The determination of peatland critical criteria and classifications: A Case study of peatland in Pontianak City, West Kalimantan Province

R W Nusantara1,2, Warganda3, R Manurung1 and R Hazriani1
1Soil Science Department Agricultural Faculty of Tanjungpura University, Jalan Prof. Hadari Nawawi, Pontianak, 78124
2Magister of Environment Science Pasca Sarjana of Tanjungpura University, Jalan Prof Hadari Nawawi, Pontianak, 78124
3Department of Agrotechnology, Faculty of Agricultural, Tanjungpura University Jalan Prof. Hadari Nawawi, Pontianak, 78124

rwiedyanusantara@gmail.com

Abstract. Critical land is one of the degraded lands causing a temporary or permanent decline in land productivity. It is characterized by the decrease of physical, chemical, and biological soil properties. The objectives of this study were to determine the determinant factor that affects the criticality level of peatlands and to set up criteria and classifications of peatland criticality degree (level) based on the determinant factors through discriminant approach. The determination of location was based on the most used land and land-use differences. The land use consists of acacia, horticulture and pineapple plantation. The research stages included the observation and measurement of land physical characteristics including water table and peat, soil sampling and analysis of soil physical and chemical characteristics. The data analysis included classical assumption consisting of multikolineritas, autocorrelation, and heterokedastisitas from an independent variable to land type, regression analysis and multivariate analysis of the determinants of peatland degradation and cluster analysis in classifying critical peatlands. The results show that there are varieties of physical, chemical and biological factors in acacia, horticulture and pineapple plantation. The four critical determinants of peatland are total phosphorus, number of bacterial, number of fungi and peat depth. The three critical land classifications are Critical, Non-Critical, and Non-Critical without soil tillage and drainage. The information about the criticality factors of peatland is expected to be considered to rehabilitate peatland and improve criteria of critical peatland.

1. Introduction
The world's tropical peatlands are about 38 million hectares, mostly in Indonesia (14.9 million hectares). About 35.16% of the total peatland is in West Kalimantan. [1]. Peatlands contribution on ecological aspects is: (1) as large carbon stock reserves (25% C terrestrial contained in peatland). Therefore, peatlands are known as global climate controllers, (2) as hydrological buffers as large water reservoirs where peat, in general, has very large absorption and water storage capacity (0.8-0.9 m³ / m³) [2], (3) as habitats and conservation of biodiversity, as there are a number of endemic species that can only grow in peat ecosystems [3].
Peat swamp forest is one of the most endangered types of wetlands in Indonesia due to human activities as well as land use conversion. It totally affects the quality of the peatlands. Land quality can be an indicator of degraded land. Land degradation is a temporary or permanent declining process of land productivity that is characterized by the decreased physical, chemical, and biological properties of the soil. Critical land is one of the degraded lands [4]. According to UU RI Number 37 the Year 2014, damaged land or critical land is a land that has reduced or less function as a planting media.

According to the Head of the Watershed Management and Protected Forest (BPDASHL) of West Kalimantan (Kalbar), 92% of the land in West Kalimantan is critical and potentially critical, and 7.41% is very critical. Plantation, Forestry and Mining Agency of Kubu Raya Regency (2013) recorded a peatland area of 24% of all West Kalimantan peatlands in which 97% of them are critical and extremely critically, the highest in Kubu Sub-district (27%) [1]. Improper land use and management can have a high potential for critical land. Until now, the data on critical land area is still uncertain especially on tropical peatland in Indonesia. It is because there are still differences in understanding the critical land, the different criteria used and the priority of handling [5].

An important function of peatlands for life buffer systems causes these ecosystems to be protected, managed wisely and returned to their functions when degraded. In order to support the successful management and rehabilitation of peatlands, the appropriate and specific information about biophysical and critical characteristics are to be needed [6]. In general, the quality of the physical environment is mostly considered from the aspect of water and air, while the soil is ignored [7]. The limited understanding of these matters has resulted ineffective in the rehabilitation and restoration of the peat ecosystem. It is reflected in the assessment of the current critical levels of forest and land use [8]. First, the criteria and the indicators of assessment in Permenhut Number P.32 / Menhut-II / 2009 illustrate the characteristics of dry land. Thus, their application to wetlands yields inappropriate assessment results. Secondly, criteria to determine the critical level of peatlands in Permenhut Number P.12 / Menhut-II / 2012 have only 3 aspects, namely the density of canopy/land cover, waterlogging and subsidence, while the peatland criticality factor can be much related to the physical, chemical and biological properties of soil peat. Third, the standard criteria for the damage to the peat ecosystem both as a function of protection and cultivation have more emphasized on the aspect of the existence of drainage, exposure to pyrite sediment, reduction of cover and groundwater level more than 0.4 m [9].

Therefore, it is necessary to determine the critical level of peatland specifically based on physical, chemical and biological characteristics of peat soil. The results are expected to determine the direction of government policies in restoring the function of peat ecosystems including rehabilitation, restoration and revegetation, and sustainable management of peatlands. The objective of this study was to determine the determinant factors that affect the criticality level of peatland and to set up the criteria and classification of peatland criticality level.

2. Methods
2.1. Time and location
The study location was in Southeast Pontianak, West Kalimantan (West Kalimantan). The determination of location was based on the most used land and differences in land cultivation ie acacia, horticultural and pineapple plantations (Figure 1). The research period was April to October 2017.

2.2. Research procedures
The research in this field included observation and physical measurement of land: water-table depth and peat depth, and peat soil sampling. The analysis of soil samples on the physical, chemical and biological properties was done in the Soil Chemistry and Fertility Laboratory, Soil Physics and Conservation and Soil Biology and Biotechnology of Tanjungpura University. Each point of water-table depth observation used a paralonic stick that was plugged into the depth of mineral soil. The water-table depth was measured based on the distance of water table level against the soil surface in
centimeters (cm) every 2 weeks. The peat depth was measured based on peat soils to reach mineral soil using a peat drill in cm units.

2.3. Soil sampling
Each location of study took 6 (six) sampling points as the replicates. The number of samples in the three fields were 18 samples. Undisturbed peat soil sampling was done from 10 cm thick peat drill for weighted content variables whereas other variables were disturbed soil samples in topsoil (0-20 cm). Soil samples were separated from plant roots, gravel, and other impurities. The sample was weighed, preparing the soil sample with <2mm and <0.5 mm by pounding and sieving so that the soil sample was ready to be analyzed.

![Figure 1. Research location in Southeast Pontianak, West Kalimantan (West Kalimantan). In 3 land use are acacia, horticultural and pineapple plantations](image)

2.4. Analysis of soil samples
The measurement of soil reaction (pH) used pH-meter. The total nitrogen used the Kjeldahl method. The total phosphorus used P-Bray. Exchangeable-K was determined by a flame photometer and Atomic Absorption Spectrophotometer (AAS). The analysis of ash content, organic matter, and organic carbon were done by loss on ignition (LoI) method. The content weight was measured by the method of a liter (measuring tube). The moisture was determined by the difference of wet weight and dry weight of peat soil. The analysis of biological characteristics as the main parameter in the form of total bacteria and fungi used total plate count (TPC)

2.5. Data analysis
The data analysis included classical assumptions consisting of multi collinability, autocorrelation, and heteroscedasticity of independent variables (water-table depth, peat depth, bulk density, water content, pH, organic matter, organic carbon, ash content, total nitrogen, total phosphorus and exchangeable-K for land types (acacia, horticulture and pineapple plantation.). The next stage was carrying out a regression analysis of the determinants of the curvature of peatland which affected the land type and
multivariate analysis on the determinant variables. The determination of criticality classification of peatlands was based on cluster analysis using average linkage (between groups). The analysis of the data used SPSS software ver. 24.

3. Result and Discussion
3.1. Characteristics of peatlands, physics, chemistry, and biology of peat soil
The results of the analysis show that there is a diversity of data for all physical, chemical and biological factors as well as physical land in various types of land use (acacia, horticulture and pineapple plantation). Pineapple plantation generally have a higher value among the two other fields, especially nitrogen (94.5% and 95%) and Phosphor (17% and 27.2%), ash content (29.3% and 41.8%), pH (43.7% and 8.1%) and number of fungi (68.7% and 63.9%). The differences in soil chemical and biological factors are supported by higher physical conditions of soil and land such as water content, water table depth and peat depth in pineapple plantation (Figure 2).
The difference in values in the above factors relates to the presence of channels in acacia and horticultural plantations, both functioning as drainage and land ownership border. The drainage can affect the bulk density, soil moisture content, water-table depth [10], [11]; [12] and [13]. This condition also affects the number of soil organisms, both earthworms and the number of fungi and bacteria [14]. Nutrients, especially nitrogen and phosphorous, in acacia and horticultural are likely due to the high release due to soil management and the presence of drainage in both fields. Other causes are in the vegetable plantation because the absorption of nutrients is large enough to plant tissues in early growth (vegetative) and the harvesting process that can bring some nutrients out of the soil [12].

In addition to the presence of drainage, the soil compaction due to land management and fertilization can affect nutrient solubility in soil solutions. The soil compaction can be described by an increase in the weight of the peat soil. Although the differences in the weight of the acacia and horticultural to pineapple plantation are only 9% and 4.7%, the decrease in nutrients can reach 95% of total nitrogen. In line with previous studies, compared to controls (secondary forest), the increase in

Figure 2. Diversities of (a) bulk density, (b) water content, (c) pH, (d) organic matter, (e) organic C, (f) ash, (g) total nitrogen, (h) total phosphor, (i) exc-KK, (j) number of bacteria, (k) number of fungi, (l) peath depth, (m) water-table depth in the AF, HF, PF.
content weight reached 9.4% -10.5% in maize and oil palm plantations causing a decrease in nitrogen by 24.3% and 44.5% [15]. These findings contrast with the results of the study [16], that there is an increase in C, N-total, P-total and K due to fertilization in the Puerto Rico tropical wet forest. Similarly [17] reported an increase in N-total due to drainage on peatlands in West Kalimantan. The water content of peat soil is affected by the water-table depth. The deeper the water-table depth, the lower the soil water content. In pineapple plantations, the shallowest water table depth (21.7 cm) compared to acacia land (41.3 cm), the difference in water content of both is 16.4%. Both characteristics of the peat can affect the presence of soil organisms. Lisnawati [18] suggests that the distribution of soil fauna types is determined by 3 physical properties of peat soil water content, water table depth, and maturity (C/N).

### 3.2. Determinants of peatland critically

The results of the classical assumption analysis of twelve physical, chemical and biological factors of peat soil and physical land obtained four parameters that did not occur multicollinearity and autocorrelation, namely total phosphorus, bacterial count, number of fungi and peat depth. The next stage is a regression analysis of these parameters that affect the type of land (Figure 3). However, the relationship between parameters such as the number of bacteria and phosphorus (Figure 3a), the number of fungi with phosphorus (Figure 3b), the depth of peat with phosphorus (Figure 3c), the depth of peat with the number of bacteria (Figure 3d), the depth of peat with the number of fungi (Figure 3e) is very weak, with r value is 0.054, 0.108, 0.091, 0.162 and 0.124 respectively.

![Figure 3](image-url)  
Figure 3. The correlation between peatland biophysical factors (a) number of bacteria and phosphorus, (b) a number of fungi and phosphorus, (c) peat depth and phosphorus, (d) peat depth and a number of bacteria, (e) peat depth and number of fungi.

The microorganisms organic decomposer is composed of fungi and bacteria. These two parameters are the determinants of the criticality of peatland because they are closely related to peat soil which
has high organic matter (95.5 - 97.4%) in all three fields. Fitria [19] reported that a high microbial population indicates sufficient energy, food supply, and environment which support the development of soil microbes. Therefore, the total population of soil microbes can be used as a soil fertility index. The existence of functional soil microbes is very important in agricultural land because it is related to energy flow and nutrient cycle as a result of the main activity of soil microbes.

Bacteria are the most dominant group of soil microbes and may include half of the microbial biomass. In anaerobic conditions, most of the organic decomposer are bacteria [20]. According to the results of this study, the highest number of bacteria is in horticulture plantation with a water content of 400% and characterized by shallow groundwater depth (25.29 cm) (Figure 2k and 2b). Figure 3a and 3b show a weak correlation between the number of bacteria and the number of fungi to P-total even though according to Sibarani, bacteria affect the P cycle in peatland. It is related to the presence of phosphate solvent bacteria and soil microbial activity in producing phosphate enzymes. Phosphorus is very influential on plant growth because P is abundant in plant cells in the form of nucleotide units that play a role in plant cell development. In addition, P can stimulate the growth and development of plant roots because it plays a role in cell metabolism and acts as an activator of several enzymes [22, 23].

The same correlation is also shown in peat depth parameters with the number of bacteria and fungi (Figure 3d and 3e). The correlation between the two is weak, in which the deeper the peat assumed, the quantity of organic matters increases yet the presence of soil microbes are limited by soil anaerobic conditions. C-organic content in the soil is a food source for the growth of soil organisms. Carbon source in the soil has an influence on activities of microorganisms [24].

Peat depth is one of the four critical factors for peatland criticality. Based on a research of peatland in Germany, it was identified that the peat depth factor is a critical feature of peatland, in addition to the bulk density, pH and decomposition rate (C/N ratio) [6]. Peat depth parameter is also one of the indicators influencing soil quality index with r-value of 0.84 [12]. In the preparation of The Forest Rehabilitation and Watershed Land Technical Plan (RTK RHL-DAS), a peat depth map is one of the determinant critical level maps that will be overlay with the other maps to obtain the map of The Forest Recovery and Critical Land Plan [25].

3.3. Classification of peatland critical classes

The determination of the criticality class classification of peatlands used cluster analysis with the Average Linkage method (Between Groups). The results of the analysis of the four determinants indicate that there are three classes of peat ecosystem criticality ie Critical class (Horticulture 11), Non Critical class with tillage (Acacia 3 and 4, Horticulture 7 and 8) and Non-Critical class without tillage and drainage (Acacia 1, 2,5,6, Horticulture 9,10,11, Pineapple 13,14,15,16,17,18). The dendrogram obtained from cluster analysis can be seen in Figure 4.

3.4. Preparation of peatland critical classes

The coefficient obtained in the linear function was used to determine the factors that make the largest contribution and was used to weight the selected factors [5]. The weight of biophysical factors in peatlands is P-total of 28%, the number of bacteria is 25%, the number of fungi is 25% and the depth of peat is 22%. Based on this weight, the criticality level of peatland is influenced by the presence and activity of soil microbes (bacteria and fungi by 50% while the rest is affected by P-total and depth of peat with values of 28% and 22% respectively.

The determination of the range of values of the four factors mentioned above, the range of P-total values are based on the Soil Research Center (1983), the depth of peat is based on the peat classification criteria. Specifically, the number of bacteria and fungi is based on the Diversity Index (H ’) approach (Table 1). Based on the interval values in Table 1, a peatland is considered degraded and has the potential to become a critical land if it has a low P-total (<15%), very deep peat depth (> 300cm) and has less diverse (<10) in microbial diversity index. In contrast, a peat ecosystem will be
considered not critical if it has a high P-total (> 26%), medium peat depth (100-300 cm) and has very diverse (> 2) in microbial diversity index.

Table 1. The range of criteria value from biophysical factors for criticality peat

| Biophysical Factors          | Range Value                  |
|------------------------------|------------------------------|
| Fosfor Total (%)             | Critical | Not Critical with Tillage | Not Critical with no Tillage |
| (Weighted 28%)               | <15       | 16-25                     | >26                         |
| Number of Bacteria (CFU)     | Low       | medium                    | high                        |
| (Weighted 25%)               | < 1       | 1 – 2                     | > 2                         |
| Number of Fungi (CFU)        | less diverse | medium                  | very diverse               |
| (Weighted 25%)               | < 1       | 1 – 2                     | > 2                         |
| Peat depth (cm)              | >300 cm   | 50-100                    | 100-300                     |
| (Weighted 22%)               | very depth | shallow                  | medium                      |

Note: ¹Center of Soil Research (1983)  
²Diversity Index Shannon-Wiener  
³Peat Soil Classification

Table 2. The Criteria and indicators of peatland criticality level

| Biophysical Factors (%) | Criteria                  | Indicator       | Score |
|-------------------------|---------------------------|-----------------|-------|
| Total Phosphorus        | Low                       | P-total <15%    | 3     |
| (Weighted 28%)          | Medium                    | P-total 16-25%  | 2     |
|                         | High                      | P-total >26%    | 1     |
| Number/Diversity of Bacteria and Fungi | Less diverse | H’<1       | 3     |
|                         | Medium                    | H’ 1-2         | 2     |
| (Weighted 25% dan 25%)  | More diverse              | H’>2           | 1     |
| Peat Depth              | Very depth                | KG >300 cm     | 3     |
| (Weighted 22%)          | Shallow                   | KG 50-100 cm   | 2     |
|                         | Medium                    | KG 100-300 cm  | 1     |

Source : Result of analysis
Table 3. The range of criticality class and the number of cumulative score of every class

| Criticality Class                        | Number of Scores |
|-----------------------------------------|------------------|
| Critical                                | 300              |
| Not Critical with tillage               | 101-299          |
| Not Critical with no-tillage and drainage| 100              |

Source: Result of analysis

Furthermore, based on the results of the analysis, the criteria for critical land and indicators are presented in Table 2. The total scores of the indicators for each factor were obtained from the criticality value along with the cumulative number of each class as presented in Table 3. Based on Table 3, a peatland is assessed as critical if it has a cumulative score of 300. On non-drained and treated peatlands, the critical threshold is at the cumulative amount of 100. On peatlands that are processed, especially for cultivated areas (horticultural gardens) the critical threshold is at the value of 101-299.

The information about the four determinants of the criticality level of peatlands is expected to be considered in the effort to rehabilitate peat areas or peat ecosystems which aims to restore, maintain and improve the function of forests and peatlands so that the carrying capacity, productivity, and role in supporting life buffering systems are maintained, in accordance with the Ministry of Forestry Number P.32/Menhut-II/2009. In addition, it is expected to be considered in improving the criteria for critical levels of peatlands.

4. Conclusions
The conversion of peatland affects the sustainability of natural peat ecosystems. The determining factors that characterize the critical level of peatland are total phosphorus, number of bacteria, number of fungi and depth of peat. The information about the characteristics of critical levels of peatland is expected to be considered in the efforts to rehabilitate peatland and improve criteria for critical levels of peatland.

Acknowledgments
This research was carried out on the funding supported by grants from Tanjungpura University 2017. For that, we would like to thank. We also thank the staff of the Laboratory of Chemistry and Soil Fertility of Tanjungpura University, Pontianak and Prof. Dr. Gusti Z. Anshari, MESS for borrowing research tools both in the field and in the laboratory.

References
[1] Plantation Forestry and Mining Agency Kubu Raya District 2013 Critical Land is found out in nine district. www.kuburaya.go.id/index.php/351-riah-kritis-ditemukan-diseimbil-kecamatan (13th July, 2018)
[2] Notohadiprawiro T 1997 Ethics for Peatland Extensification (Development) for food crop agriculture. Environmental Management Workshop in Peatland Extensification (Development). Environmental Impact Management Agency (BAPEDAL). Palangkaraya Februari 10, 1997. Repository of Soil Science, Gadjah Mada University, 2006.
[3] National Peatland Management Working Group, 2006. National Strategy and Action Plan for Sustainable Management of Peatlands. Ministry of Home Affairs of The Republic of Indonesia.
[4] Dariah A Rachman A dan Kurnia U 2004 Dry Land Erosion and Degradation in Indonesia, Soil Conservation Technology in The Andulatining (Bogor: Center for Soil and Agro-climate Research and Development)
[5] Sitorus R P S Susanto B and Haridjaja O 2011 Criteria and Classification of Land Degradation Level in Dry Land (Case Study: Dry Land in Bogor Regency).
[6] Krüger J P Leifeld J Glatzef S and Alewell C 2015 Biogeochemical indicators of peatland degradation-A case study of a Temperate Bog in Northern Germany. *Biogeoosciences* **12**: 2861.

[7] James B R 1995 Conception of an idea: An International Center for Soil and Society (ICCSS). *Bull Intl. Soc. Soil Sci.* **89**: 65.

[8] Aswandi R Sadono H Supriyodan Hartono 2015 Determinant of Criticality Factors and development of criteria for tropical peat ecosystem criticality indicators in Trumon and Singkil Aceh Province. *J. Human and Environment*, **22**: 319.

[9] Government Regulation Number 71 of 2014 Concerning Protection and Management of Peat Ecosystems. [Link](https://scholar.google.co.id/scholar?q=related:iifX4dpU2hYJ:scholar.google.com/).

[10] Maswar Haridjaja O Sabiham S and van Noordwijk M 2011 Carbon Reserves, Losses and Accumulation in Palm Oil Plantations in Tropical Peatland. *Journal of Soil and Land Utilization Management* **8**: 1.

[11] Nusantara R W Sudarmadji Djohan T S and Haryono E 2014 Soil CO₂ Emissions due to conversion of Peat Swamp Forest in West Kalimantan. *Human and Enviro. J.* **21**: 268.

[12] Nusantara R W Aspan A, Alhaddad A M Suryadi U E, Makhrawie Fitria I Fakhirudin J and Rezekikasari 2018 Peat soil quality index and its determinants as influenced by land use changes in Kubu Raya District, West Kalimantan, Indonesia. *Biodiversitas* **19**: 540.

[13] Soewandita H 2008 Study of Peat Water Tabel and Its Implication to Land Degradation in Several Peat Domes in Siak District *JAI* **4**: 103.

[14] Nusantara R W and Aspan A 2017 Differentiation of soil organisms at different types of peatland in West Kalimantan, Indonesia. *Bonorow Wetlands* **7**: 26.

[15] Nusantara R W Sudarmadji Djohan T S and Haryono E 2017 Study of Carbons and Peat Soil Nutrients due to Conversion of Peatlands in West Kalimantan. *Pedon Tropika* **3**: 97.

[16] Li Y, Xu MdanZou XM 2006 Effects of nutrient additions on ecosystem carbon cycle ina Puerto Rican tropical wet forest. *Global Change Biology* **12**: 284.

[17] Anshari G Z, Afifudin M, Nuriman M, Gusmayanti E, Arianie L, Susana R, Nusantara R W, Sugardjito J and Rafiastanto A 2010 Drainage and land use impacts on change in selected peat properties and peat degradation in West Kalimantan Province, Indonesia. *Biogeoosciences* **7**: 3403.

[18] Lisnawati Y, Suprijo H, Poedjirahajoe E and Musyafa 2014 The Ecological Proximity Relationship Between Fauna and The Characteristics of Peat Soil Drained for HTI *Acacia crassicaarpa*. *J. Human and Environment* **21**: 170.

[19] Fitria R, Zul D and Bernadeta L F 2014 The total microbial population of peat soil in Teluk Meranti Riau Regency. [Link](https://scholar.google.co.id/scholar?q=related:iifX4dpU2hYJ:scholar.google.com/).

[20] Zul D, Bernadeta L, Fibrianti Yunita M, Halimah S and Komariah S 2013 Impact of land conversion on microbial biomass: Case study in Bukit Batu area, Riau. *Semirata Proc. of FMIPA University of Lampung* **173**.

[21] Sibaran S 2009 Test of Potential Isolate Phosphate Solvent Bacteria in SeiGaluh Village, Kec. Kampar Against Soybean Plant Growth (Glycine max (L) merill) on Red Yellow Pedzolic Soil. *Essay.* (Department of Biology FMIPA, Riau University)

[22] Marschner H 1998 *Mineral Nutrition of Higher Plant.* (San Diego: Academic Press Inc).

[23] Prasad R and Power J F 1997 Soil Fertility Management for Sustainable Agriculture. (New York: Lewis Publishers).

[24] Hanafiah K A 2005 *Dasar-Dasar Ilmu Tanah.* (PT. Raja Grafindo Persada : Jakarta).

[25] Peraturan Menteri Kehutanan Republik Indonesia Nomor P.12/Menhut-II/2012 tentang Perubahan Kedua Atas Peraturan Menteri kehutanan Nomor P.32/Menhut-II/2009 Tentang
Tata Cara Penyusunan Rencana Teknik Rehabilitasi Hutan dan Lahan Daerah Aliran Sungai (RTk RHL-DAS)