Potential carbon stocks of seagrass species in Bunaken Island, North Sulawesi, Indonesia

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Abstract. Seagrass meadows are highly valuable ecosystems and play crucial roles in marine ecosystem dynamics by providing food and shelters for many organisms, especially as nursery grounds for commercially important reef fishes. However, seagrass beds around the world have been heavily impacted by human activities. Although marine protected areas have been established globally, seagrass beds remain poorly represented compared to coral reefs. In this study, the researchers gathered preliminary but important baseline information on the Carbon stock (g C m^{-2}) of different seagrass species around Bunaken Island, North Sulawesi. A total of five species were quantified with the Eelgrass *Enhalus acoroides* having the highest Carbon stock (47±4.8 g C m^{-2}) while the rest of the species have Carbon stocks below 10 g C m^{-2}.

Key Words: carbon stock, nursery-ground, seagrass, meadows, Manado, North Sulawesi.

Introduction. Seagrass beds are highly valuable ecosystems (Fortes 1990), and are well known for the variety of marine flora and fauna within. They also provide food and shelters, such as nursery grounds for commercially important species of fish and macroinvertebrates (Jackson et al 2001). Unfortunately, seagrass meadows around the globe have been declining rapidly due to combination of natural and anthropogenic factors, such as climate change (Short & Neckles 1999), pollution (Neverauskas 1987; Todd et al 2010), sedimentation (Madsen et al 2001), destructive fishing (Jackson et al 2001).

Alongi (2018) compiled data on carbon sequestration around the globe and showed that only 12 observations have been made in Indonesia, with carbon sequestration estimates ranging from -1434 to 77 g C_{org} m^{-2} $year^{-1}$ (mean = -578.5). However, carbon sequestration estimates are likely underestimated as seagrasses export a substantial portion of primary production, both in particulate and dissolved forms (Alongi 2018). In terms of data on carbon stocks worldwide, as compiled by Fourqurean et al (2012a, b), most of the organic carbon are stored in soil. Alongi (2018) further emphasized the difficulty in discerning geographic trends due to the scarcity of data in some parts of the world, including Indonesia where estuarine and marine wetlands (including seagrass meadows) comprised about 17% of the world's blue carbon (Alongi et al 2016).

Wagey et al (2016) and Wagey (2018) reviewed the status of researches done on the ecology of seagrasses in Indonesia, with emphasis on the Northern Sulawesi. His review revealed that only a few studies have dealt with the carbon stocks of seagrasses in Indonesian waters (e.g. Rustam et al 2017; Kondoy 2017) and previous studies dealt mainly with seagrass morphometrics (e.g. Sakey et al 2015; Wagey 2017) or community structure (e.g. Merly et al 2013). Recently, Fortes et al (2018) noted that research output on seagrasses, especially in relation to climate change and carbon stocks in Southeast

Asia remain scarce although there is an increasing trend. The purposes of this study were to determine the number of species / species of seagrasses, to know the density and cover of seagrass, and to know the biomass value and estimation of carbon deposits in biomass in seagrasses in the form of tissue on the substrate (leaves) and at the bottom of the substrate (roots and rhizomes) on the waters od Bunaken Island.

Material and Method

Description of the study sites. This study was conducted in April and July 2018 at Bunaken Island, North Sulawesi, Indonesia. Bunaken Island is part of the Bunaken National Park (Figure 1). The seagrass meadows surveyed were all in the shallow areas. Water temperature during the survey ranged from 25 to 33°C while light intensity ranged from 66,133.8 to 330,668.9 Lux, and salinity ranged from 30 to 33 ‰.

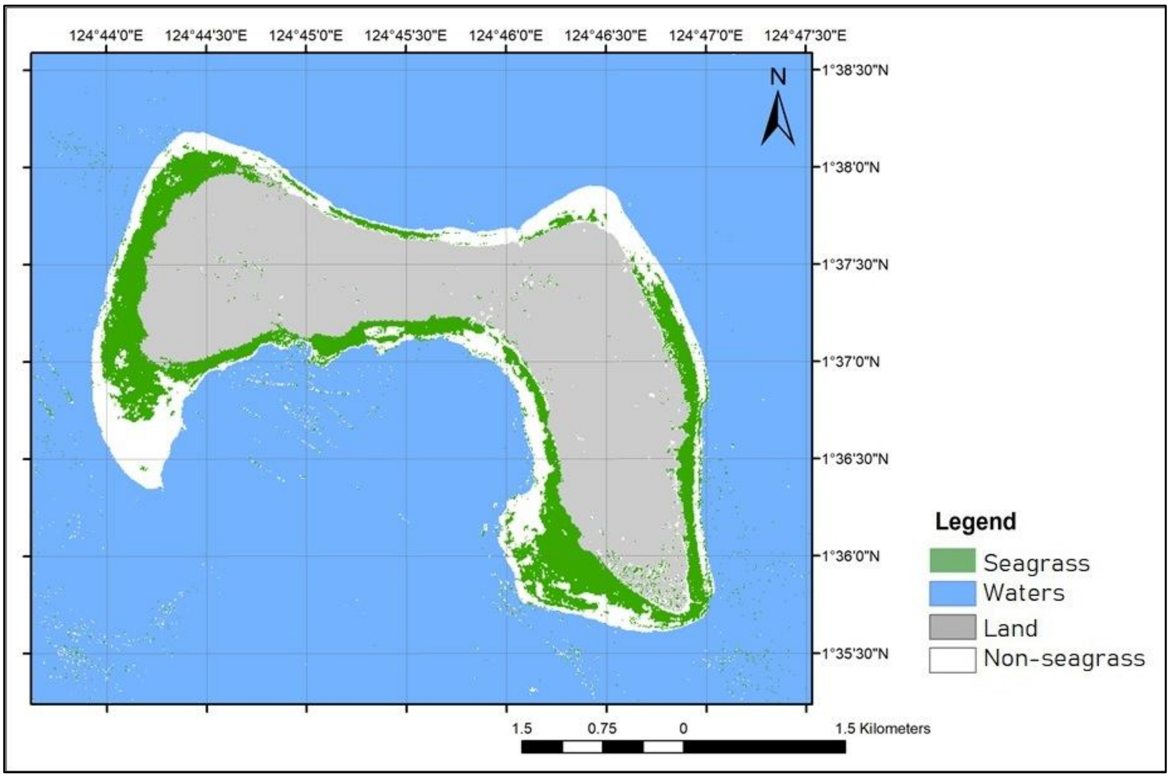

Figure 1. The location of the seagrass beds surrounding Bunaken Island, North Sulawesi, Indonesia.

Seagrass sampling. The seagrass sampling procedures described by McKenzie (2003) were followed. In each site, 50-m transect lines were laid perpendicular to the shoreline. The geographic coordinates of each transect was determined and marked by a GPS (Geographic Positioning System) unit (Garmin®). A total of 6 quadrats (each 1m x 1m) were randomly positioned in each transect. Within each quadrat, percent (%) cover of each species and the number of shoots were counted for determination of density. Photographs were also taken as part of photo-documentation and for later verification of species identification. Species identification was based on available taxonomic references (e.g. Waycott et al 2004).

All seagrass samples were collected from each quadrat, cleaned of sediments and debris, sorted to species, then components were segregated as to above-ground and below-ground parts for further laboratory processing and analyses. Wet-weight (nearest grams) were immediately determined using a portable electronic balance (AND EJ 610).

Determination of biomass and carbon stock. Only the samples collected in April were subjected to biomass and carbon stock determination. Upon arrival at the laboratory, samples from each quadrat (segregated as to above-ground and below-ground samples) were air-dried for at least 5 days then later oven-dried (~60°C) for 24-hours to constant weight. Oven-dried samples were weighed using an analytical weighing scale for determination of biomass. To quantify carbon stock (g C m^{-2}), the LOI (lost on ignition) method was used as described by Kondoy (2017) and Hulopi et al (2017).

Statistical analysis. All data were tested for assumptions of normality (Anderson-Darling Test), QQ-Plot, and homoscedasticity (Non-constant Variance Score Test) using the nortest package in R (R Core Team 2017), and were log-transformed when required. Variations between sampling stations were compared using one-way and two-way Analysis of Variance (ANOVA), followed by Tukey's post hoc test. Significance of differences was defined at $p < 0.05$. Statistical analyses were performed using RStudio.

Results. A total of 5 species of seagrasses were recorded from the sampling sites. In both sampling occasions (April and July, 2018), seagrass densities were comparable. *Thalassia hemprichii* had the highest mean densities (106.4±3.3 shoots m^{-2} (S.E.) in April and 89.2±8.7 shoots m^{-2} in July), followed by *Cymodocea rotundata* (90.5±2.7 shoots m^{-2} in April and 74.5±9.9 shoots m^{-2} in July, respectively), *Halophila ovalis* (56.5±4.2 and 42.5±4.6 shoots m^{-2}), while lower densities were observed *Enhalus acoroides* (45.5±6.6 and 42.5±4.6 shoots m^{-2}) and *Syringodium isoetifolium* (43 to 44.5 shoots m^{-2}), in that order (Figure 2). Two-Way ANOVA revealed significant difference between both sampling occasions (p-value < 0.05) and between species (p-value < 0.001). Subsequent Tukey's HSD test further showed that the observed significant differences between species was attributable to pair-wise comparisons between *C. rotundata* and *E. acoroides*, *H. ovalis*, and *S. isoetifolium*) as well as with *T. hemprichii* and *E. acoroides*, *H. ovalis*, and *S. isoetifolium*) with all p-value < 0.001.

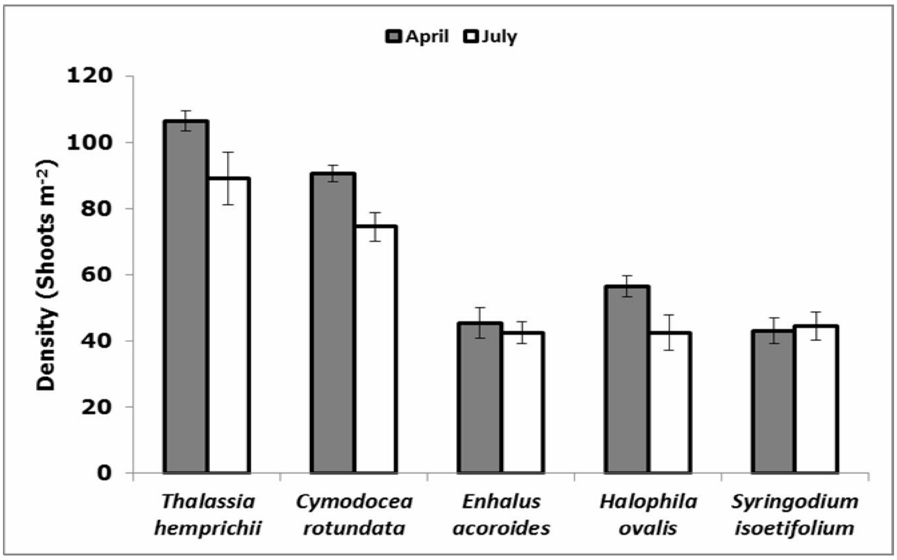

Figure 2. Mean density of seagrass species in April and July, 2018. Error bars indicate standard error values.

Mean per cent cover (Figure 3) showed no significant difference between April and July based on the Two-Way ANOVA (p-value > 0.05). Between species, however, *T. hemprichii* had the highest per cent cover (14-17%), followed by *C. rotundata* (9-13%), *E. acoroides* (10-12%), *S. isoetifolium* (7-9%), and *H. ovalis* (5-8%). ANOVA revealed that there was a significant difference in cover between species (p-value < 0.001).

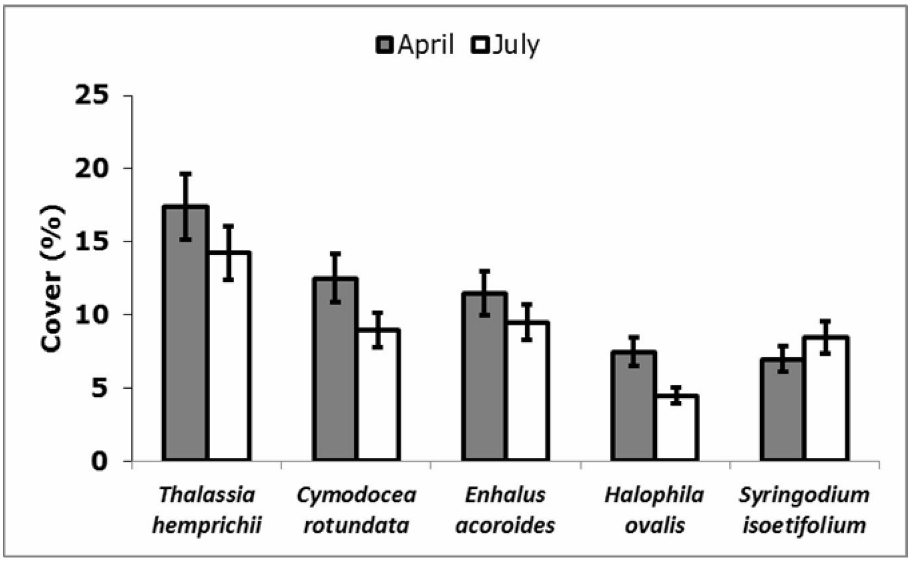

Figure 3. Mean percent cover (%) of seagrass species in April and July, 2018. Error bars indicate standard error values.

In terms of fresh (wet) weight of the seagrass species, *E. acoroides* was found to have the highest wet values (above-ground: 492±73.3 g m^{-2}; below ground: 419±42.2 g m^{-2}) followed by *T. hemprichii* (above-ground: 335±24.3 g m^{-2}; below ground: 237±37.2 g m^{-2}), *C. rotundata* (above-ground: 244±29.7 g m^{-2}; below ground: 208±21.7 g m^{-2}), *S. isoetifolium* (above-ground: 62±9.3 g m^{-2}; below ground: 49±4.5 g m^{-2}), while *H. ovalis* (above-ground: 40±4.7 g m^{-2}; below ground: 34±4.9 g m^{-2}) had the lowest wet weight values (Figure 4). Two-Way ANOVA showed wet biomass differ between above-ground and below-ground biomass (p-value < 0.05) but differences were more pronounced between species (p-value < 0.0001).

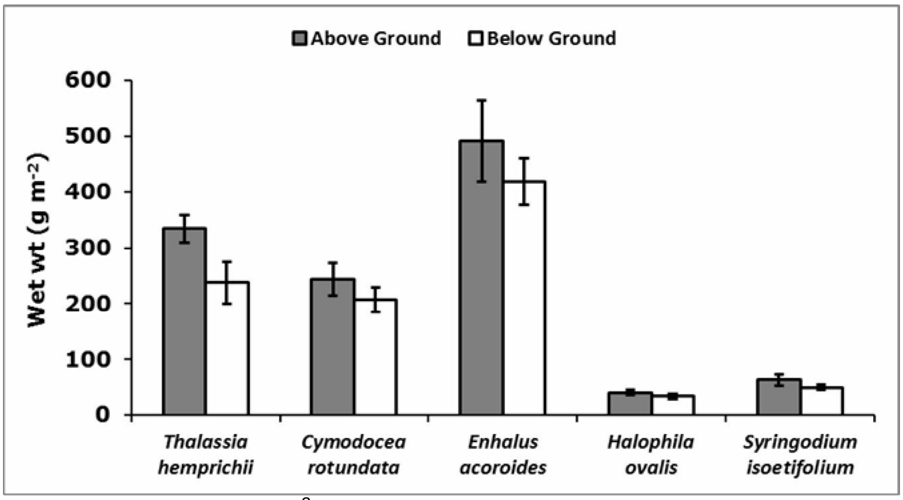

Figure 4. Mean wet weight (g m^{-2}) of seagrass species in April 2018. Error bars indicate standard error values.

Mean biomass (grams dry weight per m^2) of seagrass species appear consistent with the trend observed using wet weight values. *E. acoroides* was found to have the highest biomass (above-ground: 126±14.4 g m^{-2}; below ground: 135±18.1 g m^{-2}) followed by *T. hemprichii* (above-ground: 92±4.9 g m^{-2}; below ground: 102±6.3 g m^{-2}), *C. rotundata* (above-ground: 81±6.8 g m^{-2}; below ground: 90±4.7 g m^{-2}), *S. isoetifolium* (above-ground: 24±4.8 g m^{-2}; below ground: 21±1.8 g m^{-2}) while *H. ovalis* had the lowest dry weight biomass values (above-ground: 14±1.7 g m^{-2}; below ground: 11±1.5 g m^{-2}) (Figure 5). Two-Way ANOVA showed no significant difference between above-ground and below-ground dry biomass (p-value > 0.05) but significant differences were detected between species (p-value < 0.001).

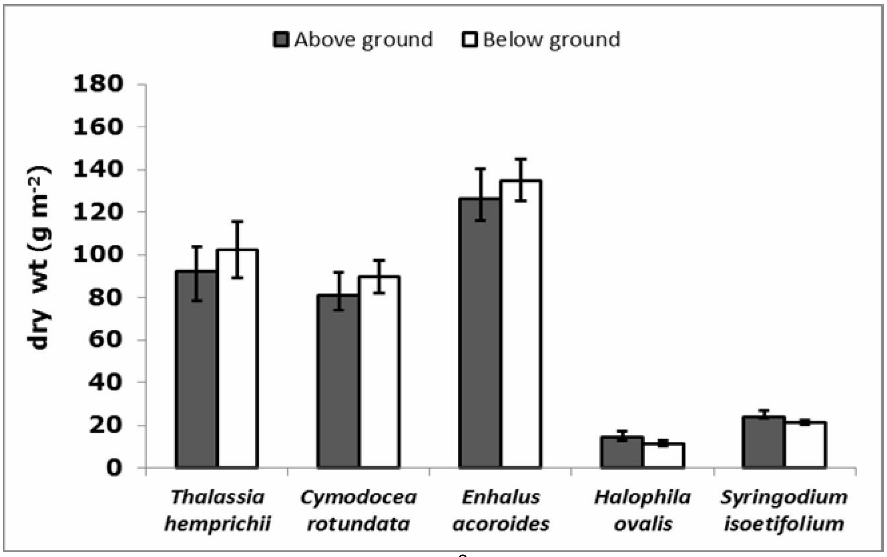

Figure 5. Mean biomass (dry weight in g m^{-2}) of seagrass species in April 2018. Error bars indicate standard error values.

As already pointed out, carbon stock was, thus far, determined and compared between species. As expected, *E. acoroides* had the highest carbon stock (47±4.8 g C m^{-2}) while the rest of the species were all below 10 g C m^{-2}. One-Way ANOVA showed significant difference in carbon stock between species (p-value < 0.001). Tukey's HSD test confirmed that the observed significant difference was due to *E. acoroides* carbon stock when compared to the rest of the species (p-values < 0.001).

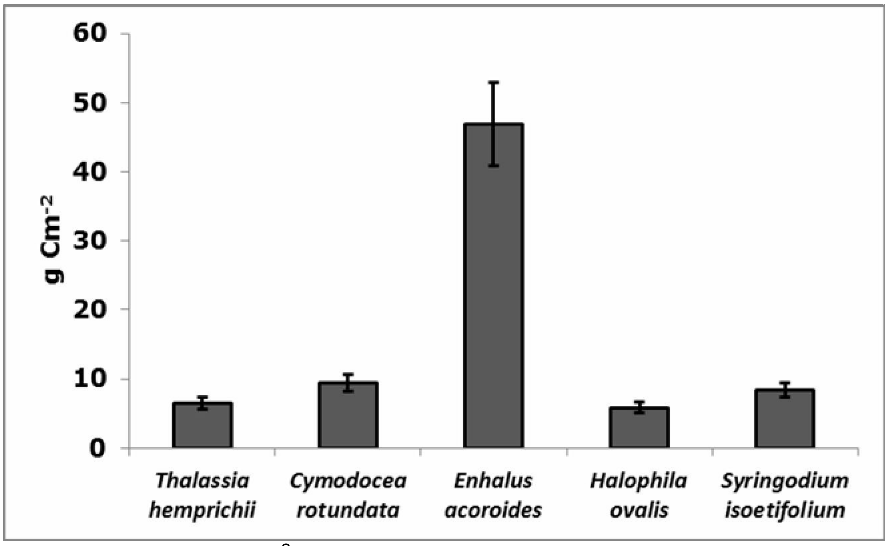

Figure 6. Carbon stock (g C m^{-2}) of seagrass species in April 2018. Error bars indicate standard error values.

Discussion. This study provides some baseline information on seagrass density, per cent cover, biomass (wet and dry), and carbon stocks of five species found in Bunaken Island in North Sulawesi, Indonesia. The results showed that density and cover were mainly influenced by two species, *T. hemprichii* and *C. rotundata* (consistent to earlier findings by Kondoy 2017). *E. acoroides* had the highest contribution in terms of biomasses and carbon stocks, despite the latter species having a sparse distribution and lower density and cover values. The results may have some implications as to the GIS-mapping and subsequently on the management of seagrass beds. For example, when seagrass cover derived from satellite imagery will be used as a proxy data to infer carbon stocks, there is a tendency of underestimating the actual carbon stocks if the seagrass beds are dominated by species with lower carbon stocks such as *T. hemprichii* and *C. rotundata*.

The carbon stock estimates presented in this study do not support the earlier study by Kondoy (2017) wherein *T. hemprichii* had the highest carbon stock in North Sulawesi. Differences might be attributable to variances in terms of the placement of the sampling sites. Kondoy (2017), however, only showed carbon stock percentages and not actual values, making direct comparisons not feasible at this stage. On the other hand, the high carbon stock of *E. acoroides* tends to parallel the findings of Hulopi et al (2017) in Galala and Tanjung Tanjung Tiram waters around Ambon Island, Indonesia. Similarly, large-sized species such as *E. acoroides* and *T. hemprichii* were also found to have the highest carbon stock in Spermonde Archiepelago, South Sulawesi, Indonesia (Rustam et al 2017). It is noteworthy that *E. acoroides* is the largest among the species and abundant throughout its range in the Indo-Pacific, making this species a blue carbon source. Likewise, Alongi et al (2016) compiled information on carbon stocks of seagrasses (extrapolated to per hectare values) in selected sites in Indonesia (no data in North Sulawesi), with *E. acoroides* as dominant species (in terms of biomass) in at least 6 sites.

Carbon stocks of seagrass species are expected to vary between locations, especially influenced by depths but no significant difference detected between intertidal and sub-tidal (Lavery et al 2013). Depth may not be a factor affecting possible variability in the sampling sites in Bunaken. However, other factors should also be taken into consideration such as the effect of substrate (Kattuk et al 2018) on the variability of biomass and carbon storage. This study did not include soil carbon content and should be included in the next phases of the project.

Conclusions. This study has documented the baseline data for carbon stocks of 5 seagrass species sampled around Bunaken Island, North Sulawesi. Pertinent data on seagrass density, cover, biomass (both wet and dry), and carbon stock were described and compared with existing information in the literature. Among the 5 species, the eelgrass *E. acoroides* had the highest biomass and carbon stock values, suggesting that this species as a potential blue carbon source.

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