Introducing a Method for Calculating Carbon Emission Reduction on the Seagrass Ecosystem for Indonesia’s Low Carbon Development Initiative

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Abstract. The increase of anthropogenic carbon dioxide (CO₂) since the industrial revolution era affects the global carbon cycle and triggers climate changes. Indonesia has ratified the Paris Agreement and declared the emission reduction for climate action (Sustainable Development Goal 13) up to 29% (independently) or 41% (with international support) in 2030 relative to the business as usual (BAU) scenario. The effort to achieve this target is implemented on Low Carbon Development Initiative (LCDI) starting in 2020. LCDI adopts marine and fisheries as one of the implementing sectors that focus on blue carbon. To implement the activities as part of the carbon emission reduction within the LCDI, we have to establish a calculation method that should be measurable, reportable, and verifiable (MRV). The present article introduces the MRV method for calculating the carbon emission reduction for the Conservation/Protection Seagrass Ecosystem’s climate change mitigation activity on Marine Protected Area (MPA).

We present how to calculate the baseline emission (business as usual), emission leakage when implementing the activity, and emission reduction. A case study on seagrass meadows of Kepulauan Seribu MPA is presented for the trial of the introduced method and formula. Using the proposed method is reliable enough to estimate carbon emission reduction from seagrass conservation activity within the MPA. We can calculate the carbon emission will reduce 4.35 tC relative to the BAU on Kepulauan Seribu MPA by 2030.

1. Introduction

The emission of greenhouse gases (GHGs), particularly carbon dioxide (CO₂), has been increasing rapidly since the start of the industrial era [1]. The major contributor to CO₂ emission is the burning of fossil fuel and land-use change [2]. The increase of CO₂ has been altering the composition of atmospheric gasses and the global carbon cycle. These changes have later induced global changes, including warming, climate change, and ocean acidification [3], [4], [5], and these changes have had a profound negative impact on biodiversity and many aspects of human life [6].
Following up on the Paris Agreement ratification, Indonesia declared a target for reducing GHG emissions up to 29% (independently) or 41% (with international support) relative to the business as usual scenario in 2030. The effort to achieve this target is implemented in the Low Carbon Development Initiative (LCDI) starting in 2020. LCDI improves the previous initiative (National Action Plan for GHG Emission Reduction) with the addition of marine and fisheries as one of the implementing sectors. In this newly added sector, the initial stage of the implementation includes the protection and restoration of mangrove and seagrass ecosystems. In the context of LCDI, these ecosystems are parts of the wetland area.

Analog to the land-use change activities, protection, and restoration program in the wetland area can be deemed as an activity for carbon emission reduction [4]. The program protects stored carbon, which would otherwise be released if degraded or unprotected, thus reducing avoidable carbon emissions. Protecting and/or restoring the ecosystems would also deliver co-benefits from the maintained ecosystem function and services. However, as part of the carbon emission reduction, the program implementation requires a calculation method that is measurable, reportable, and verifiable.

We develop a method for calculating the carbon emission reduction from the Conservation/Protection Seagrass Ecosystem’s climate change mitigation activity so that the method will meet the requirement of measurement, reporting, and verification (MRV) provisions. A similar study has been conducted but was mainly focused on the mangrove ecosystem and applied to national scale without relating specifically to the importance of MPA implementation as a nature-based solution for climate change [7]. We focused on the seagrass ecosystem as there is no MRV method currently existing in Indonesia’s LCDI. We propose a method that includes 1) minimum requirement, 2) formula development, and 3) steps to calculate: baseline emission (within the business as usual scenario), emission leakage when implementing the activity, and emission reduction.

2. Materials and Method

We use the best available data with several assumptions for the minimum parameters used in the calculation. The parameters, data, and assumption refer to these previous studies [8], [9], [10], [11], [12], [13]. We also use previously developed protocols (i.e., [14], [15]) to support the proposed method in this study. The minimum requirements for the calculation of carbon emission reduction detailed in Table 1.

| No | Parameter | Notation | Value or Formula | Unit | Compulsory or not | Reference |
|----|-----------|----------|------------------|------|-------------------|-----------|
| 1  | Coverage  | Cov      | <SCC>            | %    | Yes               | Observation result to be converted to carbon value using Seagrass Carbon Converter(SCC) [15]: http://scc.oceanografi.lipi.go.id/seagrass-carbon-converter Observation and assessment refers to [14] |
| 2  | Biomass   | Bm       | <SCC>            | g/m² | Yes/No            | Observation result to be converted to carbon value using SCC [15] Observation and assessment refers to [14] |
|   |   |   |   |   |
|---|---|---|---|---|
| 3 | Density | D | <SCC> | shoots/㎡ | Yes/No |
| 4 | Standing carbon stock from seagrass biomass: above ground dan below ground | | | |
|   | - National | $C_{stock}$ | 0.94–1.15 (med: 1.045) | tC/ha | Yes | [12] |
|   | - Province of Marine Protected Area | $C_{stock}$ | <SCC> | tC/ha | Yes | [14] |
| 5 | Sediment carbon stock (up to 50 cm depth) | $C_{sed}$ | 31.3–293.3 (median: 162.3) | tC/ha | No | [16] |
| 6 | Marine Protected Area | A | <calculation> | Ha | W | [14] |
| 7 | Percentage of degradation rate of seagrass area | %$Q$ | 5 | %/yr | Yes/No | [8] |
| 8 | Percentage of degradation rate of seagrass area by uncontrollable factors | %$Qu$ | 1.5 | %/yr | Yes/No | [13] |
| 9 | Degradation of seagrass area (total activity) | $Q$ | %$Q$*A | ha/yr | Yes/No | [14] |
| 10 | Degradation of seagrass area by uncontrollable factors (total activity) | $Qu$ | %$Qu$*A | ha/yr | Yes/No | [14] |
| 11 | Seagrass conservation activity | $Qc$ | <calculation> | ha/yr | Yes | [14] |
| 12 | Carbon emission rate on converted/degraded seagrass area | | | | |
|   | - absolute value | $Et$ | 0.55-1.09 | tC/ha/yr | No |
|   | - percentage per year | %$Et$ | 2-4 | %/yr | Yes | [9] |
|   |   |   |   |   |   |
|   | Observation result to be converted to carbon value using SCC [15] |
|   | Observation and assessment refers to [14] |
|   | Converting Cov, Bm and D to Cstock by using SCC [15] |
The disturbance activities (e.g., land-use change on seagrass ecosystem) alters the carbon balance of only the first meter of sediment and the air-exposed biomass [9]. We use that previous research finding for the present study. Carbon emission rate on the converted or degraded seagrass area is 2–4 Mg CO2/ha/yr (equal to 0.55 - 1.09 tC/ha/yr or 2–4% per year of the initial carbon stock) [9]. We use a carbon emission rate of 4% per year for the Business As Usual (BAU) scenario in the tropical region, assuming that decomposition rate and remineralization occur faster due to high surface temperature and daily inundation. Meanwhile, we use a carbon emission rate of 2% per year for leakage emission during the activity implementation (e.g., conservation or protection).

This study also presents a case study using our proposed method. We calculated carbon emission reduction in the Marine Protected Area of Kepulauan Seribu (Figure 1). The MPA of Kepulauan Seribu covers total area of 108,000 Ha (SK Menteri Kehutanan No.162/Kpts-II/95) or 107,489 Ha (SK Menteri Kehutanan No. 6310/Kpts-II/2002). The updated information about the total area of this MPA was obtained from SK Menteri Kehutanan No. 8310/Kpts-II/2002 (i.e., 113,325 Ha). This MPA located at 5°23’ - 5°40’ S, 106°25’ - 106°37’ E. The total seagrass area in Kepulauan Seribu is used to calculate the baseline scenario, and the total seagrass area in MPA is used for calculating the emission reduction scenario. Although the reef-flat area (both within the MPA and the entire area of Kepulauan Seribu) was not considered in this calculation, we also present it in this paper for further comparison.

Seagrass meadow extent in the MPA was calculated from satellite data using Google Earth Engine (GEE) platform. GEE is a cloud computing platform for analyzing remote sensing and geographical data [17], [18]. This study used Landsat surface reflectance data set provided by GEE. The process for generating surface reflectance data was based on [19]. Further, a given procedure of GEE was used to yield a cloud-free image of the study area. The cloud-free image was generated by utilizing multi-temporal satellite data scenes to mask out the cloud pixels and replace it with pixels from other image scenes. This study used two different times of images to investigate the changes of seagrass extent. The first cloud-free image was yield by combining Landsat 5 satellite data from 2015 to 2016. Then, the second image was yield by combining Landsat 8 satellite data from 2017 to 2018. Unsupervised classification using the K-means algorithm was used to extract seagrass bed information from both cloud-free images. The accuracy assessment was conducted using ground-truth data from the 2017 field survey to validate the generated map. Image classification and accuracy assessment procedures followed the previous study [14], [20].

3. Results and Discussion
The proposed method for calculating emission reduction is arranged into sections following the MRV method of Low Carbon Development, including activities description of GHG mitigation effect, baseline emission, emission leakage during mitigation activities, and emission reduction. Carbon emission can be calculated following the basic formula introduced by [8] as follows:

\[ E_{x} = E_{F_{x}} \times Q \]

\( E_{x} \) is emission by carbon pollutant, \( E_{F_{x}} \) is Emission Factor, and \( Q \) is activities resulting in the emission. The detailed formula for calculation is explained in the following sub-sections and refers to Tables 1 and 2.
Figure 1. Marine Protected Area of Kepulauan Seribu, Jakarta, Indonesia
Table 2. The formula for calculating emission factor, baseline, leakage, and emission reduction

| No | Parameter                          | Notation | Value or Formula | Unit | Remark                                                                 |
|----|------------------------------------|----------|------------------|------|------------------------------------------------------------------------|
| 1  | Emission Factor (EF)               | Cstock * %Et | EF               | tC/ha| Absolute value of EF (1.045*4)                                         |
|    |                                    |          | 4.18             |      |                                                                        |
| 2  | Emission factor for emission leakage | EFl     | EF*Q             | tC   |                                                                       |
|    |                                    |          | 2.09             |      |                                                                        |
| 3  | Baseline Emission                  | Ex       | EF*Q             | tC   |                                                                        |
| 4  | Leakage Emission                   | El       | EFl*Qu           | tC   |                                                                        |
| 4  | Emission Reduction                 | Er       | -(EF*Qc)+(El)     | tC   | Negative notation (-) shows carbon emission reduction                  |

3.1 Activity description

The proposed climate change mitigation activity following the MRV methods is Conservation/Protection Seagrass Ecosystem on Marine Protected Area. This activity is considered as an approach to preserve and/or conserve the existing seagrass ecosystem to be relatively sustainable. It has been known that the seagrass ecosystem is degrading year by year without any protective regulation. To fulfill the requirement for climate change mitigation activity, any protection or conservation activity should be adopted to be regulation (e.g., by the national or local government).

Without regulation for conservation and protection, the seagrass ecosystem has been degrading at a rate of 2 - 5% per year [8]. Carbon emission rate on the converted or degraded seagrass area is 0.55 - 1.09 tC/ha/yr or 2–4% /yr [13]. Any regulation for conservation or protection is needed to reduce degradation. Therefore, the protection and conservation activity can be considered as an attempt for carbon emission reduction.

3.2 Calculating baseline emission

We define the baseline emission as the emission within Business As Usual activities for specific periods. Within the Indonesia context, the baseline year (T0) should be the year with the best available data recorded, such as [11], [12], [14] (see Table 1 for minimum data and information required for the calculation). The emission is calculated by using the following steps (unit: ton C/ha/y).

1. Define the seagrass area extent (A) within the MPA using the defined method by [14].
2. Estimate or measure the seagrass coverage (Cov), biomass (Bm), and density (D). The minimum data that should be available is one of the three kinds of parameters. However, validity will increase if data for all parameters are available.
3. Convert the coverage, biomass, or density to carbon stock value (Cstock) by using Seagrass Carbon Converter [15]
4. Calculate total carbon stock: Stock total=A*Cstock
5. Calculate degradation rate: Q=%Q*A
6. Calculate Emission Factor (EF): EF=Cstock*%Et (note: %Et is 4%, see Table 1)
7. Calculate Baseline Emission: Ex=EF*Q
8. Projected Business As Usual (BAU) as carbon emission increase from T0 (baseline year) to Tn.
3.3 Leakage emission during mitigation activities

Emission leakage is defined as natural emission and/or emission by uncontrollable factors on the seagrass ecosystem. Uncontrollable factors include natural and anthropogenic factors that occur incidentally or continuously, although positive intervention (conservation or protection for climate change mitigation) is already implemented. For instance, seagrass extent can contract or expand due to environmental change, terrestrial input, geomorphological cycles, or seagrass biomass. This can degrade due to prolonged aerial exposure caused by inundation changes and diurnal tides. Another cause may be seagrass vulnerability in pandemic outbreaks due to species dominance [21].

Climate change mitigation action can be calculated and considered if only there is an intervening regulation (i.e., conservation regulation). The calculation of leakage emission during the implementation of conservation regulation follows the steps below.

1. Define the seagrass area \( A \) within the MPA using the defined method by [14].
2. Estimate or measure the seagrass coverage \( Cov \), biomass \( Bm \), and density \( D \). One of these three parameters must be available, but complete parameters are preferable as a result would be more robust.
3. Convert the coverage, biomass or density to carbon stock value \( C_{\text{stock}} \) by using Seagrass Carbon Converter [15]
4. Calculate total carbon stock: \( \text{Stock total} = A \times C_{\text{stock}} \)
5. Calculate degradation rate: \( Qu = \% Qu \times A \)
6. Define Emission Factor for Leakage (EFI): \( EFI = C_{\text{stock}} \times \% Et \) (note: \( Et \) is 2%, see Table 1)
7. Calculate Leakage Emission total: \( El = EFI \times Qu \)

3.4 Emission reduction

Calculation of carbon emission reduction using the following steps.

1. Define the seagrass area \( A \) within the MPA using the defined method by [14].
2. Estimate or measure the seagrass coverage \( Cov \), biomass \( Bm \), and density \( D \). One of these three parameters must be available, but complete parameters are preferable as a result would be more robust.
3. Convert the coverage, biomass or density to carbon stock value \( C_{\text{stock}} \) by using Seagrass Carbon Converter [15]
4. Calculate total carbon stock: \( \text{Stock total} = A \times C_{\text{stock}} \)
5. Calculate the extent of mitigation action \( Qc \) according to the total seagrass protected area. For the seagrass area within the MPA, \( Qc = Qu \). If there is any additional new protected area activity, \( Qc \) is calculated according to the protocol [13].
6. Define Emission Factor (EF): \( EF = C_{\text{stock}} \times \% Et \) (note: \( Et \) is 4%, see Table 1)
7. Calculate Emission Reduction (Er): \( Er = -(EF \times Qc) + (El) \). Negative notation \((-\) shows carbon emission reduction (Table 2).

3.5 A case study of Kepulauan Seribu MPA

The seagrass extent of Kepulauan Seribu in the year of T0 (2015-2016) and T1 (2017-2018) is 1,251.44 ha and 884.22 ha, respectively. Further, the seagrass extent in the MPA area at T0 and T1 are 769.20 ha and 548.82 ha, respectively. In this study, the MPA border followed the decree of the Forestry Minister in 2002 (Kep MenHut No. 8310/Kpts-II/2002. 13 June 2002), which has defined 113,325 ha of MPA area. The reef flat area of Kepulauan Seribu accounts for 5,126.62 ha. The seagrass bed occupies 24.4% of the reef flat area in Kepulauan Seribu and 24.6% of reef flats in the MPA.
The accuracy assessment was conducted only for T1 image data because the ground-truth data represent the study area’s current condition. The overall accuracy in T1 is 64.2%. The yield map’s accuracy has met the minimum accuracy of shallow water mapping in Indonesia [20]. This accuracy is also relatively similar to other studies using a medium-resolution satellite image with accuracy ranging from 30 to 90% with a rate of 65% [22]. Even high-resolution satellite images may often not result in better accuracy. Based on a study by [23], the Worldview-2 high-resolution image might only be able to yield a coral reef map in Kemujan Island with an accuracy of less than 65%.

Following up the estimation of seagrass extent in Kepulauan Seribu, we conducted a trial calculation of carbon emission reduction. Table 3 shows the result of the trial calculation by using the proposed method. It is shown that the baseline carbon emission from the seagrass area of Kepulauan Seribu is 5.39 tC/yr. Meanwhile, the emission reduction is calculated up to 0.49 tC/yr.

Table 3. Trial calculation using study case in MPA of Kepulauan Seribu

| Kepulauan Seribu | Value  | Unit          | Formula                  |
|------------------|--------|---------------|--------------------------|
| Average of 7 sites |        |               |                          |
| Density (D)*     | 285.00 | shoots/m²     | D                        |
| Biomass (BM)*    | 693.22 | DW g/m²       | Bm                       |
| Coverage (Cov)*  | 39.71  | %             | Cov                      |
| Total seagrass extent of Kepulauan Seribu |      |               | At                       |
| T0 (2015-2016)   | 1,251.44 | ha           |                          |
| T1 (2017-2018)   | 884.22  | ha           |                          |
| Seagrass extent of MPA |      |               | Am                       |
| T0 (2015-2016)   | 769.20  | ha           |                          |
| T1 (2017-2018)   | 548.82  | ha           |                          |
| Total reef flat area of Kepulauan Seribu |      |               |                          |
| 5,126.62 ha      |        |               |                          |
| Total reef flat within the MPA |      |               |                          |
| 3,128.56 ha      |        |               |                          |
| Total MPA |      |               | 113,325.00               |
| Average standing stock (C_{stock}) | 214.35 | gC/m²         | It was calculated using SCC according to D, Bm and Cov value |
| 2.14 tC/ha      |        |               |                          |
Baseline emission

| Total carbon stock | 2,682.40 tC | \( At^{\ast}C_{stock} \) |
|--------------------|-------------|---------------------------|
| Degradation rate (\( Q \)) | \( Q=%Q^{\ast}At \) (note: \( %Q=5\% \), see Table 1) |
| . estimation \( Q \) | 62.57 ha/yr |
| . observation (T1-T0) \( Q \) | 183.61 ha/yr |
| Emission Factor \( EF \) | 0.09 |
| Baseline Emission (\( Ex \)) | 5.36 tC/yr | \( Ex=EF^{\ast}Q \) |

Leakage emission

| Total carbon stock | 1,648.74 tC | \( Am^{\ast}C_{stock} \) |
|--------------------|-------------|---------------------------|
| Degradation rate (\( Qu \)) | \( Qu=%Qu^{\ast}Am \) (note: \( %Qu=1.5\% \), see Table 1) |
| . estimation \( Qu \) | 11.54 ha/yr |
| . observation (T1-T0) \( Qu \) | 110.19 ha/yr |
| Emission Factor \( EFl \) | 0.04 |
| Emission leakage (\( El \)) | 0.49 tC/yr | \( Ex=EFl^{\ast}Qu \) |

Emission reduction

| Total carbon stock | 1,648.74 tC | \( Am^{\ast}C_{stock} \) |
|--------------------|-------------|---------------------------|
| Degradation rate (\( Qc=Qu \)) | \( Qc=%Qc^{\ast}Am \) (note: \( %Qc=%Qu=1.5\% \)) |
| . estimation \( Qc \) | 11.54 ha/yr |
| . observation (T1-T0) \( Qc \) | 220.38 ha/yr |
| Emission Factor \( EF \) | 0.09 |
| Emission reduction (\( Er \))** | \( Er=-(EF^{\ast}Qc)+(El) \) |
| . with leakage \( Er \) | -0.49 tC/yr |
| . without leakage \( Er \) | -0.99 tC/yr |

Note: * data D, Bm, and Cov retrieved from [10]; ** negative notation shows emission reduction

Carbon emission projection within the Business As Usual (BAU) and conservation intervention (MPA) can be projected up to 2030 (Figure 2). We use the cumulative value of emission baseline (\( Ex \)) for the BAU projection (see sections above). Emission during the MPA intervention was estimated by
subtracting Ex with the emission reduction. Projection year by year is calculated cumulatively with the following formula (see Table 1 and 2 for the details):

\[
Ex_n = \sum_{i=1}^{n} \left( (C_{stock} \times \%Et) \times (\%Q \times AEt_{i-1}) \right)
\]

Then, the emission projection if the MPA regulation is implemented as a positive intervention is calculated by using the following formula (see Table 1 and 2 for the details):

\[
E_n = \sum_{i=1}^{n} \left( (Ex_n) + (Er_i) \right)
\]

Figure 2. Carbon emission projection on Kepulauan Seribu for implementation of seagrass conservation within the MPA. Emission within BAU was projected based on the potential emission of land-use change of the total seagrass area of Seribu Island.

Figure 2 shows the projected carbon emission starting from the baseline periods, i.e., 2016 to 2030. By implementing the conservation of the seagrass ecosystem within the MPA regulation, carbon
emission on the ecosystem is 42.48 tC in 2030. This emission is reduced by 4.35 tC relative to the BAU. Estimation of total carbon emission reduction in 2030 will increase 1.3 times higher than in 2020. As explained in the previous study, the seagrass ecosystem contributes 50% of carbon burial in marine sediments, equivalent to the sequestration of 1-2% of current global CO$_2$ emissions from fossil fuel combustion [24]. Therefore, conservation of the seagrass ecosystem is vital to avoid the damage of these ecosystems. Damaging the seagrass ecosystem will risk the release of carbon back to the atmosphere. On the contrary, the conservation of the seagrass ecosystem will contribute to climate change mitigation activity.

Both baseline emission and mitigation scenario projections are based on only two years of data and a pre-defined degradation rate. Ideally, change detection analysis of several years of image data is required to represent valid emission extrapolation (based on changed areas). Our proposed method will give estimates of the potential carbon emission reduction. However, to obtain the detailed calculations that site-specific, we need several years of change detection of the seagrass extent. Therefore, a systematic and more thorough investigation is necessary for further study.

4 Conclusion

The measurable, reportable, and verifiable (MRV) method for calculating carbon emission reduction, especially within the seagrass conservation activity, is developed and trialed in seagrass areas within an MPA. We expect that the method is reliable enough to support the MRV method within the Low Carbon Development Initiative’s entire carbon inventory. During the trial, the process and formula presented in this article show a reliable result. We can calculate the carbon emission reduction (i.e., 0.49 tC/yr) when the seagrass conservation within the MPA is implemented. Projecting up to 2030, protecting the seagrass ecosystem will reduce the emission by 4.35 tC relative to the BAU. Therefore, seagrass conservation can be used as one of the climate change mitigation activities under SDG13.

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