Characteristics of mangrove ecosystems in Weda Bay: Environment, Vegetation, and Aboveground Carbon Stocks

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Abstract. Weda Bay is one of the largest mangrove habitat in North Maluku and one of mega-biodiversity spots in Indonesia. However, data and information of mangrove vegetation and its ecosystem services particularly carbon stocks were limited. Mangroves were mapped using GIS-remote sensing and vegetation were sampled using transects in five sites of mangroves across Weda Bay. Transects were extended from seaward to landward to cover all vegetation variation and hydrodynamic conditions. Environmental data (water and substrate): temperature, pH, Dissolved Oxygen (DO), particle size of sediment, and nutrient (phosphate and nitrate) were collected. The objective is to identify characteristics of mangrove landscape and vegetation, it is environment, and it ecosystem services in term of aboveground carbon stocks. The study showed that the characteristics of landscape and vegetation of mangrove varied among hydrodynamic conditions. The bay is important habitat for 8.5% (17 species) of mangrove species in Indonesia. *Rhizophora apiculata* and *Bruguiera gymnorrhiza* were the most dominant mangroves. The environmental conditions of Weda Bay particularly northern part of the bay were suitable for mangrove growth. Substrate of mangrove did not vary significantly with distance from the seaward which was mainly dominated by mud and clay (3.9 - 63 µm). Mean water temperature in the mangrove area was 29.3°C, salinity 34.1 psu, mean water suspension was 46 mg l⁻¹, mean dissolved oxygen was 3.2 mg l⁻¹, and water current was 10 m s⁻¹. Aboveground carbon stock was considerable (752 ± 17.6 Mg C ha⁻¹). Change in aboveground carbon stocks over the distance from the seaward edge to landward edge was not significantly different. In contrast, aboveground carbon stocks varied among hydrodynamic conditions: estuarine, delta, and riverine mangroves. Delta mangrove contained the highest carbon stock (993 ± 27.7 Mg C ha⁻¹), followed by estuarine mangroves (645 ± 12.2 Mg C ha⁻¹) and riverine mangroves (244 ± 8.6 Mg C ha⁻¹). However, this ecosystem faced some threats such as mangrove extraction and plastic pollution. Better mangrove management e.g. reducing mangrove extraction and pollution are required to protect the functions and ecosystem services of mangroves. In addition, conserving mangrove forests will allow the government to achieve blue economy goals and to mitigate climate change through carbon sequestration.

Keywords: Mangrove, landscape, spatial metrics, vegetation, Weda Bay, aboveground carbon
1. Introduction

Indonesia is the largest habitat (23%) of global mangrove [1]. Mangrove grow in the interface areas between terrestrial and estuarine (marine ecosystem) known as lagoon, estuary, river, and coastal area. Mangroves are categorized as true mangroves and false mangroves (associate mangroves). About 67% (40 species) of true mangrove species in the world can be found in Indonesia [2]. At least 14 species of mangroves in Indonesia are endangered species and three of them are endemic species [2][3].

The importance of mangrove forest providing a variety of ecological function has been well documented. This ecosystem is habitat for both terrestrial species (such as birds, monkeys, snakes, and mammals) and marine biota (such as molusk, fishes, and crabs) [4]. Mangroves also important as spawning and nursery ground of fishes which is crucial for their life cycle [4]. The ecosystem also support numerous ecosystem services including shoreline protection, sediment control, filtering runoff, and nutrient and organic matter processing. The social and cultural values of mangrove forests are also well known including for traditional and educational resources. The economic values of mangrove forest is at least US$ 1.6 billion y\(^{-1}\) [5][6].

The potential of mangrove ecosystem as explained above is important to help the government to achieve blue economy goals particularly for food security [7]. For example, mangrove plants (leaf, fruite, wood bark, etc.) are important raw material of food, medicine, and other products including wax and handicraft [4]. Mangrove forests potentionally can be used to achieve at least five aspects of blue economy including coastal management and conservation, climate change mitigation and adaptation (blue carbon), tourism, fisheries, and small island management [8].

One of the largest habitat of mangrove in Indonesia is Weda Bay, Halmahera Island, North Maluku. Halmahera sea (including Weda Bay) is one of the Indonesian Troughflow (ITF) which play an important role for climatic and oceanic prediction, in turn useful for sea transportation, fisheries, and marine infrastructure development [9]. Coastal areas of Weda Bay is central of development and more than 65% of human population living in the coastal zone, 150 km of a coastaline. This drive mangrove deforestation and degradation for coastal development, aquaculture, and human settlement. Mangrove ecosystem also face tremendous threats due to human activities such as wood exploitation and industries. For example, marine ecosystem of Weda Bay including mangroves and waters are threatened due to tailing from Weda Bay Nickel (WBN Project) [10].

Data and information about conditions and characteristics of mangrove forest in Weda Bay is very limited, especially mangrove landscape and vegetation, mangrove environment, and its ecosystem services in term of aboveground carbon stocks. These data and information is required to achieve blue economy goals particularly to better manage and ensure sustainable use of mangrove forests. In addition, aboveground carbon (blue carbon) stock assessment is crucial to mitigate climate change. The aims of this study are: (1) to identify the conditions and characteristics of mangrove landscape and vegetation; (2) to assess the characteristics of environmental conditions of mangroves; (3) to quantify an ecosystem services in term of aboveground carbon stocks of mangroves forests. GIS-remote sensing, survey of mangrove vegetation and its environment (water and substrate), and particle analysis were conducted to address the described objectives.

2. Methodology

The study was undertaken in Weda Bay, Halmahera, North Maluku, Indonesia (Figure 1). Weda Bay is surrounded by Halmahera Island in north and west, and some small islands (< 200 km\(^2\)) in south and west. The coastal morphology of Weda Bay is relatively flat with some medium size of rivers, but some coastal areas are steep, the depth of the bay up to 1700m particularly toward Halmahera Sea. Mean water temperature was 29.2°C (range from 24 to 45 °C), mean salinity was 34.0, and mean dissolved oxygen was 7.0 mg l\(^{-1}\). The land surrounded the bay was urban area (Weda City) and rural area.
Three main methods were applied: GIS-Remote sensing, vegetation survey, and environment (water and sediment/substrate) samplings (Figure 2). Landsat Enhanced Thematic Mapper (ETM) year 1974 and Landsat Operational Land imager (OLI) images year 2013 were used to map mangrove cover change and characteristics of mangrove landscape. Landsat images were downloaded from the US Geological Survey (USGS) Website (https://earthexplore.usgs.gov). The improved image analysis (Maximum Likelihood Classification and Knowledge-Based Classification) was applied for image classification [11]. Maps were processed and analysed using ArcGIS 10.2 and coordinates were presented in terms of Universal Transverse Mercator (UTM). Mangrove landscape characteristics in term of spatial metrics were assessed using ArcGIS 10.5 and exported to Fragstats [12]. Landscape and vegetation characteristics were calculated by hydrodynamic categories: estuarine, delta, and riverine mangroves [11]. Digital Elevation Model 2012 was applied to assess geomorphology of coastal area including rivers, sloop, etc.

**Figure 1.** Study area of Weda Bay and five locations of mangrove transects in the bay.
Figure 2. Flowchart of methods: GIS-Remote sensing, vegetation survey, and environment (water and substrate) survey used in the study

A vegetation survey was conducted in March 2013 in eight mangrove transects containing total 112 plots (Table 1) representing estuarine mangroves, riverine mangroves, and delta/island mangroves located in five locations in Weda Bay (Figure 1). Transects were extended from the landward edge to seaward fringe. Size of plot for trees was 10 x 10 m, for saplings was 5 x 5 m, and for seedlings was 1 x 1 m. We measured diameter breast height (DBH) and height of trees and saplings and counted seedlings. Trees defined as stem with diameter > 10 cm, tree height > 4 m, saplings were diameter 2 -< 10 cm, height 2-4 m, and seedlings were diameter < 2 cm, height < 2 m. Vegetation data were analysed to identify vegetation characteristics including species composition, zonation, density, importance value index, and SIMPSON’s diversity index using formula developed by Cox [13]. A generic allometric equations developed by Chave et al. [14] was applied to quantify aboveground biomass and then converted into aboveground carbon stocks using the wood carbon fraction of 0.50 determined for tropical mangroves [15]. Monte Carlo simulation approach developed by Yanai et al. [16] was modified and applied to estimate the uncertainty in aboveground carbon stocks. Seedlings were excluded from the above ground carbon stock estimation because their carbon stock is negligible [15].

Table 1. Location of transects used for vegetation and environmental survey

| Code | Location       | Category    | No. of plots | Latitude       | Longitude     |
|------|----------------|-------------|--------------|----------------|---------------|
| B1   | Halmahera Botlol 1 | Estuarine   | 10           | 00°18'24.8''   | 128°00'10.6'' |
| B1   | Halmahera Botlol 2 | Estuarine   | 21           | 00°16'08.7''   | 128°47'49.8'' |
| B2   | Yevi            | Estuarine   | 19           | 00°20'13.9''   | 127°53'51.6'' |
Top layer sediment (10 cm) samples were collected in the centre of plots along the transects using a piston corer. Sediment was analysed using Particle analyser Malvern-Mastersizer 3000 to measure particle size and to assess sediment types. Water samples were collected in the tidal channel near the plots. It used to measure dissolved oxygen, salinity, phosphate, and nitrate.

3. Result and discussion
3.1. Characteristics of mangrove landscape

Total area of mangrove forest in Weda Bay in 2013 was 2,227 ha. This estimation may underestimate because the map of mangrove forest cover was produced using medium spatial resolution images could not detect small patches of mangrove forest. Mangrove forests were distributed mainly in northern part of the bay (Figure 3). There was not much change of mangrove forest cover during the study period 1974–2013, deforestation rate: 2.5 ha y⁻¹ (0.11 % y⁻¹). However, the study found extensive plastic pollution and mangrove extraction in mangrove area particularly in Weda City.
The spatial metrics of estuarine and riverine mangrove were similar, they were complex landscape ecosystem (Table 2). In contrast, spatial metrics of delta mangrove was very different from estuarine and riverine mangroves. Delta mangrove was less complex (mean patch size: 13 ha, mean perimeter: 2.1 km, and mean shape index: 1.21) and more isolated (proximity index: 112) than estuarine and riverine. Similar finding was found in temperate mangroves of Auckland, New Zealand which spatial metrics of delta mangroves were different from estuarine and riverine mangroves [11]. Information of mangrove landscape characteristics in term of spatial metrics provided ecological meaningful such as complexity and connectivity of mangrove landscape ecosystem. For example, spatial metrics of mangrove landscape affect marine biota living in the mangroves (e.g. community structure, foraging behaviour, migration) and ecosystem services of mangroves such as shore protection [17][18][19] [20].

| Table 2. Spatial characteristics of hydrodynamic categories of mangroves: estuarine, delta, and riverine |
|---------------------------------------------------------------|
| Estuarine mangroves | Delta mangroves | Riverine mangroves |
|---------------------|-----------------|--------------------|
| Mean patch size (ha)| 52              | 13                 | 25                 |
| Mean perimeter (km) | 5.7             | 2.1                | 3.4                |
| Mean shape index    | 3.59            | 1.21               | 4.81               |
| Mean proximity index| 1218            | 112                | 784                |

3.2. Characteristics of mangrove vegetation

This study managed to record 17 species of mangrove (11 family) in the Weda Bay, North Maluku (Table 3). This showed that the bay was habitat for 8.5% of mangrove species in Indonesia [2]. Thirteen of the mangrove species in Weda Bay were true mangroves and four species were false mangrove. Most of false mangroves were presence in riverine and estuarine mangroves (Table 4). Bruguiera gymnorrhiza, Rhizophora apiculata, and Rhizophora stylosa were the most common species which present in all mangrove categories (estuarine, riverine, and delta). Some mangroves were only found in riverine such as Excoecaria agallocha, Hibiscus tiliaceus, Barringtonia asiatica, Heritiera littoralis, and Pandanus tectorius. Mean diameter of mangrove trees was 22 cm and mean height was 17 m. Mean diameter of saplings was 6 cm and mean height was 5 m. There was no significant difference of diameter and height for estuarine, delta, and riverine mangroves.

| Table 3. Species composition in Weda Bay, Halmahera, North Maluku |
|---------------------------------------------------------------|
| No | Family | Species | Note* |
|----|--------|---------|-------|
| 1  | Arecaeae| Nypa fruticans | True mangrove |
| 2  | Combretaceae| Luminitzera littorea | True mangrove |
| 3  | Euphorbiaceae | Excoecaria agallocha | True mangrove |
| 4  | Lecythidaceae | Barringtonia asiatica | False mangrove |
| 5  | Malvaceae | Hibiscus tiliaceus | False mangrove |
|    | Malvaceae | Thespia populinia | False mangrove |
| 6  | Meliaceae | Xylocarpus granatum | True mangrove |
| 7  | Myrsinaceae | Aegiceras floridum | True mangrove |
| 8  | Pandanaceae | Pandanus tectorius | False mangrove |
| 9  | Plumbaginaceae | Aegialitis annulata | True mangrove |
Table 4. Presence of mangrove species in eight transect of estuarine, delta, and riverine

| Species                        | Estuarine Yevi | Delta / Island | Riverine | Maturing tanjung |
|-------------------------------|----------------|----------------|----------|------------------|
| 1. Nypa fruticans             |                |                |          |                  |
| 2. Lumnitzera littorea        |                |                |          |                  |
| 3. Excoecaria agallocha       |                |                |          |                  |
| 4. Barringtonia asiatica      |                |                |          |                  |
| 5. Hibiscus tiliaceus         |                |                |          |                  |
| 6. Thespesia populnia         |                |                |          |                  |
| 7. Xylocarpus granatum        |                |                |          |                  |
| 8. Aegiceras floridum         |                |                |          |                  |
| 9. Pandanus tectorius         |                |                |          |                  |
| 10. Aegialitis annulata       |                |                |          |                  |
| 11. Bruguiera gymnorrhiza     |                |                |          |                  |
| 12. Ceriops tagal             |                |                |          |                  |
| 13. Rhizophora apiculata      |                |                |          |                  |
| 14. Rhizophora mucronata      |                |                |          |                  |
| 15. Rhizophora stylosa        |                |                |          |                  |
| 16. Sonneratia alba          |                |                |          |                  |
| 17. Heritiera littoralis      |                |                |          |                  |

Mangrove vegetation particularly estuarine mangroves in Weda Bay formed zonation pattern: fringe (seaward) zone, middle zone, and landward zone. Fringe zone was dominated by *Rhizophora apiculata*. Middle zone was mixed vegetation (*Rhizophora mucronate, Ceriops tagal, Bruguiera gymnorrhiza*). Landward zone was mixed true mangrove and false mangrove vegetation (e.g. *Hibiscus tiliaceus* and *Pandanus tectorius*). However, zonation was not always clear because there was overlap zonation in some locations such as Yevi and Botlol. There was no clear mangrove zonation for delta and riverine mangroves. Some studies found that mangrove zonation was closely related to soil types (mud, sand, clay), salinity, wave, flooding and tide [21][22][23]. Noor et al. [2] associated mangrove zonation with ecological function such as community structure of mollusk sand crabs.

Tree and sapling density in riverine mangrove was high, mean density 533 stem ha\(^{-1}\) and 667 stem ha\(^{-1}\), respectively. This finding was in line with study conducted in Sundarbans, Bangladesh that...
mangrove density was higher in upriver than downstream due to low salinity [24]. Density of mangrove trees in delta mangrove such as Dadawe (417 stem ha$^{-1}$) and Bori-Bori (436 stem ha$^{-1}$) were high (>400 stem ha$^{-1}$) (Table 5). Our field observation showed that the condition of these delta mangroves vegetation (Dadawe and Bori-Bori) were good. In contrast, the density of mangrove in Yevi, Way Obus, and Imam were low, 268, 278 and 340 stem ha$^{-1}$, respectively. Some disturbances such as wood extractions for firewood and plastic pollution were found in these locations. The study also found mangrove recovery or mangrove succession in Botlol 1 due to mangrove logging in 1980s.

Different from tree density, the density of saplings in Yevi, Way Obus, and Imam were high, 916, 765, and 500 stem ha$^{-1}$, respectively (Table 5). This may related with wood extractions for firewood which provide space or canopy gap for seedlings and sapling establishment and growth. Other studies showed that establishment and growth of seedlings and saplings occur in canopy gaps where sufficient light is available and intra-species competition is low [25][26][27]. In contrast, sapling density in Bori-Bori was very low (138 stem ha$^{-1}$). This can be explained by the high tree density and high basal area (6.56 m$^2$ ha$^{-1}$) of mangrove trees in the island.

### Table 5. Density and basal area of trees and saplings of mangroves in Weda Bay

| Transects     | Trees | Saplings |
|---------------|-------|----------|
|               | Density (stem ha$^{-1}$) | Basal area (m$^2$ ha$^{-1}$) | Density (stem ha$^{-1}$) | Basal area (m$^2$ ha$^{-1}$) |
| Estuarine     | Botlol 1 | 570 | 10.5 | 560 | 0.34 |
| Estuarine     | Botlol 2 | 429 | 10.9 | 410 | 0.34 |
| Estuarine     | Yevi | 268 | 2.27 | 916 | 0.24 |
| Estuarine     | Way Obus | 278 | 11.3 | 765 | 0.45 |
| Delta         | Pulau Imam | 340 | 1.68 | 500 | 0.07 |
| Delta         | Pulau Dadawe | 417 | 2.05 | 483 | 0.07 |
| Delta         | Pulau Bori-Bori | 436 | 6.56 | 138 | 0.02 |
| Riverine      | Matuting tanjung | 533 | 10.4 | 667 | 0.30 |

The SIMPSON’S diversity index showed riverine mangrove was the most divers mangroves in Weda Bay (mean index: 0.74), followed by estuarine (mean index: 0.54) and delta mangroves (mean index: 0.45). Mangrove trees and saplings in Way Obus was the most divers among other transects (Table 6). This was correlated with the coastal geomorphology of Way Obus (relatively flats and long river) and conditions of substrate (mainly mud) which suitable for mangrove growth. Suitable habitat (substrate, geomorphology, tide, temperature, and salinity) are the most important factors influencing mangrove diversity [4]. Mangrove in delta mangroves (e.g. Bori-Bori) was less diverse (Table 6), this was due to the density and basal area in this delta mangroves was high (Table 5), so mangrove establishment and survival was low due to intra-species competition. Suyadi et al. [11] found that delta mangroves were characterized as low spatial heterogeneity or less complex (short edge perimeter and regular shape) and it was isolated from other mangrove patches. These characters explained low diversity of mangrove in Bori-Bori. This was also supported by the characteristics of delta mangrove landscape: regular shape, less connected, less edge perimeter, and less disturbance (Table 1).
Table 6. SIMPSON’S Diversity Index of trees and saplings of mangroves in Weda Bay

| Transects          | SIMPSON’S Diversity Index |
|--------------------|---------------------------|
|                    | Trees          | Saplings       |
| Estuarine Botlol 1 | 0.33           | 0.25           |
| Estuarine Botlol 2 | 0.59           | 0.56           |
| Estuarine Yevi     | 0.50           | 0.30           |
| Estuarine Way Obus | **0.75**       | **0.70**       |
| Delta Pulau Imam   | 0.63           | 0.69           |
| Delta Pulau Dadawe | 0.49           | 0.28           |
| Delta Pulau Bori-Bori | **0.23** | **0.20** |
| Riverine Matuting tanjung | 0.74 | 0.66 |

The most common species of mangroves in Weda Bay was *Rhizophora apiculata* dan *Bruguiera gymnorrhiza* (Table 7). These species were dominant in all transects (except Dadawe) and at all stage of mangroves (trees, saplings, and seedlings). This different from Komiyama et al. [28] found that *Sonneratia alba* was the most dominant species in Halmahera. This is due to species shifting caused by change of substrate, climatic factors, and oceanic factors. Mangrove expansion and species shifting driven by change of substrate, climatic factors, and oceanic factors are occurred in other region such in New Zealand, Australia, and USA [29][30][31][32]. Substrate of mangrove in Weda Bay may change due to sedimentation (land erosion) driven by land clearing and land mining (coastal mining) around the bay. Change in mangrove substrate (mudflat) in Auckland, New Zealand was mainly driven by land-based or catchment factors such as forest cover and sediment accumulation rate [29]. Dadawe was dominated by *Rhizophora stylosa* (Table 7) due to the substrate in this area was dominated by sand and it was less connected to other mangroves.

Tabel 7. Importance value index (%) of trees, saplings, and seedlings of mangroves

|                | Estuarine | Delta / Island | Riverine |
|----------------|-----------|----------------|----------|
|                | Botlol 1  | Botlol 2       | Yevi     | Way Obus | Imam | Dadawe | Bori-Bori | Matuting |
| Trees          |           |                |          |          |      |        |           |         |
| Aegiceras floridum | 4         |                |          |          |      |        |           |         |
| Bruguiera gymnorrhiza | 36        | 39              | 47       | 33       | 57   | 40     | 87        | 38      |
| Ceriops tagal  | 6         |                |          |          |      |        |           |         |
| Excoecaria agallocha | 3         |                |          |          |      |        |           |         |
| Heritiera littoralis |          |                |          |          |      |        |           | 3       |
| Hibiscus tiliaceus |          |                |          |          |      |        |           |         |
| Lumnitzera littorea | 6         |                |          |          |      |        |           |         |
| Rhizophora apiculata | 61        | 50              | 47       | 45       | 28   |        |           | 55      |
| Rhizophora mucronata | 4         |                |          |          |      |        |           |         |
### Aboveground carbon stocks

Aboveground carbon stock of mangrove forest in Weda Bay was 725 Mg C ha\(^{-1}\) (± 17.6 s.e.m.) across all eight transects (112 plots), with 96% stored in trees (699 ± 16.87 Mg C ha\(^{-1}\)), 4% in saplings (26 ± 0.68 Mg C ha\(^{-1}\)). This fall within the range observed in some mangrove area in Southeast Asia [33]. However, the aboveground carbon stocks in this study higher than reported by Rahman et al [24] in Sundarban, Bangladesh and it was much higher than aboveground carbon stocks of temperate mangroves in New Zealand [11][34]. Aboveground carbon stocks in delta mangroves (993 ± 27.7 Mg C ha\(^{-1}\)) were significantly higher than those in estuarine mangroves (645 ± 12.2 Mg C ha\(^{-1}\), \(p = 0.003\)) and riverine mangroves (244 ± 8.6 Mg C ha\(^{-1}\), \(p = 0.026\)), \(\chi^2 (2) = 8.92, p = 0.02\). In contrast, aboveground carbon of riverine mangrove in temperate region was higher than estuarine and delta mangroves [11]. Aboveground carbon stocks were closely related with canopy height and basal area [24][33]. But, it was not vary along transects from seaward to landward.

#### Rhizophora stylosa

| Species                  | Saplings | Seedlings |
|--------------------------|----------|-----------|
| Rhizophora stylosa       | 7        | 17        |
| Sonneratia alba          | 3        | 21        |
| Xylocarpus granatum      | 2        | 7         |

#### Saplings

| Species                  | Saplings | Seedlings |
|--------------------------|----------|-----------|
| Aegiceras floridum       | 5        | 27        |
| Bruguiera gymnorrhiza    | 25       | 45        |
| Ceriops tagal            | 10       | 35        |
| Excoecaria agallocha     |          | 33        |
| Heritiera littoralis     |          | 35        |
| Hibiscus tiliaceus       |          | 35        |
| Rhizophora aciculata     | 69       | 55        |
| Rhizophora mucronata     | 6        | 3         |
| Rhizophora stylosa       | 3        | 17        |
| Sonneratia alba          | 11       | 24        |
| Thespesia populnia       |          | 100       |
| Xylocarpus granatum      |          | 27        |

#### Seedlings

| Species                  | Saplings | Seedlings |
|--------------------------|----------|-----------|
| Bruguiera gymnorrhiza    |          | 100       |
| Ceriops tagal            |          | 27        |
| Heritiera littoralis     |          | 18        |
| Lumnitzera littorea      |          | 3         |
| Rhizophora aciculata     | 45       | 55        |
| Rhizophora mucronata     | 3        | 3         |
| Rhizophora stylosa       | 17       | 100       |
Some sources of uncertainty in the aboveground carbon stock estimation were allometric equation, sampling error, and measurement error. The Monte Carlo simulation showed that allometric equation was the highest source of uncertainty contributes 1.82% to the uncertainty in aboveground carbon tree stock estimates and 3.17%. This generic allometric equation [14] resulted higher uncertainty for temperate mangroves, up to 3.65% [29]. Local-species specific allometric equation is required to get low uncertainty in aboveground carbon stocks estimation.

3.4. Mangroves environments (coastal morphology, substrate, and waters)

Analysis of Digital Elevation Model (DEM) showed that coastal morphology of the northern part of Weda Bay (Figure 1: B2, B1, and B5) was relatively flat with some rivers. Morphology of the delta / islands such as Bori-bori Island, Dadawe Island, and Imam Island were flat and muddy. These conditions are suitable for mangrove growth [2]. Flat coastal morphology and the length of river were significantly correlated with the growth and thickness of mangroves [35]. However, western part of Weda Bay (Figure 1: B3) was steep and the rivers were narrow and short, so it was not suitable for mangrove growth.

Particle size analysis found that mud was the most dominant substrate of mangrove in Weda Bay. Mud was particles between 3.9 and 63 μm (silt and clay) and it was not vary along transects from seaward to landward. Sedimentation process (land erosion), often silt and clay rich, creates mudflats which physical condition facilitating mangrove establishment [36][37][38][39]. Other studies also found that the potential habitat of mangrove increase with sediment accumulation rate which resulted mudflats in coastal areas [40][41]. Catchment factors (e.g. sediment accumulation rate associated with upland forest cover) was the main factor of mangrove expansion in New Zealand, followed by oceanic factors (wave and salinity), and climatic factors (temperature) [29]. Substrate also determined species composition, for example, Avicennia marina and Rhizophora mucronata prefer to growth in muddy areas [23].

Dissolved oxygen in the mangrove ecosystem in Weda Bay was range from 1.18-6.09 mg l⁻¹ and pH of water in the mangrove ecosystem was range from 8.47 and 8.16. Phosphate and nitrate in the water of mangrove ecosystem was range from 0.014 to 0.010 ppm and range from 0.001 to 0.016 ppm, respectively. Organic matter content including phosphate and nitrate is the secondary triggers of
mangrove expansion after mud accretion in Australia [42][43]. Organic matter content enhanced mangrove growth, resulting in both a higher biomass and carbon stock [44][45][46][47]. It was highlighted that organic matter content and nutrient availability was the key factors of mangrove establishment and growth [48], other factors influence mangrove establishment and growth were temperature [49][50] and rainfall [48].

4. Conclusions
The study provided the first detailed mangrove cover dynamics and its spatial metrics in Weda Bay, Maluku Utara, Indonesia. The characteristics of mangrove landscape in term of complexity and connectivity varied among hydrodynamic categories of mangroves (estuarine, delta, and riverine mangroves). Landscape and vegetation of delta mangrove was characterized as less complex, less diverse, and more isolated than other categories. Further, Weda Bay is habitat for 8.5% of mangrove species in Indonesia which Rhizophora apiculata dan Bruguiera gymnorrhiza were the most common species in the bay. Mangrove ecosystems provided significant aboveground carbon stocks and it was varied among hydrodynamic categories of mangroves. Delta mangroves provide substantial aboveground carbon stocks up to 993 ± 27.7 Mg C ha⁻¹ because this mangrove category contains many large and high trees and low disturbance. Most disturbances occurred in estuarine and riverine mangroves were mangrove extraction and plastic pollution. Mangrove management should consider on the hydrodynamic conditions (estuarine, delta, and riverine mangroves). In addition, data and information of aboveground carbon stocks at the hydrodynamic conditions of mangroves are required to get accurate national blue carbon stock inventory. It is clear that mangrove conservation is crucial because this ecosystem is important carbon storage that can be used to mitigate climate change and to achieve blue economy goals.

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