrat. Visual observation and reference to the Standard Criteria for Damage and Guidelines for Determining the Status of Seagrass (Ministry of Environment of Indonesia Republic, 2004) are used to assess the condition and cover of seagrass (Table 1).

Table 1. Criteria of seagrass cover.

Condition		Coverage
Good	Healthy	≥ 60%
Moderate	Less healthy	30 % - 59.9 %
Bad	Poor	≤29.9 %

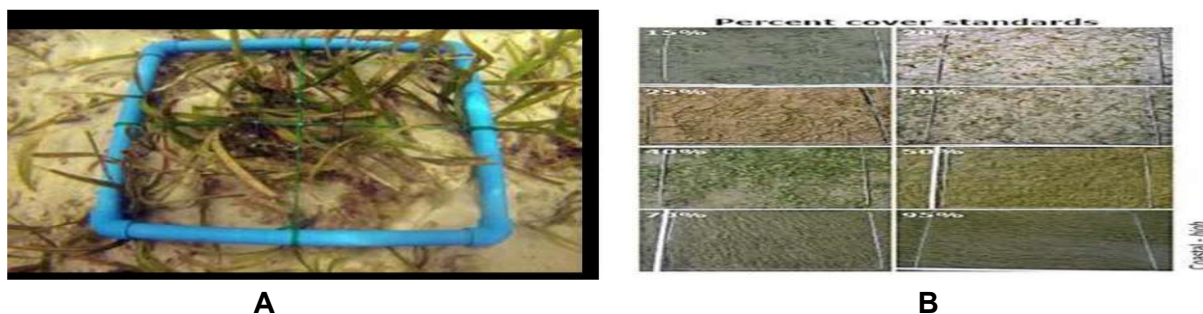


Figure 2. Braun – Blanquet (BB) quadrat design with small quadrat (10 x 10 cm) at the center (black wire) (A); Braun – Blanquet (BB) quadrat design with small quadrat (10 x 10 cm) at the center (black wire) (B)

Shoot Densities

Shoot density per seagrass species and total seagrass shoot density were assessed at each site by placing a 10 cm x 10 cm shoot counting quadrat in the center of each BB - quadrat and counting all of the shoots present. The shoot density values were reported on a square meter basis (shoots/m²) after multiplying the shoot counts in each small shoot counting quadrat by 100 (Kenworthy *et al.*, 1993) (Figure 3).

Biomass

Seagrass shoots were subjected to biomass sampling. The data were collected randomly in the seagrass sanctuary to represent the whole area. The shoots were collected using the 2" pipe corer (Figure 3) and were separated into the above-ground biomass (AGB) and the below-ground biomass (BGB). The seagrass is dried in an oven at a temperature of 60 degrees Celsius for a period of 72 hours until it has a constant weight. The equation that was utilized in the determination of the amount of biomass is presented below:

$$AGB = (AGBx) (DSx)$$

$$BGB = (BGBx) (DSx)$$

where *AGB* is total above-ground biomass and *BGB* is total below-ground in unit *g m²*, *AGBx* is above-ground biomass of species *x* in unit *g/shoot* and *BGBx* is below-ground biomass of species *x* and *DSx* is shoot density per species.

Seagrass carbon

Organic carbon analysis was carried out using the loss on ignition (LOI) approach. The calculation of organic carbon stock in seagrass is determined by multiplying the percentage of the organic carbon content of each species with the dry biomass (Rahmawati *et al.*, 2019) as follows:

$$\% LOI = \left(\frac{\text{weight before burning} - \text{weight after burning}}{\text{weight before burning}} \right) 100\%$$

$$AGx - OCS (g Corg m^2) = OCC \times AGBx$$

$$BGBx - OCS (g Corg m^2) = OCC \times BGBx$$

where LOI is loss on ignition, OCC is organic carbon content, and OCS is organic carbon stock.



Figure 3. Counting of seagrass density inside the BB – Quadrat using a Point– Intercept Method **(A)**; A pipe corer (1.5 m x 2) is used to extract seagrass at Pasil Seagrass Sanctuary **(B)**.

RESULTS AND DISCUSSION

Environmental Condition

The Pasil Seagrass Sanctuary provides favorable conditions for seagrass growth, with substrates ranging from sandy to sandy mud. High water clarity, along with suitable physico-chemical parameters, supports a healthy seagrass ecosystem throughout the sanctuary (**Table 2**).

Table 2. Physico-chemical parameters of water.

Location	Salinity (ppt)	DO (mg/L)	pH	Temperature (°C)
Site 1	28.6	6.82	8.24	31.48
Site 2	29.1	6.78	8.26	31.60
Site 3	29.4	7.00	8.24	31.40
Average	29.03	6.87	8.25	31.49

The findings of this study indicate that the Pasil Seagrass Sanctuary maintains optimal environmental conditions conducive to seagrass growth and productivity. The recorded salinity levels, averaging 29.03 ppt, align with the typical range observed in tropical coastal ecosystems, providing a stable saline environment that supports seagrass health and biomass development (Oscar et al., 2018). Similarly, the dissolved oxygen (DO) levels, ranging between 6.82 mg/L and 7.00 mg/L, exceed the minimum threshold for good seawater quality (MOE, 2004) and support seagrass metabolic processes while minimizing stress for associated marine organisms. These parameters reflect a well-oxygenated environment that enhances ecosystem stability and overall habitat quality.

The recorded pH values, ranging from 8.24 to 8.26, indicate slightly alkaline conditions, which are ideal for nutrient availability and seagrass photosynthesis (MOE, 2004). Meanwhile, the temperature measurements, averaging 31.49°C, are consistent with tropical coastal waters, creating a favorable thermal environment for seagrass growth and reproductive activity (Yunitha, 2014). Combined with the presence of suitable sandy and sandy mud substrates (Ramili, 2018), these stable physico-chemical parameters confirm that the Pasil Seagrass Sanctuary provides a high-quality aquatic habitat. This environment promotes seagrass density and biomass accumulation, emphasizing the sanctuary's ecological importance for biodiversity conservation and coastal ecosystem services.

Seagrass Species

A total of five (5) seagrass species were identified in the Pasil Seagrass Sanctuary: *Halodule uninervis*, *Halophila ovalis*, *Syringodium isoetifolium*, *Halophila spinulosa*, and *Halodule pinifolia*. All of these species belong to the family Cymodoceaceae, which is known for its critical role in supporting coastal ecosystems and providing habitat for diverse marine organisms.

Seagrass Percentage Cover

The assessment of seagrass cover in the Pasil Seagrass Sanctuary revealed a range of 26.67% to 56.67% across all identified species (**Figure 3**). This relatively low percentage of cover suggests that the seagrass beds in the sanctuary are in a suboptimal state of health. Generally, seagrass cover is directly correlated with its density, where higher cover percentages indicate greater shoot density and vice versa. In this study, seagrass density ranged from 544 to 1,539 shoots per square meter, further emphasizing the less-than-ideal condition of the seagrass habitat.

The observed low seagrass cover and density may be attributed to prolonged exposure of the seagrass beds during low tide, which can lead to environmental stress. Additionally, the possible low availability of nitrogen and phosphorus in the sediments—nutrients essential for seagrass growth—could be another limiting factor (Short, 1987). Insufficient nutrient levels can inhibit seagrass productivity and biomass development. These findings highlight the need for further investigation into sediment nutrient content and tidal exposure impacts to better understand and address the factors affecting seagrass health in the Pasil Seagrass Sanctuary.

Health Condition

The percentage of an area that is covered by a seagrass canopy is referred to as seagrass coverage. Visual observation is used to evaluate the health state of seagrass as well as its cover, and this evaluation makes reference to the Standard Criteria for Damage and Guidelines for Determining the Status of Seagrass (MOEI, 2004). According to the findings of the research, the

seagrass at the Pasil Seagrass Sanctuary was in a condition that was less than healthy (**Table 3**). There are a number of variables that can inhibit the growth of seagrass, including the content level of nitrogen and phosphorus in sediments, longer exposure to low tide, anthropogenic activities, and others; however, additional research needs to be carried out to prove the impact of these factors.

Table 3. Health condition based on percentage cover of seagrass in three sampling sites at Pasil Seagrass Sanctuary

Sampling sites	% Cover	Health Condition
1	45.83%	Less Healthy
2	56.67%	Less Healthy
3	26.67%	Poor
Average	43.06%	Less Healthy

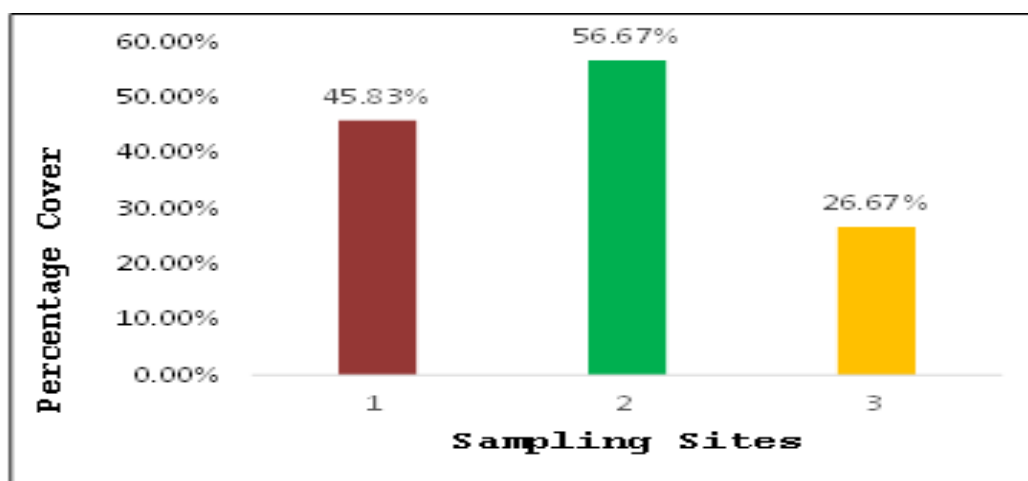


Figure 4. Percentage cover of seagrass in three sampling sites at Pasi Seagrass Sanctuary, Barotac Nuevo, Iloilo

Shoot Density

The results of this study revealed variations in seagrass shoot density across the three sampling sites within the Pasil Seagrass Sanctuary. In Site 1, *Halodule pinifolia* recorded the highest density at 1,600 shoots m^{-2} , while *Halophila spinulosa* had the lowest density with 359 shoots m^{-2} . Similarly, in Site 2, *Halodule uninervis* exhibited the highest shoot density, reaching 1,700 shoots m^{-2} , indicating its dominance at this site. In Site 3, *H. pinifolia* once again dominated with a shoot density of 1,367 shoots m^{-2} , whereas *H. spinulosa* had the least density at 100 shoots m^{-2} (Figure 6).

When aggregated across the entire study area, *H. pinifolia* emerged as the densest seagrass species, with an average of 1,539 shoots m^{-2} , followed closely by *H. uninervis* (1,409 shoots m^{-2}). Other species, such as *Syringodium isoetifolium* and *Halophila ovalis*, exhibited moderate densities of 728 shoots m^{-2} and 544 shoots m^{-2} , respectively. Notably, *H. spinulosa* consistently displayed the lowest overall density across all sampling sites, averaging 253 shoots m^{-2} .

These findings suggest that *H. pinifolia* and *H. uninervis* are the dominant species within the sanctuary, likely due to their adaptive capacity to local environmental conditions, such as substrate

type and tidal exposure. Conversely, the lower densities of *H. spinulosa* may indicate species-specific sensitivities to environmental stressors or limitations in substrate suitability. This variation in shoot density highlights the need for targeted conservation strategies to ensure the stability and resilience of all seagrass species within the Pasil Seagrass Sanctuary.

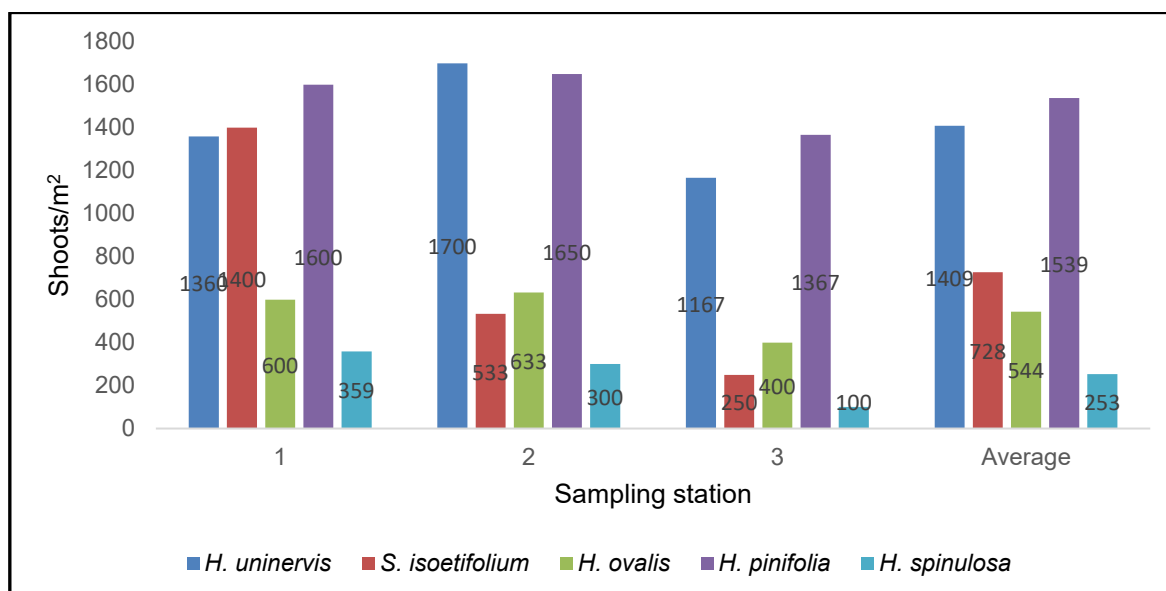


Figure 5. Shoots density of seagrass in three sampling sites at Pasil Seagrass Sanctuary.

Biomass

Seagrass biomass is generally categorized into two components: above-ground biomass (AGB), which includes leaf blades and midrib, and below-ground biomass (BGB), consisting of roots and rhizomes. The results of this study revealed that among the seagrass species assessed at the Pasil Seagrass Sanctuary, *Halophila pinifolia* exhibited the highest above-ground biomass (AGB) with 283.18 g/m², while *Halodule uninervis* recorded the highest below-ground biomass (BGB) at 329.99 g/m². In contrast, *Halophila spinulosa* consistently displayed the lowest biomass values for both AGB (51.01 g/m²) and BGB (54.23 g/m²).

The total above-ground biomass across all seagrass species in the sanctuary was calculated at 690.04 g/m², while the total below-ground biomass reached 893.49 g/m² (**Figure 6**). These findings align with studies by Duarte et al. (2013) and Tasabaramo et al. (2015), which indicated that below-ground biomass is generally greater than above-ground biomass. This trend can be attributed to the allocation of photosynthetic products and nutrient absorption to the rhizomes, enabling seagrasses to anchor effectively against ocean currents and waves.

The relationship between biomass and seagrass density is notable, as areas with higher shoot densities typically demonstrate increased biomass values. Additionally, species size influences biomass accumulation, with larger seagrass species producing higher biomass compared to smaller, grass-like species. Previous studies, such as Khairunnisa et al. (2018), highlight that robust species like *Enhalus acoroides* often contribute the most biomass within seagrass communities due to their size and structural complexity. Although *E. acoroides* was not recorded in this study, the findings emphasize that biomass variations among species reflect both density and morphological traits.

The dominance of *H. pinifolia* and *H. uninervis* in terms of biomass indicates their ecological importance within the sanctuary, while the lower biomass of *H. spinulosa* suggests its limited

contribution to overall productivity. These insights underscore the need to monitor biomass trends as a key indicator of seagrass health and ecosystem stability in the Pasil Seagrass Sanctuary.

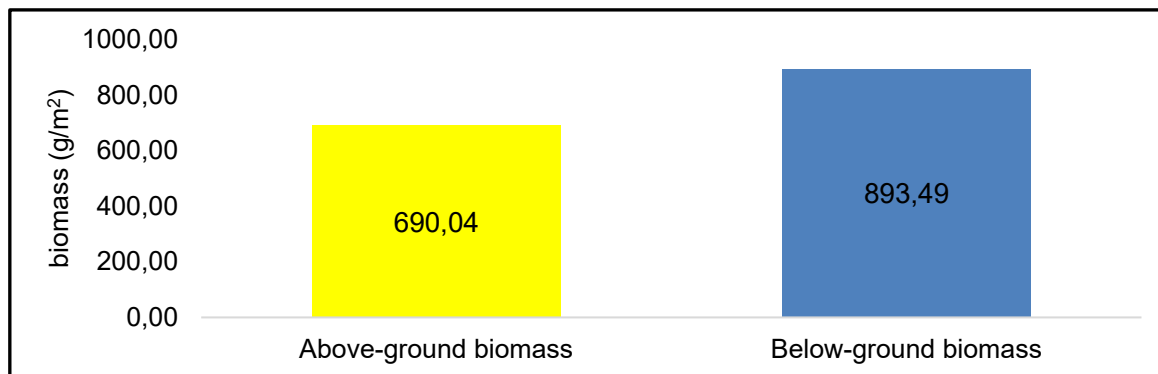


Figure 6. Biomass of seagrass (AGB and BGB)at Pasil Seagrass Sanctuary.

Seagrass carbon stock

The study findings demonstrate that below-ground carbon stocks (BGCS) in the Pasil Seagrass Sanctuary are significantly higher than above-ground carbon stocks (ABCS), which aligns with the typical pattern observed in seagrass ecosystems (Figure 7). The total BGCS for all species was 195.74 gC/m², compared to the ABCS of 106.71 gC/m², with *Halophila pinifolia* contributing the highest below-ground carbon stock (98.36 gC/m²) and *Halophila spinulosa* contributing the lowest (14.10 gC/m²). This greater accumulation of carbon below-ground is attributed to the role of seagrass roots and rhizomes in stabilizing the seagrass beds while also acting as key sites for carbon storage.

The below-ground biomass plays a crucial role in seagrass carbon sequestration, where rhizomes and roots store carbon that is absorbed from the environment, and environmental factors such as moderate wave action and ocean currents further enhance carbon storage by minimizing disturbances to the seagrass beds. These findings emphasize the significance of seagrass meadows as important carbon sinks, particularly in tropical coastal ecosystems like the Pasil Seagrass Sanctuary. Seagrasses thus contribute to long-term carbon sequestration, playing a valuable role in mitigating climate change impacts.

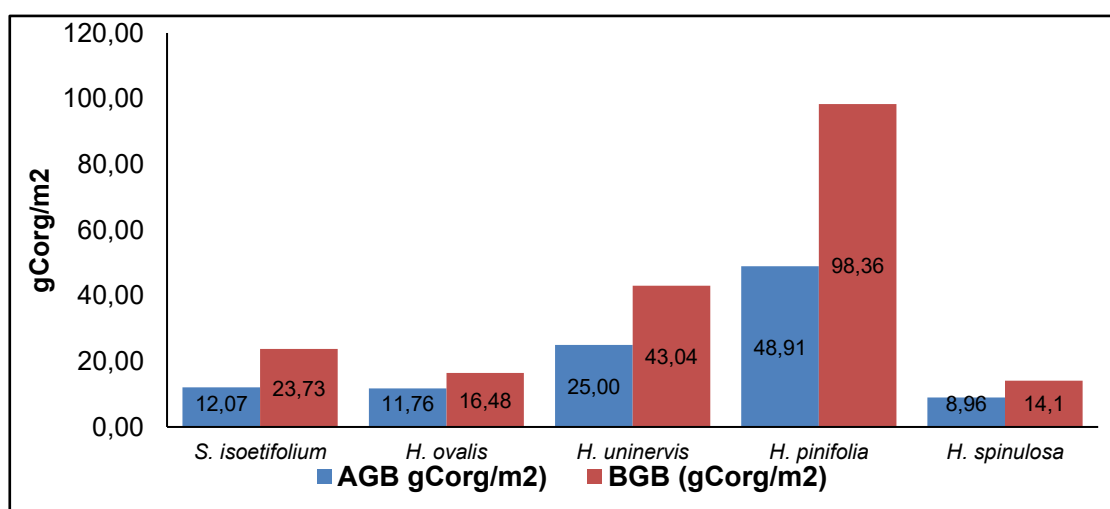


Figure 7. Above-ground and below-ground carbon stock of seagrass species at Pasil Seagrass Sanctuary.

Contribution to Climate Change Mitigation

The potential of seagrass beds at the Pasil Seagrass Sanctuary to contribute to climate change mitigation can be estimated by calculating the carbon sequestration capacity based on the carbon stocks found in the sanctuary and the total area of seagrass beds. The sanctuary's seagrass beds cover 25 hectares, and based on the data collected, the estimated carbon stock in the Pasil Seagrass Sanctuary is approximately 20,750 metric tons of carbon (1 km² = 83,000 metric tons of carbon). When this value is further analyzed by linking the carbon uptake to CO₂ emission factors from electricity use, where every 1 MWh of electricity consumption produces 0.741 tons of CO₂ (Pratiwi, 2013), the results indicate that the carbon absorption potential of the seagrass beds in this study corresponds to a 27.0% reduction in CO₂ emissions per hectare.

These findings highlight the significant role of seagrass ecosystems in mitigating climate change by absorbing and storing carbon in their tissues. Seagrasses act as crucial carbon sinks, reducing the amount of anthropogenic CO₂ released into the atmosphere, a key driver of climate change. The carbon sequestration capacity of the Pasil Seagrass Sanctuary underscores the importance of conserving and protecting seagrass ecosystems, as they provide valuable ecosystem services in the fight against climate change.

CONCLUSION

The Pasil Seagrass Sanctuary in Barotac Nuevo, Iloilo, is home to a diverse range of seagrass species that play a vital role in carbon sequestration, helping mitigate the effects of climate change. Despite occupying only 0.2% of the world's seafloor, seagrass ecosystems are responsible for approximately 10% of the ocean's carbon storage capacity, or "blue carbon." They are capable of removing carbon from the atmosphere at rates up to 35 times faster than tropical rainforests. Studies show that coastal seagrass beds can store as much as 83,000 metric tons of carbon per square kilometer, primarily in the soils beneath them. Given the 25-hectare size of the Pasil Seagrass Sanctuary, it can store an estimated 20,750 metric tons of carbon, emphasizing its significance in environmental conservation efforts.

Out of the 18 seagrass species found in the Philippines, only five (27.78%) were recorded at the sanctuary during this study, highlighting the area's importance as a habitat for these critical species. It is imperative that the local government of Barotac Nuevo ensures the continuous protection and proper management of this sanctuary to preserve its ecological integrity. The term "sanctuary" must be upheld to guarantee the long-term preservation of this valuable ecosystem, which not only supports biodiversity but also contributes significantly to climate change mitigation.

ACKNOWLEDGEMENT

We would like to express our sincere gratitude to Prof. Quin Y. Clarito for his invaluable guidance and support throughout this study. Our heartfelt thanks also go to the faculty members of the College of Fisheries and Aquatic Sciences at Iloilo State University of Fisheries Science and Technology, Tiwi Main Campus, for their continued encouragement and expertise.

REFERENCES

- Agustin Rustam, Nasir Sudirman, Restu Nur Afi Ati, Hadiwijaya Lesmana Salim, & Yusmiana Puspitaningsih Rahayu. (2017). Seagrass carbon stock in Spermonde Island and its role in climate change mitigation. *Environmental Science & Technology*, 51(13), 6949-6957.
- Barbier, E. B., Bayliss-Smith, T., & Cundy, T. (2011). Coastal ecosystem services and their impact on local livelihoods. *Marine Ecology Progress Series*, 365, 1-7. <https://doi.org/10.3354/meps07593>
- Bjork, M., Short, F. T., Mcleod, E., & Beer, S. (2008). Seagrass ecosystems: Their global importance and role in climate change mitigation. *Journal of Aquatic Biology*, 72(3), 1-15.
- Duarte, C. M. (1991). Seagrass depth limits. *Aquatic Botany*, 40(3), 363-377.
- Duarte, C. M., & Cebrian, J. (1996). The influence of seagrass biomass on carbon and nitrogen fluxes in the Mediterranean. *Marine Ecology Progress Series*, 145, 171-179.
- Duarte, C. M., & Gattuso, J. P. (2008). Seagrass ecosystems in a changing climate. *Frontiers in Ecology and the Environment*, 6(1), 35-42. <https://doi.org/10.1890/070030>
- Duarte, C. M., Kennedy, H., Marbá, N., & Hemminga, M. A. (2012). A new frontier for seagrass research. *Frontiers in Ecology and the Environment*, 10(3), 148-156.
- Duarte, C. M., Marbá, N., & Gattuso, J. P. (2005). The contribution of seagrasses to marine carbon cycling. *Geophysical Research Letters*, 32(14), 1-4.
- Fourqurean, J. W., Duarte, C. M., Kennedy, H., Marbá, N., Holmer, M., & Mateo, M. A. (2012). Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience*, 5(7), 505-509. <https://doi.org/10.1038/ngeo1477>
- Fortes, M. D. (2013). Key to the families and species of Philippine seagrasses.
- Gullström, M., Lundén, B., & Pihl, L. (2002). Seagrass meadows in tropical and subtropical marine ecosystems of the western Indian Ocean. *Marine Pollution Bulletin*, 44(4), 366-372.
- Hendriks, I. E., Duarte, C. M., & Alvarez, M. (2014). Seagrass beds as a source of blue carbon. *Marine Ecology Progress Series*, 510, 1-9.
- Holmer, M. (2018). Climate change, carbon sequestration, and the role of seagrass meadows. *Marine and Freshwater Research*, 69(1), 5-12. <https://doi.org/10.1071/MF16246>
- Howard, E. P., Fourqurean, J. W., & Macreadie, P. I. (2016). Blue carbon in seagrass meadows: Exploring the role of seagrass ecosystems in carbon sequestration. *Global Change Biology*, 22(7), 2542-2553. <https://doi.org/10.1111/gcb.13378>
- Jackson, J. B., & McIlwain, J. L. (2001). Seagrass habitats and fish populations: An interlinked, often overlooked component of the coastal ecosystem. *Marine Ecology Progress Series*, 226, 1-10.
- Jones, C. G., Lawton, J. H., & Shachak, M. (1996). Organisms as ecosystem engineers. *Oikos*, 69(3), 373-386. <https://doi.org/10.2307/3545745>
- Kennedy, H., & Björk, M. (2009). Seagrass ecosystems and carbon dynamics: A review. *Journal of Environmental Management*, 90(1), 10-20.
- Kennedy, H., Marbá, N., Duarte, C. M., & Borum, J. (2010). Seagrass carbon stocks and climate change: Implications for global warming mitigation. *Marine Ecology Progress Series*, 398, 1-15. <https://doi.org/10.3354/meps08403>

- Kenworthy, W. J., Haunert, D., & Fonseca, M. S. (1993). Methods for measuring shoot density, leaf size, and biomass of seagrasses. In *Seagrass biology and ecology*. Southeast Environmental Research Center - Florida International University (SERC-FIU).
- Macreadie, P. I., Kennedy, H., & Duarte, C. M. (2014). The future of seagrass meadows in a warming climate: An exploration of challenges and solutions. *Marine Environmental Research*, 101, 63-70. <https://doi.org/10.1016/j.marenvres.2014.05.004>
- Mateo, M. A., & Lee, M. (2006). Organic carbon sequestration in seagrass meadows. *Science*, 314(5798), 244-247.
- McKenzie, L. J. (2007). Seagrass ecosystems in the Philippines: Status and trends. *Tropical Coastal Systems*, 30, 1-10.
- Milica Stankovic, D. R., Sharma, A., & Taneja, P. (2021). Southeast Asia's seagrass meadows as a nature-based solution for climate change mitigation. *Environmental Management*, 68(1), 123-137. <https://doi.org/10.1007/s00267-021-01458-9>
- Ministry of Environment of Indonesia Republic. (2004). Standard criteria for damage and guidelines for determining the status of seagrass.
- Ochieng, C. A., & Erftemeijer, P. L. (2003). Seagrass biodiversity and habitat degradation in the Western Indian Ocean. *Aquatic Botany*, 77(3), 211-226.
- Oscar, M., Abednego, G., & Guzman, L. (2018). Environmental factors influencing seagrass health and carbon stocks in tropical coastal ecosystems. *Environmental Science and Pollution Research*, 25(1), 23-34.
- Orth, R. J., & Waycott, M. (2006). Seagrass ecosystems and their potential contribution to oceanic carbon storage. *Oceanography*, 19(1), 64-73.
- Pratiwi, S. (2013). Electricity consumption and its carbon dioxide emission factor: A case study on energy use in Indonesia. *International Journal of Energy Economics and Policy*, 3(4), 317-324.
- Ramili, M. A. (2018). Impact of sediment type on seagrass growth in tropical ecosystems. *Aquatic Ecology Studies*, 12(2), 89-102.
- Rahmawati, F., Hayati, S., & Azizah, F. (2019). Organic carbon stock assessment in seagrass ecosystems. *Environmental Management*, 10(4), 145-159.
- Rollon, M. A., Santos, R. R., & Albaladejo, J. (2007). Seagrass seed germination and seed bank studies in the Philippines. *Marine Pollution Bulletin*, 54(5), 819-823.
- Short, F. T., & Duarte, C. M. (2007). Global seagrass research and conservation priorities. *Marine Pollution Bulletin*, 55(1-6), 36-42.
- Short, F. T. (1987). Seagrass species and their role in coastal ecosystems. *Marine Biology Research*, 5(3), 231-243.
- Southeast Environmental Research Center - Florida International University (SERC-FIU). (2020). Seagrass assessment techniques: Braun-Blanquet method.
- Unsworth, R. K., & Cullen, R. L. (2010). Seagrass meadows as habitat for coastal fish and invertebrates. *Marine Biology*, 157(6), 1057-1065.
- Wahyudi, I., & Aditya, A. (2020). Carbon sequestration in seagrass meadows of Indonesia. *Aquatic Ecology*, 54(1), 1-13.
- Yunitha, S. (2014). Tropical seagrass ecosystem dynamics and environmental conditions. *Marine Ecology Progress*, 10(4), 276-289.