Properties and carbon stocks of tropical tidal peat soils deposited on coral limestone in Numfor and Supiori Islands, Papua Province

R A Gani, P A Barus and Sukarman

Indonesian Center for Agricultural Land Resources Research and Development, Bogor, West Java, Indonesia

E-mail: ganisoil79@gmail.com

Abstract. Tidal peatlands in Numfor and Supiori Island, Papua are unique because it accumulates above coral limestone on the tidal environment. The substratum layer is solid coral limestone (lithic contact). The objective of this study was to determine the characteristics and carbon stocks in these areas. The soil samples were collected from each horizon for chemical and physical analysis. Carbon stocks estimation was calculated by multiplying peat thickness, area, bulk density, and organic C content in each soil map unit. The results showed that tidal peat soil reaction was acid to neutral (pH H$_2$O 4.9 to 7.3), while soil salinity was very high (8.32 to 22.3 dS m$^{-1}$). The cation content is very high in the order of dominance of Na$>$ Ca$>$ Mg$>$ K. Peat thickness varied from shallow to deep (50 to <300 cm). Soil organic C content ranged from 23.03 to 46.99% and bulk density ranged from 0.12 to 0.36 g cm$^{-3}$. The average of carbon stock in each peat soil map unit was 1.151 to 1.314 t ha$^{-1}$. Peat soils deposited on coral limestone in this region should be preserved as conservation areas due to its functions as a carbon sink and part of a tidal hydrological unit.

1. Introduction

Based on the map of Indonesian peatland scale 1:50,000, the total peatland areas in Sumatra, Kalimantan, Sulawesi, and Papua are 13,430,517 hectares [1]. On the island of Papua, peatlands cover an area of 3,011,811 hectares or 22.43%. Based on the results of mapping by Indonesia Center for Land Resources Research and Development [2, 3], peatlands in Papua were located on Numfor Island, Biak Numfor Regency, and Supiori Island, Supiori Regency, which covering 1,771 ha.

The genesis process of peat soil started from the presence of a shallow lake which is slowly overgrown by water plants and wetland vegetation. The dead and decaying plants gradually formed a layer which then became a transitional layer between the peat soil and the mineral substratum. The subsequent plant grew in the transitional layer and thickened the peat layer [4].

Peat soils in the inland of Papua generally have equal characteristics as peat soils in Kalimantan and Sumatra. However, the peat soils of Numfor Island, Biak Numfor Regency, and Supiori Island, Supiori Regency developed on solid limestones (lithic contact) in several places on the coast of the two islands. The peat soils are affected by tidal activities. Based on the hydrological setting, peat soils are divided into (a) ombrogenous peat soil, formed in an environment that depending only on rainwater and (b) topogenous peat soil, formed in the interior of the coastal plain/river, which is
affected by runoff from tide/flood that contains lots of minerals, so it is relatively more fertile [5]. Peat soils in both locations are classified as topogenous peat soils that are affected by tidal activity.

Under natural conditions, peat soils have a function as a carbon sequester, thereby contributing to reducing greenhouse gas (GHG) emissions into the atmosphere up to 5.4 t of CO₂ ha⁻¹ year⁻¹ [4]. If peat forests are cleared and drained, the carbon stored in the peat soils will be easily oxidized, releasing CO₂ gas, that contributes to global warming [6]. Carbon-rich peat soils are highly vulnerable to threats from climate change, hydrocarbon exploration, and deforestation [7]. The peat soils management requires careful planning with great care to avoid subsidence and carbon release.

Peatlands have various economic and environmental benefits that are very important for local people and the global community, therefore it is necessary to maintain a balance between these two benefits. The approach to sustainable peatland management is site specific; for example, paludiculture cannot be applied to all peatlands [8]. Information about the distribution, characteristics, and classifications of peat soils are needed for establishing sustainable ecological management. On the Numfor and Supiori Islands, the peat soil was formed above coral limestone and affected by tidal. We hypothesize that peat soils above coral limestone have unique properties compared to other peat soils. Based on the differences in the environment in which peat soil is formed, this study was conducted to determine the distribution, characteristics, carbon stock, and ecological function of tropical tidal peat soils in both islands.

2. Materials and methods
This research method followed the Indonesian National Standard Guidelines (SNI 7925: 2013) on Peat Soil Mapping at a scale of 1:50,000 [9]. Mapping activities consisted of several stages, including: (1) Data collection and compilation, (2) Determination of land unit interpretation map, (3) Field survey and verification, (4) Soil sample analysis, (5) Reinterpretation data and images, and (6) Compile the database for the final map. The research locations were in Numfor Island, Biak-Numfor Regency and Supiori Island, Supiori Regency, Papua Province, Indonesia (Figure 1).

Data collection and compilation were obtained from the results of previous soil research/surveys. Delineation of land units was done by overlaying Landsat image data with Digital Elevation Model (DEM), geological maps, and topographic maps using the ArcGIS program. The peat soils in the study area were classified according to the National Soil Classification [10] and Soil Taxonomy [11]. Peat soil samples were collected through the augering method using the Eijkelkamp auger.

Figure 1. The research locations on Papua Province
Analysis of physical properties consisted of bulk density (BD), ash content, and fiber content. Chemical analysis included soil organic C content (Walkley and Black), total N content (Kjeldahl), soil reactions (pH H₂O and pH KCl with a soil solution ratio of 1:5), Potential P₂O₅ and K₂O (HCl 25%), available P₂O₅ (Bray-1), exchangeable cations (Ca, Mg, K, Na) and cation exchange capacity (CEC) using 1 N NH₄OAc extract pH 7.0, base saturation (BS), total sulfur (HNO₃), and electrical conductivity (EC, ratio 1:5). All soil sample analysis procedures followed the Technical Guidelines for Soil, Water, Plant and Fertilizer Analysis [12]. The degree of peat decomposition was determined in the field by estimating the volume of the peat soil sample that came out after the sample was squeezed in a hand. Carbon stock (below ground) is estimated from the formula: Stock C (t) = L x D x BD x C-organic; where L is the area of peat (m²), D is the thickness of the peat (m), BD is the bulk density (g cm⁻³), and C-organic = organic carbon content [13].

3. Result and discussion

3.1. The distribution and classification of peat soils

Based on the results of the peat soil mapping, the peat soils on Numfor Island are 196 ha, while on Supiori Island, the peat soils cover an area of 1,575 ha. The total area of peat soils is 1,771 ha (Table 1). The depth of peat layer in the two locations varied from shallow (50 to <100 cm) to deep (200 to <300 cm). The substratum layer on the peat soil is solid coral limestone (lithic contact). The peat soils are topogenous peat soils that are influenced by brackish water. In general, the peat soils in both locations are located in the mangrove ecosystem (Figures 2 and 3).

![Figure 2. The mangrove forest in Numfor Island.](image1)

![Figure 3. The mangrove plants in Supiori Island.](image2)

From field observations, the peat soils in both islands are formed above coral limestone and limestone in the basin areas. It is suspected that some of the basin was a coastal doline that collapsed and peat soil was later formed in the basin. Based on the Geological Map of the Biak Sheet, Irian Jaya [14], the study area in Supiori Regency is composed of the Mokmer formation (Qm) consisting of coral limestone and limestone. Meanwhile, according to the Manokwari Sheet Geological Map [15], the geological formation on Numfor Island is the Manokwari Formation (Qpm) which is consisting of reef limestone, calcarenite, conglomerates, breccias.

The classification of peat soils in the study area is presented in Table 2. The classification uses the National Soil Classification [10] and Soil Taxonomy [11] as their equivalents. On Numfor Island, peat soils are dominated by Organosol Hemic or equivalent to Typic Haplohemists which generally have moderate peat depth (>200 cm). Other soil types that were found were Organosol Fibric which corresponds to Lithic Haplobrepts, and Organosol Hemic which corresponds to Lithic Haplohemists. Both of these soils generally have a depth of less than 100 cm. On Supiori Island, the types of soil
found include Organosol Sapric or equivalent to Typic Haplosapripts, Organosols Hemic or equivalent as Typic Haplohemists, and Organosol Fibric or equivalent as Lithic Haplofibrists.

### Table 1. The distribution and depth of peat soils in the study area.

| No. | Island | Districts   | Depth (cm) | Area (ha) |
|-----|--------|-------------|------------|-----------|
|     |        |             | 50 - <100  | 100 - <200 | 200 - <300 |          |
| 1   | Numfor | West Numfor | 28         | 118       | -          | 146       |
| 2   | Numfor | North Numfor| 38         | 12        | -          | 50        |
|     | **Sub total** |           | **66**     | **130**   | -          | **196**   |
| 1   | Supiori| West Supiori| 77         | -         | 37         | 114       |
| 2   | Supiori| East Supiori| 190        | 24        | 430        | 702       |
| 3   |        | South Supiori| -         | 280       | -          | 305       |
| 4   |        | Aruri Island | 419       | -         | -          | 453       |
|     | **Sub total** |           | **737**    | **331**   | **506**    | **1.575** |
|     |         | **Total Numfor and Supiori Islands** |           |           |           | **1.771** |

### 3.2. The soil reaction and electrical conductivity

All values for chemical properties of peat soil are based on soil fertility criteria [16]. Table 2 shows the pH H₂O is higher than pH KCl which indicates that the peat soil is negatively charged.

### Table 2. Peat soil chemical properties of the study field.

| Pedons and horizons | Depth (cm) | National Soil Classification and Soil Taxonomy | Geographic Coordinate | pH (1:5) | EC (1:5) | C | N | C/N |
|---------------------|------------|-----------------------------------------------|-----------------------|----------|----------|---|---|-----|
| Numfor Island       |            |                                               |                       |          |          |   |   |     |
| SO-06/I 0-17        |            | Organosol Hemic (Typic Haplohemists)          | 134° 49' 19.808°E 0° 57' 14.735°S | 7.1      | 6.6      | 13.64 | 24.80 | 1.06 23 |
| II 17-100           |            |                                               |                       | 5.4      | 5.1      | 18.08 | 26.44 | 1.01 26 |
| III 100-150         |            |                                               |                       | 5.5      | 5.2      | 16.27 | 23.03 | 0.68 34 |
| IV 150-200          |            |                                               |                       | 5.2      | 5.0      | 10.42 | 29.43 | 0.83 35 |
| SO-11/II 0-27       |            | Organosol Hemic (Lithic Haplofibrists)        | 134° 48' 46.850°E 0° 58' 10.121°S | 6.4      | 6.0      | 15.55 | 46.99 | 1.25 38 |
| II 27-50            |            |                                               |                       | 5.6      | 5.3      | 14.21 | 44.44 | 1.15 39 |
| III 50-75           |            |                                               |                       | 6.0      | 5.7      | 13.89 | 45.15 | 1.16 39 |
| IV 75-90            |            |                                               |                       | 5.5      | 5.1      | 17.25 | 46.47 | 1.12 41 |
| SO-16/II 0-40       |            | Organosol Hemic (Lithic Haplofibrists)        | 134° 48' 54.990°E 0° 57' 32.119°S | 7.0      | 6.5      | 13.25 | 33.72 | 1.11 30 |
| II 40-75            |            |                                               |                       | 7.2      | 6.6      | 14.52 | 30.69 | 0.88 35 |
| Supiori Island      |            |                                               |                       |          |          |     |   |     |
| SO-17/I 0-10        |            | Organosol Sapric (Typic Haplosapripts)        | 135° 44' 0.607°E 0° 47' 06.112°S | 4.2      | 3.7      | 9.65  | 35.19 | 0.92 38 |
| II 10-50            |            |                                               |                       | 5.9      | 5.4      | 8.27  | 31.89 | 0.86 37 |
| III 50-170          |            |                                               |                       | 6.5      | 6.0      | 12.41 | 19.11 | 1.00 19 |
| SO-22/I 0-60        |            | Organosol Hemic (Typic Haplohemists)          | 135° 30' 9.875°E 0° 39' 45.097°S | 5.0      | 4.5      | 1.99  | 40.97 | 1.29 32 |
| II 60-160           |            |                                               |                       | 4.3      | 3.8      | 2.82  | 38.32 | 1.13 34 |
| III 160-235         |            |                                               |                       | 3.3      | 2.8      | 5.93  | 35.64 | 1.04 34 |
| SO-35/I 0-60        |            | Organosol Fibric (Lithic Haplofibrists)       | 135° 43' 42.341°E 0° 46' 34.018°S | 4.9      | 4.6      | 17.84 | 29.93 | 0.85 35 |
Peat soils on Numfor Island are slightly acidic to neutral at the uppermost layer (6.4 to 7.1) and acidic to neutral at the subsurface layer (5.2 to 7.2). Meanwhile, the peat soil reaction on Supiori Island was very acidic to acidic in the uppermost layer (4.2 to 5.0) and very acidic to slightly acidic in the subsurface layer (3.3 to 6.5). Low pH values come from SO-22 soils (Table 2).

The tidal effect is reflected in the electrical conductivity (EC) value (Table 2). Moreover, the high EC is also a reflection of the mineral enrichment in the peat soil [17]. It is clear that the peat soils in both islands are classified as eutrophic peat soils with high mineral nutrients due to the tidal influence [18]. The peat soils in Supiori and Numfor have high EC value except for SO-22 soil.

Suratman et al. [19] explained that the peat soil reaction is influenced by hydrological conditions. The relatively high soil pH value in the uppermost layer is caused by brackish water or saltwater from tidal activity. Brackish water contains alkaline cations that can neutralize organic acids in peat soils. The pH H₂O in the upper layer tends to be high as a result of the tidal influence, whereas the lower layer with low pH on peat soils with medium to deep thickness is more caused by organic acid and moderate levels of sulfur (Table 3). SO-22 soil has a low EC value and low pH, indicating the weak influence of brackish water from the tidal activity on this pedon.

### 3.3. Organic C and ash content

Table 2 also shows the soil organic carbon content (SOC) in the studied peat soils. The SOC content of the peat soils on Numfor Island ranges from 23.03 to 46.99 %. The C/N ratio for peat soils on Numfor Island ranged from 23 to 41. The peat soils on Supiori Island contained SOC ranging from 19.11 to 40.97%, while the C/N ratio ranged from 19 to 38. There is no clear pattern in the distribution of SOC in the soil, but several profiles show a tendency to decrease SOC content with soil depth. The high SOC content and the C/N ratio indicate the low decomposition process of the peat soil.

### Table 3. Peat soil chemical properties of the study field (continue).

| Pedons and horizons | Depth (cm) | HCl 25% mg 100 g⁻¹ | Bray-I | Exchangeable cations ppm | CEC cmol/kg⁻¹ | BS | S | Ash content % |
|---------------------|-----------|---------------------|-----|--------------------------|---------------|---|---|--------------|
| **Numfor Island**   |           |                     |     |                          |               |   |   |              |
| SO-06/I             | 0-17      | 508 109 80.2        | 19.19 | 5.65 2.16 72.13          | 99.13 68.58  >100 | 2.27 | 51.58 |
|                     | II        | 17-100 517 129 91.2 | 21.47 | 6.47 2.45 191.24          | 221.63 71.35  >100 | 6.87 | 50.54 |
|                     | III       | 100-150 734 116 150.3 | 15.56 | 5.64 2.34 126.04          | 149.58 65.00  >100 | 4.43 | 57.23 |
|                     | IV        | 150-200 603 105 117.7 | 30.37 | 9.91 2.13 73.55           | 115.96 78.59  >100 | 4.34 | 45.70 |
| SO-11/I             | 0-27      | 174 125 32.3        | 35.50 | 6.59 2.47 173.73          | 218.29 100.61 >100 | 7.73 | 16.00 |
|                     | II        | 27-50 143 138 28.7  | 27.50 | 6.75 2.69 156.38          | 193.32 96.81  >100 | 8.06 | 18.85 |
|                     | III       | 50-75 86 131 16.1   | 30.47 | 6.50 2.60 161.51          | 201.08 100.75 >100 | 6.19 | 16.92 |
|                     | IV        | 75-100 141 130 27.3  | 25.36 | 6.52 2.60 186.63          | 221.11 102.08 >100 | 7.80 | 15.93 |
| SO-16/I             | 0-40      | 253 92 40.5         | 41.20 | 6.46 1.78 89.66           | 139.10 86.00  >100 | 6.33 | 30.90 |
|                     | II        | 40-75 176 92 32.8   | 36.92 | 5.98 1.75 100.11          | 144.76 73.60  >100 | 4.81 | 37.33 |
| **Supiori Island**  |           |                     |     |                          |               |   |   |              |
| SO-17/I             | 0-10      | 103 52 21.3         | 14.02 | 5.21 0.82 56.98           | 77.03 67.76  >100 | 11.40 | 33.10 |
|                     | II        | 10-50 162 45 33.8   | 22.61 | 5.28 0.82 53.38           | 82.09 57.03  >100 | 13.48 | 41.43 |
|                     | III       | 50-170 179 133 39.4 | 23.75 | 5.49 2.56 96.39           | 128.19 51.17  >100 | 1.85 | 59.56 |
| SO-22/I             | 0-60      | 13 9 3.1           | 47.53 | 2.50 0.17 0.59           | 50.79 84.56  60 | 4.49 | 23.42 |
|                     | II        | 60-160 8 7 2.9      | 45.45 | 2.67 0.14 0.76           | 49.02 79.39  62 | 11.88 | 28.21 |
|                     | III       | 160-235 14 14 3.6   | 62.97 | 3.49 0.27 1.59           | 68.32 74.47  92 | 11.74 | 33.51 |
| SO-35/I             | 0-60      | 27 228 6.1          | 41.72 | 11.20 4.46 187.80         | 245.18 93.88  >100 | 8.77 | 36.81 |

Table 3 shows ash content is high in all peat soils. On the peat soils of Supiori Island, all pedons showed an increase in ash content with increasing soil depth. Meanwhile, the peat soils on Numfor
Island do not show a clear pattern regarding the distribution of ash content. The ash content of peat represents the presence of nutrients and is often correlated with the number of mineral particles [17]. The high amount of ash was evidence of mineral enrichment in these peat soils.

3.4. Cation exchange capacity (CEC) and base saturation (BS)

The CEC value on all tidal peat soils is generally high, ranging from 51.17 to 100.75 cmol_\text{c} kg^{-1} (Table 3). The interesting finding is that the total base cations are higher than the CEC value except for SO-22 soil. This shows that all the negative charges bind the base cation, causing nearly all of the hydrogen (H\textsuperscript{+}) ions to be neutralized [20]. Moreover, base saturation reaches > 100% in all soil except for SO-22 soils (Table 3). The order of magnitude of exchangeable cations in the soil is Na > Ca > Mg > K. The exchangeable Na content in almost all soils reaches more than 100 cmol_\text{c} kg^{-1}. This inevitably occurs due to the enrichment of mineral nutrients from the tidal influence. The abundance of alkaline cations eventually neutralizes the organic acids from the peat, causing that the soil pH to be in the slightly acid to neutral range. For SO-22 soils, base saturation (BS) ranges from 60 to 92% with the order of magnitude of exchangeable cations in the soil is Ca > Mg > Na > K. The exchangeable Na content in SO-22 soil is much lower compared to other pedons, but the exchangeable Ca content reaches 45.45 to 62.97 cmol_\text{c} kg^{-1}. The relatively high Ca content in SO-22 soil is thought to be derived from the weathering of coral limestone.

The chemical properties of tidal peat soils in Numfor Island and Supiori Island are unique and distinctive compared to other peat soils. This condition can occur due to several reasons, including the influence of the location of peat soils, the magnitude of tidal dynamics, and the influence of coral limestone as a substratum.

3.5. Degree of peat decomposition and water content

Understanding of physical characteristics will be very useful in determining the peat strategy [21]. The physical characteristics studied were the degree of peat decomposition, moisture content, and bulk density (BD). The degree of peat decomposition determines the level of peat soil's productivity because it affects the level of peat soil fertility and nutrient availability [22].

| Soil Samples code | Depth (cm) | Peat Maturity | Volume (cm\textsuperscript{3}) | Weight peat sampled (g) | Water content X-% | Water content U-% | Dry peat sampled (g) | Bulk Density (g cm\textsuperscript{-3}) |
|-------------------|-----------|---------------|-------------------------------|-------------------------|------------------|------------------|---------------------|----------------------------------|
| SO-06             | 0 - 50    | hemic         | 200                           | 327.1                   | 76.6             | 327.5            | 72.6                | 0.4                              |
| SO-11             | 50 - 100  | hemic         | 200                           | 258.0                   | 86.5             | 639.1            | 33.2                | 0.2                              |
| SO-16             | 0 - 50    | fibric        | 200                           | 215.7                   | 88.2             | 748.6            | 24.5                | 0.1                              |
| SO-17             | 50 - 100  | sapric        | 200                           | 579.9                   | 82.2             | 461.7            | 100.0               | 0.25                             |
| SO-35             | 0 - 50    | fibric        | 600                           | 753.8                   | 84.0             | 526.4            | 117.4               | 0.2                              |

Note: X = water content in the field capacity; U = water content when saturated

The degree of peat decomposition and water content in the study area are presented in Table 4. The saturated water content of the peat soil samples on Numfor Island was higher than that on Supiori Island. The degree of peat decomposition on Numfor Island is generally dominated by fibric (SO-11) and hemic (SO-06 and SO-16) with an average moisture content of 76.6 to 88.2%. Meanwhile, the degree of peat decomposition on Supiori Island was not only fibric (SO-35) and hemic (SO-22) but also sapric (SO-17) with an average moisture content of 82.2 to 84.7%. Peat soils with a degree of
fibric decomposition have a higher ability to retain water compared to hemic or sapric peat soils [21]. This means that the studied peatlands are useful for resisting seawater intrusion.

![Figure 4. Results of cross-sectional augering on sapric peat soils on Numfor Island.](image)

![Figure 5. Results of cross-sectional augering on hemic peat soils on Supiori Island.](image)

### 3.6. Bulk density (BD)

The results of the study in both islands showed BD in the peat layer with the degree of decomposition classified as fibric ranged from 0.17 to 0.20 g cm\(^{-3}\) (Table 4). The layer with the degree of decomposition classified as hemic had BD values ranging from 0.12 to 0.36 g cm\(^{-3}\). Meanwhile, the BD value in the layer with the degree of decomposition classified as sapric ranged from 0.25 g cm\(^{-3}\). The BD value obtained in this study was not much different from the BD value of peat soil from the results of other studies [19, 23]. The bulk density (BD) of peat soils varies greatly depending on the degree of peat decomposition with a tendency to decrease in BD value along with soil depth [24].

### 3.7. The potential carbon stocks

Based on calculations in the two study areas, the total carbon stock in Supiori Regency is 1.253 Mt on peat soils covering an area of 1,575 ha with thickness variations between 0.5 to 3 m [2, 3]. The average carbon stock is 1.15 t C ha\(^{-1}\). Meanwhile, the total carbon stock in Numfor Regency is 306.4 thousand tonnes on 196 ha of peat soil with an average of 1,314 t C ha\(^{-1}\). Sukarman et al. [25] stated that the characteristics of peat soils and environmental factors that most influence the amount of greenhouse gas emissions, especially CO\(_2\), are groundwater content, total acidity, cation exchange capacity, ash content, groundwater level depth, and fiber content. The carbon stock information in the two study areas could potentially be used in the soil database to determine predictive carbon stocks in peat soils with similar characteristics. [26].

### 3.8. The ecological function of peat soils

Peatland management requires scientific and technological innovation according to the characteristics of the peat soil and its hydrological settings [27]. Peat soils have very large porosity values (90 to 95%) so they can absorb very large water [18]. Shallow peat soils above coral limestone and limestone are located along the coast. Based on these conditions, the topogenous peat soils on the two islands function as a buffer for the entry of seawater into the land. Referring to its function as carbon storage and part of the tidal hydrological unit, the peat soils above the coral limestone on the two islands need to be preserved as a conservation area. Therefore, conservation, including protection from land conversion, and restoration, is urgently needed to prevent further loss of carbon stocks [6].
4. Conclusions
Peat soils in Numfor and Supiori Islands formed in basins in the coral limestone environment and were affected by tidal activity. The degree of decomposition of peat soils are sapric, hemic, and fibric. The peat soils have a very large water content in saturated conditions. The bulk density values are low. The peat soils have very acid to neutral soil reaction (pH H2O 4.2 to 7.2), very high organic C (23.03 to 46.99%), high to very high BS (62 \( \times \) to >100%), and very high CEC (51.17 to 102.08 cmol. kg\(^{-1}\)).
The potency of peat soils carbon stocks is 1.314 t C ha\(^{-1}\) in Numfor Island and 1.151 t C ha\(^{-1}\) in Supiori Island. Tropical tidal peat soils in these areas have ecological functions as a carbon pool and can be able to reduce saline water impact to the inland.

Acknowledgment
All of the authors are the main contributor to this paper. The authors are very grateful to The Indonesian Center for Agricultural Land Resources Research and Development (ICALRRD) for involving the authors in research activities and peatland mapping surveys and also the Peoples at Papua and West Papua Province which is helped us during the research.

References
[1] Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian 2019 Peta lahan gambut Indonesia skala 1:50.000 (in Bahasa) Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian, Kementerian Pertanian, Edisi Desember 2019.
[2] Sukarman and Seprianto 2018 Atlas peta sebaran lahan gambut skala 1:50.000 Kabupaten Biak Numfor Provinsi Papua (in Bahasa) Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian 19 pp. ISBN 978-602-459-177-9.
[3] Sukarman, Seprianto, Muslihat L and Gani RA 2018 Atlas peta sebaran lahan gambut skala 1:50.000 Kabupaten Supiori Provinsi Papua (in Bahasa) Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Badan Penelitian dan Pengembangan Pertanian. 19 pp. ISBN 978-602-459-195-3.
[4] Agus F and Subiksa I G M 2008 Lahan gambut: potensi untuk pertanian dan aspek lingkungan (in Bahasa). Badan Penelitian dan Pengembangan Pertanian.
[5] Sukarman 2016 Pembentukan, sebaran dan kesesuaian lahan gambut Indonesia. p 2-15 In: Nurida N L dan Wiharjardika (Eds.) Panduan Pengelolaan Berkelanjutan Lahan Gambut Terdegradasi (in Bahasa). Badan Penelitian dan Pengembangan Pertanian, Bogor.
[6] Basuki I, Kaufman J B, Peterson J, Anshari G and Murdiyarso D 2019 Land cover changes reduce net primary production in tropical coastal peatlands of West Kalimantan, Indonesia. Mitig. Adapt. Strateg. Glob. Change. 24: 557–573.
[7] Dargie D C, Lawson I T, Rayden T J, Miles L, Mitchard E T A, Page S E, Bocko Y E, Ifo S A and Lewis S L 2018 Congo Basin peatlands: threats and conservation priorities. Mitig. Adapt. Strateg. Glob. Change 24: 669-686.
[8] Agus F 2020 Pemanfaatan lahan gambut dan isu lingkungan. Pemanfaatan Gambut Secara Berkelanjutan (in Bahasa) Seminar BBSDLP 28 Mei 2020. Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan, Kementerian Pertanian.
[9] BSN 2013 Pemetaan lahan gambut skala 1:50.000 berbasis citra penginderaan jauh (in Bahasa). SNI 7925: 2013. Badan Standardisasi Nasional, Jakarta.
[10] Subardja D, Ritung S, Anda M, Sukarman, Suryani E and Subandiono R E 2016 Petunjuk teknis klasifikasi tanah nasional (in Bahasa). Balai Besar Penelitian dan Pengembangan Sumberdaya Pertanian Badan Litbang Pertanian, Bogor 45 pp.
[11] Soil Survey Staff 2014 Keys to soil taxonomy. 12th Edition. Natural Resources Conservation Service-United States Department of Agricultural, Washington DC 365 pp.
[12] Eviati and Sulaeman 2012 Petunjuk teknis analisis kimia tanah, tanaman, air, dan pupuk. Edisi 2 (in Bahasa). Badan Penelitian dan Pengembangan Pertanian, Kementerian Pertanian. 234 pp.
[13] Agus F, Hairiah K and Mulyani A 2011 Pengukuran cadangan karbon tanah gambut. Petunjuk Praktis. (in Bahasa). World Agroforestry Centre-ICRAF, SEA Regional dan Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian, Bogor 58 pp.
[14] Masria M, Ratman N and Suwitodirdjo K 1981 Peta Geologi Lembah Biak Numfor Irian Jaya, Skala 1:250.000 (in Bahasa). Pusat Penelitian dan Pengembangan Geologi, Bandung.
[15] Ratman N, Robinson G P and Pieters P E 1989 Peta Geologi Lembah Manokwari Irian Jaya, Skala 1:250.000 (in Bahasa). Pusat Penelitian dan Pengembangan Geologi, Bandung.
[16] Balai Penelitian Tanah 2009 Petunjuk Teknis Analisis Kimia Tanah, Tanaman, Air dan Pupuk. Balai Penelitian Tanah (in Bahasa) Badan Penelitian dan Pengembangan Pertanian, Departemen Pertanian, Bogor
[17] Fahmi A, Nurzakiah S and Susilawati A 2019 The interaction of peat and sulphidic material as substratum in wetland: ash content and electrical conductivity dynamic IOP Conf. Ser.: Earth Environ. Sci. 393 012045.
[18] Agus F, Anda M, Jamil A and Masganti 2016 Lahan gambut Indonesia: pembentukan, karakteristik, dan potensi mendukung ketahanan pangan. (in Bahasa). IAARD Press, Jakarta 246 pp.
[19] Suratman, Widiatmaka, Pramudyta B, Purwanto M Y J and Agus F 2019 Variasi karateristik biofisik lahan gambut dengan beberapa penggunaan lahan, di Semenanjung Kampar, Provinsi Riau (in Bahasa). Jurnal Tanah dan Iklim 43(2): 97-108.
[20] Andriesse J P 1988 Nature and Management of Tropical Peat Soils FAO Soils Bulletin 59.
[21] Asria T, Basri H, Manfarizah, Zainabun and Mukhtaruddin 2020 Physical and chemical characteristics in peatlands of Aceh Jaya District, Indonesia. IOP Ser.: Earth Environ. Sci. 499 012004. Doi:10.1088/1755-1315/499/1/012004.
[22] Dariah A, Maftuah E and Maswar 2014 Karakteristik lahan gambut Indonesia. Hlm: 16-29 In: Nurida N L dan Wihardja (Eds.) Panduan Pengelolaan Berkelanjutan Lahan Gambut Terdegradasdi (in Bahasa) Badan Penelitian dan Pengembangan Pertanian, Bogor.
[23] Masganti 2013 Kajian upaya meningkatkan daya penyediaan fosfat dalam gambut oligotrofik (in Bahasa). Disertasi. Program Pascasarjana UGM, Yogyakarta 355 Hlm.
[24] Driessen P M and Rochimah L 1976 The physical properties of lowland peat of Kalimantan. Proc. Peat and Podzollic Soil and Their Potential for Agriculture in Indonesia. (Soils Res. Ins Bogor). ATA 106. Bull. 3: 56-73.
[25] Sukarman, Suparto and Mamah H S 2012 Karakteristik tanah gambut dan hubungannya dengan emisi gas rumah kaca pada perkebunan kelapa sawit di Riau dan Jambi (in Bahasa). p 95-111 In: Husen E, Anda M, Noor M, Mamah H S, Maswar, Fahmi A dan Sulaeman Y (Eds.) Prosiding Seminar Nasional Pengelolaan Lahan Gambut Berkelanjutan, Bogor 4 Mei 2012.
[26] Shofiyati R, Las I and Agus F 2010 Indonesian soil database and predicted stock of soil carbon. Proc. of Int. Workshop on Evaluation and Sustainable Management of Soil Carbon Sequestration in Asia Countries. Bogor. Indonesia Sept 28-29 2010.
[27] Hairani A and Noor M 2020 Water management on peatland for crop and horticulture production: research review in Kalimantan IOP Conf. Ser.: Earth Environ. Sci. 499 012006. Doi:10.1088/1755-1315/499/1/012006.