CO₂ dynamics on three habitats of mangrove ecosystem in Bintan Island, Indonesia

I W E Dharmawan

1 Marine Life Conservation Unit, Biak-Papua, Indonesian Institute of Sciences, Jalan Bosnik Raya, Kab. Biak-Numfor, Papua-Indonesia, 98111
E-mail: iwayanekadharmawan@gmail.com

Abstract. Atmospheric carbon dioxide (CO₂) has increased over time, implied on global warming and climate change. Blue carbon is one of interesting options to reduce CO₂ concentration in the atmosphere. Indonesia has the largest mangrove area in the world which would be potential to mitigate elevated CO₂ concentrations. A quantitative study on CO₂ dynamic was conducted in the habitat-variable and pristine mangrove of Bintan island. The study was aimed to estimate CO₂ flux on three different mangrove habitats, i.e., lagoon, oceanic and riverine. Even though all habitats were dominated by Rhizophora sp, they were significantly differed one another by species composition, density, and soil characteristics. Averagely, CO₂ dynamics had the positive budget by ~0.668 Mmol/ha (82.47%) which consisted of sequestration, decomposition, and soil efflux at 0.810 Mmol/ha/y, -0.125 Mmol/ha/y and -0.017 Mmol/ha/y, respectively. The study found that the fringing habitat had the highest CO₂ capturing rate and the lowest rate of litter decomposition which was contrast to the riverine site. Therefore, oceanic mangrove was more efficient in controlling CO₂ dynamics due to higher carbon storage on their biomass. A recent study also found that soil density and organic matter had a significant impact on CO₂ dynamics.

1. Introduction

As a greenhouse gas, carbon dioxide (CO₂) is highly responsible for climate change and global warming [1-2]. Its concentration has soared significantly due to industrialization and massive energy consumption [3]. In the last decade, NOAA has recorded that the amount of CO₂ in the atmosphere increased from 382.68 ppm (2007) to 406.41 ppm (2017) by 3 ppm/year of its rate during 2017. Its trend has been followed by the increasing of air temperature globally. Multilateral actions have been conducted to reduce CO₂ emission through a REDD+ mechanism on several UNFCCC meetings [4]. Blue carbon is the most appropriate concept to mitigate impacts of climate change in the coastal area [5-7].

Mangrove is one of blue carbon ecosystems contributed on climate change mitigation [8]. The forest might be a breakthrough for elevated atmospheric CO₂ concentration, recently [9]. CO₂ dynamics are originated by carbon sequestration and photosynthesis for biomass conversion [10-11]. Carbon on biomass is stored as long as living period of mangrove [12-14]. A small part of it will be delivered to the ecosystem by old and dead compounds known as litter [15]. It initiates food web in the ecosystem and soil metabolisms [16-17]. CO₂ is released back to the atmosphere as the final product of soil respiration and decomposition [18-20]. The ability of mangrove ecosystem to sequestrate CO₂ is known much better than their emission.

Indonesia has the largest mangrove forest in the world [21]. The area represents their prominent capacity in capturing CO₂ from the atmosphere. Indonesian mangrove is potential for global climate
change mitigation [22]. However, as many as 40% mangroves in Indonesia disappeared and were converted to shrimp ponds in the last three decades [23]. Mangroves in Indonesia were highly deforested especially in Sumatera and Kalimantan [24]. It would impact on CO₂ dynamics in the atmosphere. Indeed, mangrove deforestation in Indonesia has contributed on the highest CO₂ emission in the world by 3.51 Gg CO₂e/y [25]. On the other hand, mangrove conversion still exists causing lower CO₂ capturing area.

Carbon dynamics is a biogeochemistry process on mangrove ecosystem to regulate the amount of atmospheric CO₂ concentration from - and through the atmosphere. As long as mangrove has various habitats such as riverine, lagoon or estuarine and sea-side, carbon dynamics will be variable along each habitat. On this study, we would like to estimate mangrove CO₂ dynamics on those three habitats. Bintan mangrove was the proper study site due to its complete habitat availability and pristine mangrove condition.

2. Material and method

2.1. Study site

The investigation was conducted on three specific different habitats, such as Lagoon (L), Riverine (R) and Fringe (F) on Bintan Island to estimate CO₂ dynamics among those habitats. Lagoon site is located in western part of Bintan Island. The lagoon is surrounded by mangrove community along its edge and three river ends. The riverine site was chosen on mangrove along Dompak River, south-west part of Tanjung Pinang city. Due to its position nearby the city of Bintan, Dompak River is considered as the main receiver of rich-mineral domestic wastes from the downtown. Mangrove on the east coast was assigned for the fringing site as long as its location had less influent from the riverine system.

2.2. Mangrove community, carbon stock and soil content analysis

As many as nine (3 replications x 3 plots) 10m x 10m quadratic plots were scattered on each site to assess mangrove community structure [26]. Species number, trunk diameter size, total density and Important Value Index (IVI) were targeted on each habitat [26-27]. Carbon stock of mangrove was assessed by allometric equation [28]. The equation relates between wood density (ρ) and diameter (D).

There were two equations used for estimating aboveground (Cₐg) and belowground carbon stock (C₉b) which are shown on equations below.

\[
C_{ag} = (0.251 \rho D^{2.46}) \times 50\% \quad \ldots \ (1)
\]

\[
C_{bg} = 0.199 \rho 0.899 D^{2.22} \times 39\% \quad \ldots \ (2)
\]

Soil samples were taken from each vegetation plot using 2.5” PVC core with no depth separation. Organic carbon in soil (%) was analyzed from each soil sample using Walkley and Black method. On the other hand, total nitrogen (%) and phosphorous (ppm) were assessed after Kjeldahl digestion and Bray I, respectively. All of the soil analysis procedure was conducted at Soil Sciences and Land Resource Laboratory, Bogor Agricultural Institute.

2.3. CO₂ dynamics estimation

In this study, CO₂ dynamics on mangrove ecosystem were delivered by three main components, which are sequestration, emission, and decomposition. CO₂ sequestration was estimated using litter fall analysis following the assumption that litter production rate was equal to the rate of carbon sequestration [19]. To collect the litter, as many as nine traps were hung on each habitat and placed in proper height to avoid tidally flooded (± 2m). Each trap was 0.5 m x 0.5 m x 0.5 m which was constructed using 0.5 inch PVC tube and covered by 1 mm mesh size of the net on the bottom and each side. Litter product in the trap was collected every two week, dried at 60 °C and weighted. A number of sequestered CO₂ is related to Net Primary Productivity of carbon and its relative molecular mass of CO₂ gas.
Estimation of CO2 emission from mangrove soil was done by gas sampling on four replications on each plot. The closed-chamber method was used to collect gas samples from low tide period in four-time intervals i.e., 0, 10, 20 and 30 minutes [18, 29]. CO2 concentrations were analyzed on Gas Chromatography (GC) Agilent 7890A mounted by flame ionization detector (FID) for CO2-CH4. As many as 1 ml gas sample was injected into GC. Standard curves were made using gas standard on different injected concentrations. CO2 fluxes were calculated by comparing peak areas of samples against Agilent Greenhouse Gas Checkout Sample [30].

The rate of litter decomposition data was taken by a mesh bag experiment which was filled by 10 gr yellowish leaves. Each bag was tightened on the soil surface and collected on several periods such as 2, 4, 7, 14, 28, 42 days. As many as three bags were yielded from each plot and period. The rest of left litter was cleaned gently, dried on 60°C for 3-5 days and weighed (W2). Decomposition rate was estimated using the following formula which included weight conversion factor (f= ~0.68) [31]. Litter mass losses during decomposition were assumed as released CO2 by multiplied with 3.67.

3. Result and Discussion
3.1. Mangrove ecosystem and carbon stock
Overall, mangrove community was dominated by Rhizophora apiculata (RA) species on each site (Table 1). The riverine habitat was the densest community since its total density was 7,550 tree/ha, followed by lagoon and fringe sites at 3,883 tree/ha and 3,550 tree/ha respectively. Nevertheless, average diameter on Lagoon site was the highest among other sites by 10.66 cm. Though its position faced the sea, aboveground carbon (Cag) and belowground carbon (Cbg) of the fringing site were estimated higher and differed significantly than the others. The trend was commonly found in other studies [32]. A wider range of salinity in the lagoon and riverine sites triggers more mangrove species occupying these habitats [33]. MDS ordination showed that mangrove community in Bintan river was standalone from the others (Figure 1).

![Figure 1. Multi-dimensional scaling (MDS) analysis combined with complete linkage cluster of Bintan mangrove vegetation data on three different habitats (O=oeceanic; L=lagoon; R=riverine).](attachment:image.png)

Table 1. Density (tree/ha), mean diameter (Dmean), species number (SN), Important Value Index (IVI), aboveground (Cag) and belowground carbon (Cbg) of three mangrove habitats in Bintan Island.

| Habitat  | Density (tree/ha) | Dmean (cm) | SN | IVI(%)   | Cag (Mg C/ha) | Cbg (Mg C/ha) |
|----------|------------------|-----------|----|---------|---------------|---------------|
| Lagoon   | 3883             | 10.66     | 8  | BG: 5.41 | 116.11 ± 66.51 | 46.17 ± 22.70 |
| Oceanic  | 3550             | 7.86      | 3  | BG: 35.08 | 193.80 ± 199.29 | 74.96 ± 69.35 |
| Riverine | 7550             | 6.50      | 8  | BG: 6.14 | 115.83 ± 31.29 | 53.78 ± 11.13 |
According to its soil characteristics, riverine mangrove had a clear differentiation than the others (Table 2). The oceanic mangrove was more base than the riverine and lagoon sites significantly (P<0.05) which would be caused by higher salinity and lower organic content. Carbon organic on the riverine sites were followed by total nitrogen and organic matter (TOM). It might be influenced by salinity which was normally increasing to the seaward site due to tidal mixing. In contrast, the density of soil had the highest value in the oceanic mangrove due to a higher concentration of sand. There was only phosphor total -Bray that had no significant differences among observed habitats. Rich organic and nutrient content in the riverine site was delivered from citizen domestic waste [34].

Table 2. Soil characteristic on three mangrove habitats in Bintan Island.

| Component          | Lagoon            | Oceanic           | Riverine          |
|--------------------|--------------------|-------------------|-------------------|
| Soil description   | Muddy sand         | Sand              | Mud               |
| Soil pH            | 3.59 ± 0.17<sup>a</sup> | 5.85 ± 1.34<sup>b</sup> | 3.8 ± 0.44<sup>a</sup> |
| Soil density       | 0.46 ± 0.11<sup>a</sup> | 0.61 ± 0.17<sup>b</sup> | 0.26 ± 0.07<sup>c</sup> |
| C-organic (%)      | 5.76 ± 1.84<sup>ab</sup> | 4.38 ± 1.83<sup>a</sup> | 8.54 ± 3.61<sup>b</sup> |
| N-Kjeldahl (%)     | 0.17 ± 0.05<sup>a</sup> | 0.17 ± 0.05<sup>a</sup> | 0.45 ± 0.16<sup>b</sup> |
| P-Bray (ppm)       | 11.875 ± 3.16<sup>a</sup> | 11.78 ± 0.95<sup>a</sup> | 10.52 ± 2.60<sup>a</sup> |
| TOM (%)            | 8.33 ± 2.02<sup>a</sup> | 9.37 ± 4.02<sup>ab</sup> | 17.12 ± 9.21<sup>b</sup> |
| NaCl (PSU)         | 29.50 ± 0.67<sup>a</sup> | 31.94 ± 0.86<sup>b</sup> | 25.42 ± 3.15<sup>c</sup> |

<sup>ab</sup>: Tukey test to define the significance of each soil component among three observed habitats (alpha=0.05).

3.2. Estimation of CO2 dynamics

Total sequestered CO2 was estimated at 0.81 ± 0.41 Mmol CO2/ha/year in Bintan Island. By each site, the fringing site was the best CO2 capturer among the others at 1.04 ± 0.41 Mmol CO2/ha/year followed by the lagoon and riverine system at 0.91 ± 0.38 Mmol CO2/ha/year and 0.47 ± 0.24 Mmol CO2/ha/year, respectively. No significant difference was found among sites. Bintan mangrove showed massive CO2 capturing rate and higher than another study on three sites in China which used the same approach [19]. The sequestration rate of Bintan mangrove ecosystem was influenced by soil density and salinity.

Soil-to-atmosphere CO2 flux had no significant difference among three habitats. On average, as many as 0.017 ± 0.018 Mmol CO2 was released annually per hectare by mangrove soil. The fringing site was the most exhausting CO2 at 0.019 ± 0.018 Mmol CO2/ha/year (Figure 2). There was no significant correlation between CO2 efflux and any soil characteristics. The emitted CO2 in Bintan mangrove was higher than other studies [18, 35-36]. However, it was lower than the emission from 75 sites in the world [37] and Australia [17].

On the other hand, decomposition process contributed on releasing 0.124 ± 0.100 Mmol CO2/ha/y, averagely. Unlike soil respiration emission, the fringing site had the lowest rate through decomposition followed by the lagoon and riverine sites (Figure 2). Organic matter and soil density were highly correlated to litter decomposition rate (Table 4). A recent study showed that Bintan mangrove was efficient in regulating CO2 in the ecosystem. As many as 82.47% of the carbon from total sequestrated CO2 was still kept in the ecosystem as biomass carbon stock by plants and biotas (Table 3). CO2 efflux by mangrove ecosystem was approximately 19.27% from total sequestrated whereas 80.73% would be used in the ecological system [16].
Figure 2. CO₂ sequestration of mangrove community (left); CO₂ emission during decomposition and soil respiration efflux through the atmosphere in Bintan mangrove ecosystem (right).

Table 3. CO₂ budget (sequestration – released) on three habitats of mangrove ecosystem in Bintan (Mmol CO₂/ha/year).

| Habitat     | Sequestration | Released CO₂ | Budget         |
|------------|---------------|--------------|----------------|
|            |               | Decomposition | Efflux         |
| Riverine   | 0.47          | -0.175       | 0.279 (59.36%) |
| Lagoon     | 0.91          | -0.104       | 0.788 (86.59%) |
| Oceanic    | 1.04          | -0.097       | 0.924 (88.85%) |
| Total Average | 0.81      | -0.125       | 0.668 (82.47%) |

Table 4. Spearman correlation between CO₂ flux and soil characteristics.

| Soil Components | Sequestration | Decomposition | Efflux |
|-----------------|---------------|---------------|--------|
| Soil pH         | 0.208         | 0.000         | -0.010 |
| Soil Density    | 0.542*        | -0.613*       | -0.062 |
| C-organic (%)   | -0.267        | -0.109        | 0.045  |
| N-Kjeldahl (%)  | -0.413        | -0.459        | 0.110  |
| P-Bray (ppm)    | 0.469         | -0.219        | 0.139  |
| TOM (%)         | -0.097        | 0.796**       | -0.189 |
| NaCl (psu)      | 0.525*        | -0.360        | -0.101 |

*: significance at P<0.05  
**: significance at P<0.01

4. Conclusions
CO₂ dynamics on pristine Bintan mangrove showed high sequestration and low production rates of CO₂ from- and through the atmosphere. It will be meaningful for maintaining and reducing CO₂ concentration in the atmosphere to cope climate change impacts on the coastal community. The government should conserve the mangrove forest in this area to improve their ability to capture CO₂ over years.

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