Country-specific emission factor for developing a tier 3 system of Indonesia’s seagrass carbon inventory

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Abstract. Climate action regarding carbon inventory requires baseline assessment, data regarding annual changes, and evaluation of reductions in carbon emissions. However, many studies of seagrass ecosystems have focused only on carbon stock and sequestration, neglecting the importance of the carbon emission factor. It is known that emission factors for land-use change, including those in seagrass ecosystems, can be derived from biomass and sediment carbon stock. Since currently Indonesia only has data for biomass carbon stock, we propose the measurement of province-based emission factors. This study combines the available carbon stock data reported in national or international publications and conducts a meta-analysis to obtain emission factor values. The results show that the biomass standing carbon stock of Indonesia’s seagrass meadows ranges from 0.30 tC/ha (i.e., Special Region of Yogyakarta) to 16.51 tC/ha (i.e., Gorontalo province), while emission factor ranges from 0.012 tC/ha/yr to 0.661 tC/ha/yr (equal to 0.05 t CO2/ha/yr to 2.42 t CO2/ha/yr). These findings will be beneficial for developing Tier 3 carbon inventory since they allow country-specific emission factor for the seagrass ecosystem to be measured.

Keywords: biogeochemistry, carbon inventory, country-specific, emission factor, seagrass

1. Introduction

Indonesia has been reported as having a verified seagrass area of 293,464 ha out of a potential extent of 1,847,341 ha [1, 2]. However, according to recent trends reported in Southeast Asia, seagrass ecosystems are experiencing degradation at a rate of up to 2.82% per year, accounting for carbon emissions of 1.65 to 2.08 Tg of CO2/year [3]. A carbon inventory system is therefore necessary at the national scale to monitor changes in seagrass areas and their potential to store carbon. Furthermore, carbon inventory will be helpful in following up the achievements of the National Low Carbon Development Initiative policy that seeks to put Blue Carbon in the mainstream of climate change mitigation.

Climate action on carbon inventory requires baseline assessments, data about annual changes, and evaluation of carbon emission reductions, and these assessments require specific methodological approaches that depend on their success on the quantity of information available and the analytical methods used. The Intergovernmental Panel on Climate Change (IPCC) has categorized methodological approaches into three tiers [4, 5]: Tier 1 employs the gain-loss method according to IPCC guidelines and uses default emission factors; it, therefore, applies to simplified assumptions about some carbon
pools. Meanwhile, Tiers 2 and 3 generally use the same methodological approach as Tier 1 but apply country-specific emission factors and other parameters. Tiers 2 and 3 can also apply carbon stock change methodologies. Furthermore, Tier 3 applies higher-order methods, including models and the utilization of plot data that specifically address national circumstances [4, 5].

Baseline assessment of carbon inventory requires the establishment of emission factors. According to the United Nations Framework Convention on Climate Change (UNFCCC), the emission factor (EF) is "a coefficient which allows converting activity data into greenhouse gas emissions. It is the average emission rate of a given source, relative to units of activity or process/processes." Within the Blue Carbon context, this "activity" is related to land-use change and any changes (conversion or degradation). Any anthropogenic activities (either active or passive) may result in ecosystem degradation. The degradation process contributes to carbon emissions, especially those caused by land-use change. Land-use changes have been reported to contribute to 67% of total national emissions in Indonesia, and these emissions have to be addressed accordingly [6].

The study of seagrass as an aspect of the Blue Carbon approach has received increasing attention in the recent decade [2, 3]. The data obtained from these studies in Indonesia will be more than enough to set country-specific emission factors. The emission rate can be calculated based on seagrass biomass carbon stock data. The carbon emission rate of converted or degraded seagrass areas is 0.55 to 1.09 tC/ha/yr or 2%-4% per year of initial carbon stock. The specific percentages reflect the fact that the disturbances experienced alter the carbon balance of only the first meter of sediment and the air-exposed biomass [7]. It is expected that tropical areas such as Indonesia can apply a 4% per year carbon emission rate, reflecting fast remineralization resulting from high surface temperatures and daily inundation [8].

This study aims to acquire data on seagrass biomass carbon stock from published documents and to use those data to determine province-based carbon emission factors. This setting of emission factors will be beneficial for developing Tier 3 carbon inventory in respect to country-specific emission factors. Since emission factor is not the only variable applied in developing carbon inventory systems, we also investigate the other variables narratively by looking at how to capitalize the available data in Indonesia (seagrass carbon, ecosystem) and what kind of data is needed (e.g., area extent, annual change) for a nationally determined contribution (NDC) document.

2. Materials and Methods

This study was conducted based on a meta-analysis of recent publications on carbon stock assessment of Indonesia's seagrass ecosystems. The data were acquired from studies published in the Google Scholar database within the last five years (2017–2021; access date: May 19, 2021) and a study by [2]. The Google Scholar database was used to obtain international and national publications, especially for local studies rarely reported in the common global databases and citations. The following keywords were used, namely: 1) "karbon" "padang lamun" AND "Indonesia", which generated 868 documents; 2) "seagrass carbon stock" AND "Indonesia", which generated 49 documents; and 3) "seagrass" AND "carbon stock" AND "Indonesia", which generated 4,850 documents.

Fast reading of the titles and keywords of each page identified that many documents were not relevant to this study. We only acquired 80 articles that could be considered suitable, including theses, journals, and proceedings documents. However, after reading in depth only 53 articles reported pertinent information about seagrass vegetation and carbon data. The seagrass vegetation and carbon data presented in those articles were acquired and curated to meet the standards set (same units, valid method, correct terms, etc.).

If the literature presented the carbon stock data (either above or below ground, or both), we used the data as it was. However, some sources only reported ecological data (i.e., density, biomass, or coverage). We put the latter datasets into the Seagrass Carbon Converter (SCC) (http://scc.oceanografi.lipi.go.id/) to obtain the relevant carbon stock data. We also used seagrass carbon stock datasets [9] and combined them with those obtained from the literature. The emission factor of the seagrass ecosystem was determined following the process used by Lovelock et al. [7], i.e. multiplying standing carbon stock by
4%, on the assumption that the carbon emission rate of the converted seagrass area is a maximum of 4% per year of the initial carbon stock.

3. Results and Discussion

3.1. Seagrass carbon stock and emission factor

Data reported by [9] was obtained for the period 2010–2018, while data from the meta-analysis of the literature published 2017–2021 covered the period 2014–2019. Therefore, our acquired data represent a total period of a decade (2010–2019).

Seagrass carbon stock data is already available for 22 of Indonesia's provinces, and emission factors can be derived from this carbon stock data. Meanwhile, 12 provinces do not have any data on their seagrass ecosystems (Table 1), and we cannot, therefore, determine the emission factor for the seagrass areas of these provinces. However, the national average of emission factors of 0.126 tC/ha/yr can be used (Table 1). Among these 12 provinces, five are located in Sumatra (Bengkulu, Jambi, Lampung, Riau, and South Sumatra), four in Kalimantan (Central, South, North, and West Kalimantan), two in Sulawesi (Central and West Sulawesi), and one in Java (West Java). In order to obtain representative data for these administrative regions, we encourage the future collection of data in these provinces for seagrass extent and vegetation data (density, biomass, and coverage). We may estimate the carbon stock of the vegetation data by the best formula reported by [2] or by simply using the SCC.

For the provinces that at present do not have seagrass data, we encourage conducting an assessment of their coastal ecosystems for, at minimum, seagrass extent and one of the vegetation parameters (either coverage, density, or biomass). Conversion to carbon stock value can then be conducted using SCC or Carbon Inventory for Seagrass Ecosystem (CISE). CISE is a mobile-operating-system-based application that can be used to calculate carbon stock and to make projections for the emission reduction potential of the seagrass conservation programs in place within the Marine Protected Area (MPA). Both SCC and CISE have been developed based on the work of [2].

Figure 1. Emission factors (tC/ha/yr) for seagrass ecosystem of 34 provinces in Indonesia (province ISO code refers to Table 1).
The average of standing carbon stock (sum of above- and below-ground carbon stock) of Indonesian seagrass meadows ranges from the lowest figure of 0.30 tC/ha (Special Region of Yogyakarta) to the highest of 16.51 tC/ha (Gorontalo Province). Following Lovelock et al.’s assertion [7] that the carbon emission rate of converted seagrass areas is a maximum of 4% per year, we can determine the emission factor as being 4% of the standing carbon stock (Figure 1). This finding simply confirms that more carbon will be emitted if seagrass degradation happens in provinces with a wider seagrass extent. However, if serious action is taken, i.e. conservation of the seagrass ecosystem, such provinces will see larger reductions in carbon emissions.

Since the acquired data represents the period 2010–2019 for 65% of provinces in Indonesia, we propose setting the year 2020 as the baseline (T0) for carbon inventory. Any future study of seagrass carbon inventory may then refer to this baseline year. For instance, any changes in seagrass carbon stock and area in future assessments will be able to be compared to the 2020 baseline data. A similar approach has been proposed for the mangrove ecosystem [10], which used 2016 as the baseline year. We propose using 2020 as the baseline rather than earlier years because of the quantity of data available. Furthermore, the extent of seagrass area in a recent year is already verified as 293,464 ha [1], which is a more robust finding than for previous years.

Table 1. Seagrass standing carbon stock and emission factors of Indonesia provinces.

| Province          | ISO code | Average seagrass standing carbon stock [tC/ha] | Emission factor* | References |
|-------------------|----------|-----------------------------------------------|-----------------|------------|
| Aceh              | ID-AC    | 0.91                                          | 0.037, 0.134    | [2] [9]    |
| Bali              | ID-BA    | 0.84                                          | 0.033, 0.123    | [11] [12] [13] [14] [15] [2] [9] |
| Bangka Belitung Islands | ID-BB    | 0.81                                          | 0.032, 0.119    | [2] [9]    |
| Banten            | ID-BT    | 0.89                                          | 0.035, 0.130    | [2] [9]    |
| Bengkulu          | ID-BE    | NA                                            | NA              | NA         |
| Central Java      | ID-JT    | 4.40                                          | 0.176, 0.646    | [16] [17] [18] [19] [20] [21] [22] [23] [24] [25] [26] |
| Central Kalimantan| ID-KT    | NA                                            | NA              | NA         |
| Central Sulawesi  | ID-ST    | NA                                            | NA              | NA         |
| East Java         | ID-JI    | 1.13                                          | 0.045, 0.166    | [27]       |
| East Kalimantan   | ID-KI    | 0.84                                          | 0.034, 0.123    | [2] [9]    |
| East Nusa Tenggara| ID-NT    | 0.68                                          | 0.027, 0.100    | [2] [9] [28] |
| Gorontalo         | ID-GO    | 16.51                                         | 0.661, 2.422    | [29]       |
| Jambi             | ID-JA    | NA                                            | NA              | NA         |
| Province               | ISO code | Average seagrass standing carbon stock [tC/ha] | Emission factor* | References |
|------------------------|----------|-----------------------------------------------|------------------|------------|
| Province               | ISO code | EF=Cstock * [%Et (note: %Et = 4%)] [tC/ha/yr] | EF*(44/12) [ton CO₂/ha/yr] | References |
| Province               | ISO code | EF=Cstock * [%Et (note: %Et = 4%)] [tC/ha/yr] | EF*(44/12) [ton CO₂/ha/yr] | References |
| Lampung                | ID-LA    | NA                                            | NA               | NA         |
| Maluku                 | ID-MA    | 1.39                                          | 0.056            | 0.204      | [30] [31] [32] [2] [9] |
| North Kalimantan       | ID-KU    | NA                                            | NA               | NA         |
| North Maluku           | ID-MU    | 0.95                                          | 0.038            | 0.140      | [2] [9] |
| North Sulawesi         | ID-SA    | 11.38                                         | 0.455            | 1.669      | [33] [34] [35] [36] [2] [9] |
| North Sumatra          | ID-SU    | 0.94                                          | 0.037            | 0.137      | [37] [2] [9] |
| Papua                  | ID-PA    | 2.07                                          | 0.083            | 0.304      | [38] [2] [9] |
| Riau                   | ID-RI    | NA                                            | NA               | NA         |
| Riau Islands           | ID-KR    | 2.83                                          | 0.113            | 0.415      | [39] [40] [41] [42] [43] [44] [45] [46] [47] [2] [9] |
| South Kalimantan       | ID-KS    | NA                                            | NA               | NA         |
| South Sulawesi         | ID-SN    | 0.90                                          | 0.036            | 0.131      | [48] [49] [50] [51] [52] [53] [2] [9] |
| South Sumatra          | ID-SS    | NA                                            | NA               | NA         |
| Southeast Sulawesi     | ID-SG    | 0.94                                          | 0.038            | 0.138      | [2] [9] |
| Special Capital Region of Jakarta | ID-JK | 1.36                                          | 0.054            | 0.199      | [54] [55] [56] [2] [9] |
| Special Region of Yogyakarta | ID-YO | 0.30                                          | 0.012            | 0.045      | [57] |
| West Java              | ID-JB    | NA                                            | NA               | NA         |
| West Kalimantan        | ID-KB    | NA                                            | NA               | NA         |
| West Nusa Tenggara    | ID-NB    | 4.06                                          | 0.162            | 0.595      | [58] |
| West Papua             | ID-PB    | 1.70                                          | 0.068            | 0.249      | [59] [38] [2] [9] |
| West Sulawesi         | ID-SR    | NA                                            | NA               | NA         |
| West Sumatra           | ID-SB    | 13.66                                         | 0.547            | 2.004      | [60] [61] [2] [9] |
| **National average**   |          | **3.159**                                      | **0.126**        | **0.463**  | The present study |

*Note: The atomic weight of carbon is 12 atomic mass units while the weight of carbon dioxide is 44 (including two oxygen atoms each weighing 16). One ton of carbon equals 44/12 = 11/3 = 3.67 tons of carbon dioxide.
3.2. Are the available data sufficient for developing a Tier 3 carbon inventory?
Many studies of seagrass as a Blue Carbon ecosystem are emerging. Some studies explicitly address their carbon sequestration for climate change mitigation [2, 3, 62]. Other studies address specifically carbon stock [12, 50, 56] or ecosystem health and quality [63, 64]. The present study also recorded 53 local assessments of seagrass carbon stock and sequestration. However, there is still no study specifically addressing carbon inventory for the issue of GHG emission reductions.

The IPCC has already set up supplemental guidelines for wetland carbon inventory, including for seagrass [65]. Data is required for several variables, including area extent, spatiotemporal variability, vegetation data (coverage, biomass, density), and carbon stock data (above ground, below ground, and soil/sediment). According to Tier 2 and 3 requirements, local data is necessary, including specific emission factors (EF). We identified these requirements in comparison to the available data for Indonesia (Figure 2). Sufficient vegetation and carbon data are available although it is still developing in terms of methodology (e.g. [2, 3]). However, Indonesia does not yet have provincial or national data for variability in seagrass extent. Given the estimated degradation rate of 2.8% per year [3], it is necessary to monitor changes in the country’s seagrass extent. According to national needs, especially for carbon inventory for the marine and fisheries sector, the variability of seagrass extent should be delineated for each province, as well as obtaining the total area at the national scale. An innovative process is necessary, for instance, using remote sensing for rapid assessment of seagrass extent variability.

Some research using the remote-sensing approach has been conducted for rapid assessment of seagrass area, coverage, and carbon stock [21, 60, 66, 67]. The common challenge in this kind of study is the inundated seagrass ecosystem that is optically complex for remote sensing. Other challenges include accuracy and robust correlation between remote-sensing parameters and seagrass coverage or biomass carbon stock. Figure 2 shows that the remote-sensing approach will help stakeholders to gather data, including seagrass extent per province, its variability (area changes per year), the method for converting remote-sensing parameters to vegetation data, and area extent variability that is likely to affect carbon emission.

Figure 2. Fishbone diagram showing the data and method requirements for seagrass carbon inventory. MPA = Marine Protected Area; Cov = coverage; D = density; Bm = biomass; CC = climate change.

4. Conclusion
Based on the meta-analysis of various literature published within the last five years, the biomass standing carbon stock of Indonesia seagrass meadows ranges from the lowest value of 0.30 tC/ha (Special Region of Yogyakarta) to the highest value of 16.51 tC/ha (Gorontalo province). The emission factor ranges from 0.012 tC/ha/yr to 0.661 tC/ha/yr (equal to 0.05 t CO₂/ha/yr to 2.42 t CO₂/ha/yr). Besides carbon stock and emission factor, there are other variables applicable in developing a Tier 3 system of carbon
inventory: area extent, spatiotemporal variability, and vegetation data (coverage, biomass, density). An innovative approach is required to obtain these data to support stakeholders at national and local scales.

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