Carbon sequestration index as a determinant for climate change mitigation: Case study of Bintan Island

A'an J Wahyudi1, Afdal1, Bayu Prayudha1, I W E Dharmawan2, Andri Irawan3, Haznan Abimanyu4, Hanny Meirinawati1, Dewi Surinati1, Agus F Syukri2, Chitra I Yuliana5, Putri I Yuniati6

1 Research Center for Oceanography LIPI, Jakarta 14430
2 Biak Marine Life Conservation Unit LIPI, Papua
3 Research Center for Deep Sea LIPI, Ambon 97233
4 Research Center for Chemistry LIPI, Banten 15314
5 Research Center for Quality System and Testing Technology LIPI, Banten 15314
6 Research Center for Quality System and Testing Technology LIPI, Banten 15314
7 Economic Research Center LIPI, Gedung Widya Graha LIPI Lantai 4-5, Jakarta 12190
E-mail: aanj001@lipi.go.id

Abstract. The increase of the anthropogenic carbon dioxide (CO2) affects the global carbon cycle altering the atmospheric system and initiates the climate changes. There are two ways to mitigate these changes, by maintaining the greenhouse gasses below the carbon budget and by conserving the marine and terrestrial vegetation for carbon sequestration. These two strategies become variable to the carbon sequestration index (CSI) that represents the potential of a region in carbon sequestration, according to its natural capacity. As a study case, we conducted carbon sequestration research in Bintan region (Bintan Island and its surrounding), Riau Archipelago province. This research was aimed to assess the CSI and its possibility for climate change mitigation. We observed carbon sequestration of seagrass meadows and mangrove, greenhouse gas (CO2) emission (correlated to population growth, the increase of vehicles), and CSI. Bintan region has 125,849.9 ha of vegetation area and 14,879.6 ha of terrestrial and marine vegetation area, respectively. Both vegetation areas are able to sequester 0.262 Tg C yr-1 in total and marine vegetation contributes about 77.1%. Total CO2 emission in Bintan region is up to 0.273 Tg C yr-1, produced by transportation, industry and land use sectors. Therefore, CSI of the Bintan region is 0.98, which is above the global average (i.e. 0.58). This value demonstrates that the degree of sequestration is comparable to the total carbon emission. This result suggests that Bintan’s vegetation has high potential for reducing greenhouse gas effects.

1. Introduction
Coastal marine vegetation has an important role in global carbon cycle. Marine vegetation in the coastal ecosystem (e.g. mangrove and seagrass) has relatively narrow areas compared to the ocean (~0.5%) or land ecosystems. However, this ecosystem can be expected to sequester more than 50% of total carbon sequestration in the marine sediment, i.e. 216 TgC per year [1]. Furthermore, the coastal marine vegetation has relatively high net primary production/NPP. Seagrass and mangrove areas in Indonesia are about 3.000.000 and 4.390.756,46 ha, respectively (RCO-LIPI, 2017; unpublished data). These two ecosystems have high capacity to seclude carbon. For instance, the global carbon stock in seagrass ecosystem is from 4.2 up to 8.4 PgC [2].

The capacity in carbon sequestration can be used as mitigation approach for climate change. There are two approaches to mitigate climate change i.e. maintaining the greenhouse gasses (GHG) emission
below the level of the carbon budget and conserving the ecosystem services of the marine and terrestrial vegetation for carbon sequestration. Maintaining the GHG emission is related to the carbon budget, i.e. the maximum carbon emission that can be emitted to the atmosphere so that the earth surface temperature will not exceed a certain limit [3-5]. However, this approach should be complemented with the environmental conservation, which means to ensure the sustainability of the ecosystem services, especially the service for carbon sequestration.

The ecosystem services correlated to the climate change mitigation is the carbon sequestration capacity of the marine vegetation. The ratio of carbon sequestration and total emission of CO2 will be used to determine the carbon sequestration index (CSI). This index is used to determine whether or not the marine vegetation capacity to sequester carbon is comparable to the total emission of the study area.

The pilot study is conducted in order to test the CSI of Bintan region consisting of two administrative governances (i.e. Tanjungpinang city and Bintan district), which can be used further for the practical usage to develop local or national policy. The aim of this study is to develop the index for carbon sequestration that can be used for projection and direction of climate change mitigation policy. The detail objectives of this study are 1) to determine the carbon sequestration capacity of Bintan area, 2) to determine the total CO2 emission, 3) to define the development planning that might alter ecosystem services and carbon emission based on the social economy snapshot, and 4) to estimate the carbon sequestration index.

2. Methods

The study was conducted in Bintan area (i.e. Tanjungpinang city and Bintan district), Riau Archipelago province in Sumatra. The water-mass in the surrounding areas is affected by the South China Sea and specifically Karimata Strait. The primary data for coastal ecosystem were obtained from the survey in 2013 and 2014 [6,7]. Carbon sequestration capacity of Bintan area was defined by assessing carbon sequestration rate of mangrove and seagrass vegetation, following the previous studies [6,7]. Remote sensing and geographic information system were also used to determine the area of the terrestrial and marine vegetation [6,7]. Total GHG emission was determined using secondary data consisting of total industry, transport, etc., and then were estimated following the methods applied in National Action Plan for Greenhouse Gas reduction/RAN-GRK [8]. Field survey and observation for social economy were conducted in 2016 using questionnaire survey and in depth interview.

CSI was determined using the following approach: determining the total carbon sequestration and dividing it by the total carbon emission in the area

\[
\text{CSI} = \frac{(T_{\text{seq}} + M_{\text{seq}})}{(A_{\text{ems}})}
\]

i.e. CSI: carbon sequestration index; \(T_{\text{seq}}\): carbon sequestration by terrestrial vegetation; \(M_{\text{seq}}\): carbon sequestration by marine vegetation; \(A_{\text{ems}}\): total GHG emission of the area.

3. Results and Discussions

3.1 CSI determination

According to the datasets of Global Carbon Project, the global CSI value is 0.58 [9], which means that the capacity to sequester carbon is lower than the actual anthropogenic carbon emission (i.e. land and ocean sequestration divided by carbon emission = 315 GtC / 545 GtC) [9]. Table 1 and 2 are the primary and secondary data of carbon sequestration capacity of marine and terrestrial vegetation which is used to determine CSI. Total value of the carbon sequestration of terrestrial and marine vegetation is up to 0.262 Tg C yr\(^{-1}\), and the total emission value in Bintan is 0.273 Tg C yr\(^{-1}\). The CSI calculation is based on total carbon sequestration capacity divided by Total carbon emission. Thus, the CSI of Bintan is 0.262/0.273 = 0.98. The result of CSI calculation in Bintan from several factors are shown in Table 3.
Table 1. Vegetation area and its capacity in carbon sequestration.

| Vegetation | Area (ha) | Sequestration | |
|------------|-----------|---------------|-----------------|-----------------|-----------------|-----------------|
|            |           | Ton CO2 ha⁻¹ yr⁻¹ | TonC ha⁻¹ yr⁻¹ | Tg C ha⁻¹ yr⁻¹ |
| Bushes     | 54513.03  | 1.38           | 0.38            | 3.78E-07        |
| Forest     | 18009.81  | 4.88           | 1.33            | 1.33E-06        |
| Cropland   | 43900.44  | 0.99           | 0.27            | 2.70E-07        |
| Plantation | 9426.63   | 1.38           | 0.27            | 2.70E-07        |
| Seagrass   | 3130.18   |                | 38.02           | 3.80E-05        |
| Mangrove   | 11749.42  |                | 7.06            | 7.06E-06        |

Table 2. The range of carbon sequestration rates for four terrestrial vegetation.

| Terrestrial vegetation | Range of CO2 sequestration rate |
|------------------------|---------------------------------|
|                        | Ton CO2 acre⁻¹ yr⁻¹ | Ton CO2 ha⁻¹ yr⁻¹ | (median) |
| Cropland               | 0.2 - 0.6                | 0.99              |
| Forest                 | 0.05 - 3.9               | 4.88              |
| Grassland              | 0.12 – 1.0               | 1.38              |
| Swamp/Floodplain/Wetland | 2.23 – 3.71         | 7.34              |

*a Data based on TEEIC, 2016 [10]*

Table 3. CSI determination for Bintan area.

| Sector                      | CO2 emission |
|-----------------------------|--------------|
|                             | Ton CO2 yr⁻¹ | Ton C yr⁻¹ | Tg C yr⁻¹ |
|                             | Min          | Max         | Min | Max   | Min  | Max  |
| Transportation              | 450615.4     | 620318.7    | 122984.6 | 169300.9 | 0.123 | 0.169 |
| Industry                    | 67592.3      | 93047.9     | 18447.7 | 25395.2 | 0.018 | 0.025 |
| Land use change             | 162221.4     | 223314.8    | 44274.4 | 60948.4 | 0.044 | 0.061 |
| Wetland natural emission    |              |             |        |        | 0.017 |       |
| Total Emission (a)          |              |             |        |        | 0.273 |       |

| Vegetation | Area (ha) | CO2 sequestration | |
|------------|-----------|-------------------|-----------------|-----------------|
|            |           | Ton CO2 yr⁻¹ | Ton C yr⁻¹ | Tg C yr⁻¹ |
| Mangrove   | 11749.42  |              | 0.119          |             |
| Seagrass   | 3130.18   |              | 0.083          |             |
| Bushes     | 54513.03  | 75434.53     | 20588.0        | 0.021        |
| Forest     | 18009.81  | 87893.76     | 23988.5        | 0.024        |
| Cropland   | 43900.44  | 43392.10     | 11842.8        | 0.012        |
| Plantation | 9426.63   | 9317.48      | 2543.0         | 0.003        |
| Total Sequestration (b)     |              |              | 0.262          | 0.98          |

3.2 CSI Interpretation and its application for policy making

According to the previous research (2013-2014), Bintan has terrestrial and marine vegetation areas of 125.849,9 dan 14.879,6 ha, respectively [6] [7]. Both vegetation areas can sequester carbon up to 0,262 Tg C yr⁻¹ (i.e. 0.060 and 0.202 Tg C yr⁻¹ for the terrestrial and marine vegetation, respectively). Hence, marine vegetation contributes up to 77,1% for total sequestration.
Bintan’s carbon emission is 700-950 kilo ton CO₂ yr⁻¹, which is produced by transportation, industry, land used change and wetland sectors. This emission is equal to maximum 0.273 Tg C yr⁻¹ (note: 1 Tg C = 10⁶ ton C = 3.664 ton CO₂). Comparing the total carbon sequestration to the total carbon emission, thus CSI of Bintan is 0.98, which is above the global CSI (i.e.0.58). Bintan CSI shows that the degree of sequestration is comparable to the total carbon emission. However, the total emission has already reached the carbon budget of Bintan area.

Indonesia, according to the Global Carbon Project, has carbon budget 25 Gt CO₂ up to 2050 (i.e approximately 0.62 Gt CO₂ per year) [9]. Considering Indonesia’s population in 2015, which is 255.2 million people [11,12], carbon budget per capita of Indonesia is 98 ton CO₂. Referring to Bintan’s population (Tanjungpinang and Bintan district), which is about 337,000 people, and carbon budget per capita, therefore, the carbon budget of Bintan is 33 Mton CO₂ up to 2050 (about 943 kilo ton CO₂ yr⁻¹).

Following those facts above, the local government policy for local development may follow suggestions below. Firstly, carbon emission in Bintan is 700-950 kilo ton CO₂ yr⁻¹, which is the same as the carbon budget; therefore, it is necessary to maintain the total emission below the carbon budget. This approach can be applied by certain policy:

- To implement the Local Action Plan for Greenhouse Gas reduction (RAD GRK) which is in line with the National Action Plan for Greenhouse Gas reduction (RAN GRK). This plan has been initiated by Indonesian Ministry of National Development/ National Development Planning Agency (Bappenas) altogether with Ministry of Forestry and Environment.
- To manage the land use change. Land use sector contributes 67% of total national emission, higher than other sectors [8]. Land use change affects the capacity of marine and terrestrial vegetation in carbon sequestration. Deforestation, for instance, can increase the carbon emission to the atmosphere instantly.
- To carry out the campaign for using environmentally friendly fuel and low emission technologies. This approach is in line with the RAN/RAD-GRK.

Secondly, although Bintan’s CSI is higher than the global’s CSI, it is still necessary to initiate the conservation program for marine vegetation. According to our primary data and also suggested by the previous study [1,13], marine vegetation can be crucial because its contribution in carbon sequestration is higher than terrestrial vegetation. The policy making then can consider the following recommendations:

- To determine coastal ecosystem protection area. This policy can consider the province policy in Plan for Zoning of Coastal Areas and Small Islands (Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil or RZWP3K).
- To carry out the rehabilitation program for terrestrial vegetation ecosystem.
- To carry out strictly the national policy for the green open space (Government Regulation or PP no 26 year 2008 about Rencana Tata Ruang Wilayah nasional).
- To rehabilitate the coastal ecosystem and aquatic conservation areas (President Regulation or Perpres no 61 year 2011 about RAN GRK; Appendix 2).

4. Conclusions

Bintan’s CSI (0.98) shows the degree of sequestration that is comparable to the total carbon emission in the area. However, the total emission already reaches the carbon budget (quota limit). Considering these facts, the government policy for local development should be implemented, including maintaining the GHG emission below carbon budget and conserving both terrestrial and marine vegetation.
Acknowledgments
Acknowledging the funding support from the Government of Indonesia on the Core Competence/DIPA research project FY2013-2014 of Research Center for Oceanography entitled “The study of carbon stock and sequestration of the coastal ecosystems of Bintan Island”, and Research grant of “Unggulan LIPI” program FY2016-2017 sub program 04 (The Mitigation of the Disaster and Global Climate Change). We acknowledged comments and suggestions from the reviewer and the editor of GCGE2017.

References
[1] Duarte C, Middelburg J and Caraco N 2005. Major role of marine vegetation on the oceanic carbon cycle. Biogeosciences 2:1-8
[2] Fourqurean J W, Duarte C M, Kennedy H, Marba N, Holmer M, Mateo M A, Apostolaki E T, Kendrick G A, Krause-Jensen D, McGlathery K J and Serrano O 2012 Seagrass ecosystems as a globally significant carbon stock. Nat. Geo. 5:505-9
[3] Intergovernmental Panel on Climate Change 2014a Climate Change 2013: The Physical Science Basis - Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed T F Stocker et al. (Cambridge: Cambridge University Press) p 1535
[4] Intergovernmental Panel on Climate Change. (2014b). Climate Change 2014 : Synthesis Report - Summary for Policymakers (Cambridge: Cambridge University Press) p 32
[5] Intergovernmental Panel on Climate Change. (2014c) Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, ed R K Pachauri and L A Meyer (Geneva, Switzerland: IPCC) p 151
[6] Afdal, Darmawan I W E, Rahmawati S, Meirinawati H, Prayudha B, Wahyudi A J and Alfiansyah Y R 2014 Carbon sequestration potential at coastal area of Bintan Island – Final Report II (Jakarta: RCO-LIPI)
[7] Afdal, Darmawan I W E, Rahmawati S, Prayitno H B, Ismail M F A, Prayudha B and Fitria N 2013 Carbon sequestration potential at coastal area of Bintan Island – Final Report I (Jakarta: RCO-LIPI)
[8] Kementerian PPN/Bappenas 2014 Potret Rencana Aksi Daerah Penurunan Emisi Gas Rumah Kaca (RAD-GRK) (Jakarta: Kementerian PPN/Bappenas) p 180
[9] Le Quéré C et al. 2015 Global Carbon Budget 2015. Earth System Science Data 7:349-396 http://dx.doi.org/10.5194/essd-7-349-2015
[10] TEEIC 2016 Terrestrial Sequestration of Carbon Dioxide (http://teeic.indianaffairs.gov/er/carbon/apptech/terrapp/index.htm Accessed on 4 October 2016
[11] BPS 2015a Hasil Survei Penduduk Antar Sensus 2015 - Result of the 2015 Intercessal Population Census (Jakarta: Badan Pusat Statistik, ISBN: 978-979-064-912-5)
[12] BPS 2015b Statistik Indonesia – Statistic Yearbook of Indonesia (Jakarta: Badan Pusat Statistik) p 670
[13] Kalkuhl M, Edelhofer O and Lessmann K 2015 The Role of Carbon Capture and Sequestration Policies for Climate Change Mitigation. Environ Resource Econ 60:55. https://dx.doi.org/10.1007/s10640-013-9757-5