Estimating carbon emission and baseline for blue carbon ecosystems in Indonesia

Novi Susetyo Adi1*, Mohammad Sumiran Paputungan2, Agustin Rustam1, Alfabetian Harjuno Condro Haditomo3, Medrilzam4

1 Marine Research Center, Ministry of Marine Affairs and Fisheries, Jl. Pasir Putih 2, Ancol Timur, Jakarta 14430, Indonesia.
2 Faculty of Fisheries and Marine Science, Mulawarman University Jl. Kuaro, Gn. Kelua, Kec. Samarinda Ulu, Kota Samarinda-75119. Kalimatan Timur, Indonesia
3 Aquaculture Departement, Faculty of Fisheries and Marine Science, Universitas Diponegoro Jl. Prof. Soedarto Tembalang, Semarang, Central Java 50275, Indonesia
4 Directorate for Environmental Affairs, Ministry of National Development Planning/ National Development Planning Agency (BAPPENAS) Jl. Taman Suropati No.2 Jakarta 103110, Indonesia
*Corresponding author: novi_marineoptics@yahoo.com

Abstract. There is a good chance for Indonesia, the largest archipelagic state in the world, to contribute to climate change mitigation effort by optimizing the 'regulating and maintenance' ecosystem service in the form of 'blue carbon' function provided by mangrove and seagrass. These so called 'blue carbon' ecosystems have 3-5 times capacity of storing and sequestering carbon compared to terrestrial vegetation. This paper attempts to provide the estimation of baseline or Business as Usual (BAU) scenario for blue carbon ecosystems which would be required if formal emission inventory of 'blue carbon' ecosystems is to be implemented. The result shows mangrove degradation occurs both during base years of 2000 - 2016 and during the projected emission period of 2017 - 2030. Mangrove conversion to aquaculture pond is the main cause of degradation, contributing up to 72.50 % of the total carbon emission. Blue carbon climate change mitigation by mangrove rehabilitation can only reduce up to 6 % of carbon emission from baseline in 2030. Significant emission reduction of 73.38% from BAU emission in 2030 can only be achieved through integration of mangrove rehabilitation, silvofishery practice and the prevention of mangrove conversion to other land-uses.

1. Introduction

The main impact of climate change on coastal and marine ecosystems is principally altering the ecological systems which in turn modifies the provision of ecosystems services to coastal community. The Paris Agreement, which was adopted by all 196 parties to the United Nations Framework Convention on Climate Change (UNFCCC) at Conference of Parties (COP) 21 in December 2015, marked a turning point with nations now can independently decide how to lower their green house gas (GHG) emission through its Nationally Determined Contributions (NDCs). Indonesia has committed to Paris Agreement by targeting 29 % reduction of its GHG emission by 2030. Indonesia potentially contributes to reducing global green house gas as it has the largest mangrove 'blue carbon' coverage in the world (22.6 % of the world's total mangrove area) [1]. Mangrove has been included as one of climate change mitigation
components under Forestry Sector in Indonesia's Nationally Determined Contribution (NDC) submitted to UNFCC in November 2016. However, the largest carbon storage compartment (or 'carbon pool') of mangrove, which is the soil carbon pool, has not been included yet in the inventory activity [2][3]. Based on mangrove carbon stock data compiled by [4] and [5] biomass component only comprises of 19.62% and 2.16% of the total mangrove carbon stock in Indonesia, whereas its largest proportion of 78.14% is stored in the form of soil carbon component.

According to [6] mangrove degradation rate in Indonesia between 1980-2005 is in the range of 52,000 ha/year with mangrove-to-aquaculture conversion identified as the main cause of degradation. The conversion is estimated releasing carbon to atmosphere as much as 0.07-0.21 Pg CO2/year with average of 0.19 Pg CO2/year (equals to 0.02-0.06 Pg C/year or 0.05 Pg C/year in average). Therefore, in term of climate change mitigation it is important to establish baseline from which climate change mitigation from mangrove 'blue carbon' can be calculated and how this mitigation can be quantitavely measured from business as usual scenario (BAU). This is actually the main goal of this research and the result is expected to contribute to climate change mitigation and adaptation from 'Marine and Fisheries Sector', a sector which is not yet explicitly considered in the climate change policy in Indonesia, the largest archipelagic state in the world. Therefore, the specific objectives of this study are 1.) to develop ‘baseline emission’ of mangrove ecosystem and its projected 'business as usual' baseline emission until 2030, and 2.) to calculate potential emission reduction from mitigation actions related to mangrove ecosystems until 2030.

2. Methodology
The method used in this study is basically to calculate and to compare carbon emission from mangrove for two scenarios, first is when business as usual scenario (BAU) is applied and second is when mitigation action is implemented. Therefore, the data used and analysed include time-series mangrove area, mangrove carbon stock in Indonesia and factors trigering mangrove degradation in Indonesia. Emission calculation for both scenarios is projected until year 2030 to correspond to the target year indicated in the Indonesia's NDC.

Carbon emission due to mangrove degradation is equal to the total sum-up of carbon stored in the sediment at 1 m depth and in the biomass. However, the percentage of carbon loss varies according to the cause of mangrove degradation [7]. For instance, the percentage of mangrove carbon loss from wood extraction is smaller compared to the loss due to fish/shrimp pond conversion as the later involves the excavation of mangrove sediment, the largest carbon pool in mangrove. Biomass and soil carbon stock data used in this study is obtained from literatures on Indonesia mangrove carbon. The data are used to compile mangrove emission factor for calculating carbon emission from mangrove cover change over time [8,9]

The percentage of mangrove carbon emission is calculated based on [7] which is implemented in the inVEST model developed by [10] and [11]. Stock difference method of [11] is applied in this study where the quantity and rate of emission is determined by the type of factors / activities causing mangrove degradation [10].

Equation (1) is used to calculate annual carbon emission from mangrove cover change from year 2000-2030 (modified from [7]):

\[ E_t = E_0 e^{kt} \]

- \( E_t \) : emission after mangrove degradation (tC)
- \( E_0 \) : initial emission or carbon stock in soil or biomass (tC)
- \( k \) : constant rate of carbon stock reduction in soil or biomass
- \( t \) : total time after mangrove degradation (year)
The method of [11] is used to calculate carbon reduction from carbon accumulation or absorption in biomass and soil. An example of mitigation action is mangrove rehabilitation program where carbon starts to accumulate after mangrove plantation program is conducted [11]. Equation (2) and (3) are used to calculate carbon accumulation in mangrove biomass and soil (modified from [11]).

$$S_b = (B \times (1 + R)) \times CF \times A$$  \hspace{1cm} (2)

\(S_b\) : annual carbon absorption in biomass (t C)

\(B\) : annual growth of above-ground biomass (9,9 t dry weight of biomass/ha)

\(R\) : ratio between above-ground biomass dan below-ground biomass (0,49)

\(CF\) : conversion factor from biomass unit to carbon unit (0,451 t C/ton dry weight of biomass)

\(A\) : total area of mangrove rehabilitation (ha)

$$S_t = A \times F_a$$  \hspace{1cm} (3)

\(S_t\) : annual carbon absorption in soil (t C)

\(F_a\) : carbon accumulation factor in mangrove soil(t C/ha/)

\(A\) : total area of mangrove rehabilitation (ha)

2.1 Emission from Business as Usual Scenario (BAU)

Carbon emission under BAU scenario is basically the emission that results without any mitigation action [8]. It is calculated from mangrove cover change occurring during the 'selected base years' which is then linearly projected until 2030. The selected base years are from 2000 - 2016.

The estimation of mangrove area in 2030 due to fish / shrimp pond conversion is calculated using the estimated required fish / shrimp pond areas in 2030 based on the estimated production of total aquaculture production (excluding marine vegetation culture) in 2030 according to [12]. Series of linear regression analysis are then applied to obtain estimation of mangrove area and shrimp / fish pond area. The regression analysis includes: fish / shrimp pond production versus total aquaculture production (excluding marine vegetation culture), shrimp / fish pond production versus shrimp / fish pond area, and shrimp / fish pond area versus mangrove area using data from 2005-2016 (the results are not shown here). Those data are then projected until 2030 based on total aquaculture production of [12].

Mangrove cover change is estimated using mangrove use / conversion scenarios of [13] which uses 3 types of mangrove use / conversion from 2015-2035 (Table 1). Emission from these uses / conversions is calculated using equation (1).

| Type of mangrove use / conversion | Minimum use / conversion | Maximum use / conversion |
|----------------------------------|--------------------------|--------------------------|
| Wood extraction                  | 550 ha/year              | 1,800 ha/year            |
| Agriculture expansion            | 1,500 ha/year            | 4,800 ha/year            |
| Coastal development              | 300 ha/year              | 400 ha/year              |

2.2 Emission from Mitigation Action Scenarios

Mitigation scenario used is based on mangrove rehabilitation program defined in the decree No. 4 year 2017 issued by the Coordinating of Ministry of Economics of Indonesia which targets mangrove rehabilitation area of 3,49 million ha in 2045 (it is called as national mangrove management program or STRANAS, see Table 2).
Table 2. Annual targeted mangrove rehabilitation program (modified from STRANAS, see above text)

| Year | Targeted mangrove rehabilitation (ha) |
|------|--------------------------------------|
| 2016 | 10000 |
| 2017 | 10000 |
| 2018 | 30000 |
| 2019 | 30000 |
| 2020 | 40000 |
| 2021 | 40000 |
| 2022 | 40000 |
| 2023 | 40000 |
| 2024 | 40000 |
| 2025 | 64000 |
| 2026 | 64000 |
| 2027 | 64000 |
| 2028 | 64000 |
| 2029 | 64000 |
| 2030 | 84000 |

Carbon absorption gained from this program is calculated using equation (2) and (3). Mitigation action using minimum scenario of [13] is also used (see Table 1)

3. Results and Discussion

3.1 Mangrove coverage change from 2000-2016

Table 3 shows mangrove coverage change from 2000-2016 obtained from various data sources.

Table 3. Estimated mangrove area of 2000-2016

| Year | Mangrove area (ha) | Source |
|------|--------------------|--------|
| 2000 | 3.112.989          | [1]    |
| 2001 | 3.096.093          | Interpolation |
| 2002 | 3.079.196          | Interpolation |
| 2003 | 3.062.300          | [14]   |
| 2004 | 3.048.640          |        |
| 2005 | 3.034.980          |        |
| 2006 | 3.021.320          |        |
| 2007 | 3.007.660          |        |
| 2008 | 2.994.000          |        |
| 2009 | 2.980.340          |        |
In general mangrove cover degrades over time period of 2000 - 2016. Total mangrove area reduction from 2000-2016 is 230,289 ha.

3.2 Projected mangrove coverage change of 2017-2030

Similar to general pattern of mangrove condition from 2000-2016 (Table 3), the projection analysis shows that mangrove area decreases from 2017 to 2030 (Table 4). It is also observed that the main cause of degradation is mangrove conversion to fish / shrimp pond, contributing up to 64.14% of the total degradation. The total areas of mangrove change due to wood extraction, agriculture expansion, coastal development and fish / shrimp pond conversion are 25,200 ha, 67,200 ha, 175,266 ha and 5,600 ha, respectively (Table 4). The estimated remaining mangrove area in 2030 is 2,609,434 ha, or there is a reduction of 273,266 ha from the total mangrove area in 2016.

Table 4. Estimated mangrove cover change due to various activities

| Year | Baseline Mangrove area 2016 (ha) | Fish pond (ha) | Wood extraction (ha) | Agriculture (ha) | Coastal Development (ha) | Reduced mangrove area (ha) | Estimated mangrove area 2017-2030 (ha) |
|------|--------------------------------|----------------|---------------------|-----------------|--------------------------|---------------------------|--------------------------------------|
| 2016 | 2,882,700                      |                |                     |                 |                          |                           |                                      |
| 2017 |                               | 31,063         | 1,800               | 4,800           | 400                      | 38,063                    | 2,844,637                           |
| 2018 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,826,545                           |
| 2019 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,808,452                           |
| 2020 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,790,359                           |
| 2021 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,772,267                           |
| 2022 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,754,174                           |
| 2023 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,736,082                           |
| 2024 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,717,989                           |
| 2025 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,699,897                           |
| 2026 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,681,804                           |
| 2027 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,663,711                           |
| 2028 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,645,619                           |
| 2029 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,627,526                           |
| 2030 |                               | 11,093         | 1,800               | 4,800           | 400                      | 18,093                    | 2,609,434                           |
| Total of area | 175,266         | 25,200         | 67,200              | 5,600           |                         |                           | 273,266                              |
mangrove change (ha)

3.3 Estimated baseline BAU emission
As expected from the decrease of mangrove area over time, there is a corresponding increase in carbon emission from 2000 - 2030 (Figure 1). The largest emission occurs in 2015 due to significant loss of mangrove area of 23,200 ha between 2014-2015 compared to mangrove changes in other periods (Figure 1). On the contrary the lowest emission occurs in 2014 due to small mangrove area reduction of 7,700 ha between 2013-2014. The average carbon emission from 2000-2016 is 19,132,295.50 t CO$_2$-eq.

In line with the main factor causing mangrove degradation, mangrove-to-pond conversion contributes to the largest carbon emission, accounting for 72.50% of the total emission. It is important to note that carbon emission from mangrove-to-pond conversion occurring in the past is still carried over until year 2030 as it takes around 7.5 years for mangrove soil carbon to be completely released after its first disturbance [7]. In 2030 the total estimated baseline emission using BAU scenario is 31,659,669.67 t CO$_2$-eq (Figure 1).

![Figure 1. Total annual estimated BAU emission until year 2030](image)

3.4 Projected mitigation scenarios from 2017-2030
There are two mitigation scenarios simulated in this study. The first mitigation scenario relies only on the national mangrove rehabilitation program or 'STRANAS' (see section 2.2 and Table 2). The second scenario integrates both STRANAS and the prevention of mangrove conversion to other land-uses. The result shows that only planting mangrove will reduce annual carbon emission in 2030 as much as 1,897,771.68 t CO$_2$-eq, which is 5.99% reduction of baseline emission of BAU scenario in 2030 (Figure 2).

Scenario 2, which integrates mangrove plantation, silvofishery and minimum mangrove conversion to other land-uses reduces the projected total emission in 2030 from 31,659,669.67 t CO$_2$-eq to
8.426,865,37 t CO$_2$-eq which is 23.232,804,48 t CO$_2$-eq or 73.38% reduction of the baseline emission in 2030 of (Figure 1). The annual average emission using the 2nd scenario is 7,432,488 t CO$_2$-eq/year.

The implications of the two scenarios are wide and far-reaching. From the perspective of climate change mitigation using 'blue carbon' concept, eventhough the carbon storage capacity of blue carbon ecosystems exceeds natural carbon absorption of terrestrial vegetation, only relying on mangrove plantation would give insignificant reduction to carbon emission. Scenario 2 implies that climate change mitigation should be implemented in concert with conservation action and integrated terrestrial and marina spatial planning. Another important benefit of conserving blue carbon ecosystems is to preserve and rehabilitate their ecosystem services other than blue carbon service. In addition to providing regulating and maintenance service (where blue carbon function falls under) mangrove and seagrass also provide various ecosystem services such as provisioning, cultural and supporting services [19]. These various ecosystems services are directly used by human being to support their lives. Therefore, by integrating climate change mitigation action and conservation purposes through integrated marine and terrestrial spatial planning we support local action for preserving ecosystem services and at the same time contributing to global climate change mitigation (acting locally, impacting both locally and globally).

![Figure 2. BAU baseline emission and mitigation scenarios from 2017-2030](image)

4. Conclusions
Mangrove cover change calculation conducted in this study confirms various literatures that Indonesian mangrove decreases in an alarming rate. Though various factors causing the degradation can be identified, the main cause of the degradation comes from the conversion of mangrove to aquaculture ponds. This degradation is accompanied by increasing carbon emission released from both biomass and soil carbon pools of mangrove during both baseline emission of 2000-2016 and projected emission of 2017-2030. As carbon storage capacity of blue carbon ecosystems is 3 to 5 times higher than the one of terrestrial...
vegetation, mangrove degradation would release higher carbon emission compared to emission from forest degradation.

Effective climate mitigation action from blue carbon can not rely only on mangrove rehabilitation / replantation but would need to involve integration of various actions such as mangrove rehabilitation, silvofishery and the prevention of mangrove conversion to other land-uses. The action would also need the integration of both terrestrial and marine spatial planning so that the development in the watershed area would have minimum environmental impact in the marine-coastal area where blue carbon ecosystems thrive.

The possibility of using more complex models that enable the inclusion of more parameters (e.g. environmental drivers, population growth, policy intervention) for emission projection might be required to give more accurate and realistic calculation of blue carbon emission in Indonesia.

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