The dynamics of biophysical characteristics and sustainability of peatland management under various types of land use

[1]Suratman, [2]Widiatmaka, [2]Bambang Pramudya, [2]Muhammad Y. Jaswadi Purwanto, [3]Fahmuddin Agus

[1] Indonesian Centre for Agricultural Land Resource Research and Development, Bogor, Indonesia; [2] Postgraduate of Environmental and Natural Science, Bogor Agricultural University, Bogor, Indonesia; [3] Indonesian Soil Research Institute, Bogor, Indonesia. Corresponding author: Suratman, ratman_end@yahoo.co.id

Abstract. Sustainable peatland management is expected to become the mainstream in utilizing the environmentally fragile tropical peatland. The aim of the study was to evaluate the dynamics of tropical peat characteristics and sustainability resulted from management and land use types. This study was conducted in 2013-2018 in the peat dome of the Kampar Peninsula, Riau Province, Indonesia. The types of data being used were primary and secondary data generated from the field and library. The field survey included unstructured interview with the local stakeholders and structured interview using questionnaire, while the sustainability status was evaluated using the Multi Dimensional Scaling (MDS) approach with the modification of Rapfish Method to Rappeat. The results indicated that the sapric (mature) peat expanded in area and that the peat became more stable (less rate of subsidence) with time. Peatland management systems in general were categorized as unsustainable with a MDS average value of 48.61% consisting of ecological dimension of 53.04%, social dimension of 47.34%, and economic dimension of 45.44%. The peatland management sustainability main lever attributes includes: a) maintaining of carbon stock, b) intensity and effectiveness of counselling the community about sustainable peatland management, and c) price stability of farm products. To be sustainable, from an ecological dimension we recommend the management of peat carbon stock through organic matter recycling, raising water table, and as much as possible, reducing agricultural expansion to the high carbon stock peat forests. From the social dimension, it is required an understanding by stakeholders on the regulatory and technical management of peatlands. From an economic dimension, it is necessary to have marked access and presence, as well as guarantee of agricultural production price stability.
Key Words: Multi Dimensional Scaling, peat swamp, subsidence, sapric.

Introduction. Peatland sustainable management is the mainstream of current peatland management. Sustainable management is defined as management systems carried out to meet current needs without eliminating future needs. WCED (1987) defines sustainable development as development that meets the needs of the present without compromising the future generation to meet their own needs. Sustainable management has been explicitly defined in Indonesian Law No. 32, 2009 concerning Environment Protection and Management, who defined sustainable management as conscious and planned effort that integrate environmental, social and economic aspects into development strategies to ensure the environment integrity as well as safety, ability, welfare, and the life quality of present and future generation. According to Munasinghe (1993) the sustainable development basically includes 3 important dimensions, namely; economic, social, and ecological. Thus, sustainable management is the management system that brings the fair and equitable social welfare and ecologically sustainable resources. So, the goal of sustainable development is focused on the sustainability of high economic growth, sustainability of social equity that is just and equitable (social equity), as well as ecological sustainability in a harmonious and balanced life order (ecological sustainability). According to Serageldin (1996), a development activity (including natural

www.manaraa.com

resource sustain management and its various dimensions) is declared sustainable if these activities are economically, ecologically and socially sustainable. Likewise, in the peatland management, a sustainable development approach is needed by integrating various management dimensions, such as; ecological, economic, social, technological and institutional dimensions. The management conception in view of Law No. 32 year 2009 states that environment protection and management are systematic and integrated effort carried out to preserve environmental functions and prevent pollution and/or environmental damage including planning, utilization, control, maintenance, supervision, and law enforcement.

In the last two decades the use of peatland in Indonesia has been increasing and this has been triggered by the lesser and lesser availability of land on mineral soils for agricultural and plantation expansion. The area of Indonesian peatland is estimated at about 13.4 million ha (Ritung et al 2019) and more than half of that area has been used for various purposes.

Peatland is a very fragile environment and difficult to restore when it's degraded due to mismanagement (Widjaya-Adhi & Sudjadi 1998). Tropical peat soils in Indonesia are also classified as marginal soil with very acidic characteristics, low nutrient availability, high organic acid content with its derivatives of phenolic acid that is toxic to cultivated plants. This acid is produced by the polymerization process due to the decomposition of organic matter from peat soil (Stevenson 1982; Rachim 1995; Salampak 1999).

Peat soil has a very high water content, ranging from 100 to 1,300% of its dry weight, and hence it is soft and its bearing capacity is very low (Widjaya-Adhi 1995; Subiksa et al 2010). The rate of peatland degradation is closely related to the type of land use and the management systems.

The sustainability of peatland resources is determined by both the dynamics of the anthropogenic influence, as well as the intrinsic biophysical properties, including its constituent components. Various biophysical properties have different levels of dynamics depending on environmental conditions and land cover. The initial biophysical conditions of peatland under forest or grasslands are different from those after the land is managed under different land uses such as shrub and agricultural lands with various management techniques (Istomo 2006). The degradation of peatland due to mismanagement does not only occurs on the managed areas, but it extends to the surrounding adjacent areas. The real impact that often becomes problematic that arises due to degradation is peat dryness, peat fire and decomposition by microbes releasing carbon dioxide.

Drought, decomposition and peat fire cause peat subsidence, i.e. a decrease in the thickness of the peat and changes in some peat properties that cannot easily recover in the long run (Dikici & Yilmaz 2006). Irreversible dryness, the condition in which the peat loses its ability to retain water, is a consequence of degradation. It also leads to changes of various characteristics of the land (Andriesse 1988; Thamrin et al 2007; Salampak 1999) to be less beneficial agronomically and environmentally.

The degradation involves various aspects including changes in physical quality, chemistry, decomposition process, succession of population and composition of forests, disruption of the hydrological cycle, and depletion of carbon stocks (Grace Gerda 2013). This study aimed at evaluating the dynamics of biophysical characteristics and sustainability status of peatland under various types of land uses using the Multidimensional Scaling (MDS) approach.

Material and Method

Data types and sources. The data types collected in this study of biophysical characteristics of the peatland management sustainability under various types of land uses, included primary and secondary data. Primary data were obtained directly in the field, especially those related to peatland management by conducting survey to farmers and to agriculture services, and field observations. The field data collection follows the standard method of semi-detailed land survey and mapping (Hikmatullah et al 2014). This included evaluation of land cover sequence and description of peat soil layer under

www.manaraa.com

each main land cover type. Meanwhile secondary data were those collected from various sources representing the variation of characteristics in the survey area (Nasution 2011). Secondary data sources were derived from official documents in the form of research results, journals, annual reports or study reports related to peatland management, both in the forms of softcopies and hardcopies obtained from related agencies.

Respondent in this study included general respondents and expert respondents. The general respondents, about 15 persons, were respondents who were selected from the community who use the peatland. While expert respondents were experts who met the criteria as experts, including 1) expertise in academic or researcher levels, and 2) expertise as decision maker. The total number of expert respondents were five persons. This number is in accordance with Hora (2004) who suggested 3, 5, or 7 experts who have adequate knowledge on the subject matter.

***Data collecting method**.* The method of data collection was in accordance with Sugiyono (2010). The desk study or literature study, or commonly called the documentation method was conducted to collect data related to peatland biophysical and socioeconomic aspects in the forms of notes, transcripts, books, newspapers, magazines, minutes, reports, agendas and so on. Searching the research data is done both in print (hard files) and in digital form (soft files) (Arikunto 2006; Nazir 1988).

Survey method for primary data were conducted through field observation, unstructured interview, and structured farmer survey using questionnaires. Biophysical data were collected according to the standard method of peat soil surveys according to Ritung et al (2017). Other data is obtained from the analyses of soil samples in the laboratory, for the determination of peat fibre content, ash content, organic C content, and bulk density (BD) (Eviati & Sulaeman 2012).

Interview in this study was carried out through face-to-face and question-answer directly between data collectors (enumerator) or researcher and data sources (Sugiyono 2010). The interviews were divided into structured and unstructured interviews. Structured interviews mean researchers have known exactly what information they want to extract from respondents so that the list of questions has been systematically compiled. Whereas unstructured interviews are free interviews, researcher do not use interview guidelines that contain question that will be asked specifically, but only contain important points of the problem that the respondents want to explore. This interview is intended to obtain information in general regarding the purpose of the research. The interview technique used in this study is a combination of structured interviews and unstructured interviews. Structured interviews are conducted using a close and open list of question in the form of a question in the form of a questionnaire. According to Sugiyono (2010) a questionnaire is a technique of data collection conducted by giving a set of question or written statements to respondents to be answered. Whereas according to Arikunto (2006) that a questionnaire is written statement that is used to obtain information from respondents by giving respondents flexibility in giving answers. In other words, the questionnaire given is only in the form of question without providing answer, so the answer will be given freely by the respondent. While the closed question is a close question and has been equipped with answers, where the respondent simply gives a sign on one of the answer provided.

***Data analysis method**.* The data analysis in this study is a quantitative Multidimensional Scaling (MDS) analysis with modified Rapfish software. Furthermore, the analytical method used is called Rappeat (Rapid Appraisal for Peat) (Yusuf 2017; Yusuf & Daris 2018).

Rappeat is a modification of MDS-Rapfish (Pitcher 1999). This approach is based on the Multi Criteria Analysis (MCA) principle by relying on an algorithm called MDS (Fauzi & Anna 2005). MDS is a statistical analysis technique that carries out multidimensional transformation (Kavanagh & Pitcher 2004). Modifications made in Rappeat include; management dimensions studied, attributes of each dimension and assessment or scoring given to attribute. This method is chosen considering that it can provide more stable results according to Preikshot et al (2005).

المنارة للاستشارات
www.manaraa.com

In the MDS method, there are two points or the same object mapped in a point adjacent to each other. Conversely, objects or points that are not the same are depicted with far apart points. The coordinator of distance determination technique in MDS is based on Euclidian Distance in dimensionless space. The closeness between object is obtained by the Euclid distance formula (Euclidean Distance):

$$d_{ij} = \sqrt{\sum_{k=1}^{p} (x_{ik} - x_{jk})^2}$$

where: d_{ij} = Euclidean Distance or distance between object i to j;
p = number of dimensions;
x_{ik} = the value from the i row and the k column;
x_{jk} = the value from the j row and the k column.

The technique used in regressing the equation above is ALSCAL Algorithm (Alder et al 2000; Fauzi & Anna 2005). The ALSCAL method optimized the square distance (square distance = d_{ijk}) against square data (origin = O_{ijk}), on the three dimensions (i, j, k) written in a formula called S-Stress as follows:

$$s = \sqrt{\frac{1}{m} \sum_{k=1}^{m} \left[\frac{\sum_i \sum_j \left(d^2_{ijk} - o^2_{ijk} \right)^2}{\sum_i \sum_j 0^4_{ijk}} \right]}$$

The square distance is the Euclidian distance weighted, or written as follows:

$$d^2_{ijk} = \sum_{a=1}^{r} w_{ka} \left(x_{ia} - x_{ja} \right)^2$$

Goodness of fit in MDS is reflected in the magnitude of the S-Stress value which is calculated based on the above S value and RSquare (Malhotra 2006). Low stress values indicate good fit, while high S values indicate otherwise. In the Rapfish approach, a good model is indicated by a stress value smaller than 0.25 or $S < 0.25$ (Fauzi & Anna 2005).

Through MDS, the sustainability point position can be visualized in two dimensions, namely the horizontal axis and the vertical axis, the horizontal axis shows the difference in the system studied in the “bad” (0%) to “good” (100%) ordinance for each dimension analysed. Whereas the vertical axis shows the difference of the attribute mix score between the systems studied. The complete categories of sustainability index dimensions are presented in Table 1. The result of the analysis showed a value which is the sustainability index value of the reviewed system. This ordination analysis also can be done to analyse how far the sustainability status for each dimension is. An overview of the sustainability analysis between dimensions can be visualized in a kite diagram.

The sustainability scale of the system studied has an interval of 0-100%. If the index value is more than 50%, then the system studied can be categorized as sustainable and if the index is less than 50%, then the system under study can be categorized as unsustainable. In this study the sustainability criteria are based on Pitcher (1999), as presented in Table 1.

Table 1

Categories of sustainability index

Index value (%)	*Category*
0 – 25	Unsustainable
26 – 50	Less sustainable
51 – 75	Quite sustainable
76 – 100	Very sustainable

Sensitivity analysis (leverage) in this study was conducted to see which attributes were very dominant or sensitive affecting sustainability compared to other attributes. The

www.manaraa.com

types of attributes included in the analysis were environmental, social and economic attributes. Various attributes of each dimension are presented in Table 2. To evaluate the impact of random errors on all dimensions in the ordinance value estimation process Monte Carlo analysis was used with the method of "scatter plot" (Kavanagh 2001; Fauzi & Anna 2005). This analysis is a simulation method that can see aspects of uncertainty caused by, among others; 1) the impact of scoring errors due to lack of information, 2) the impact of diversity in scoring due to differences in assessment, 3) errors in data entry, and 4) high stress value obtained from ALSCAL algorithm.

Table 2

Peatland management sustainability assessment attributes

No	*Dimension*	*Atribute*
A	Ecological dimension	Peat thickness, water quality, water source, vegetation closure, drainage (water drainage rate), development of observed land GHG emission levels, efforts to maintain carbon stocks, groundwater level at the beginning and end of observation, inundation/flood potential, peat soil pH, peat fires, frequency of pesticide use in peat soil.
B	Social dimension	Community perception of peatland management, knowledge and experience on climate change, knowledge and experience about controlling plant pest and diseases organism, counselling intensity and effectiveness to the community about sustainable peatland management, existence and togetherness of Farmer Groups, farmer's actions to preserve peatland, methods of land preparation and cultivation, farmers' response in implementing peatland conservation and sustainable management, local wisdom related to sustainable agriculture, participation of female workers in farming management.
C	Economic dimension	The potential of family labour in farming, the use of family labour for farming, land tenure and management intensity, investation in farming, farming objectives, stability of farm product prices, ease of marketing of farm products, availability of farm tools, farming contribution to total farmer income, revenue/cost ratio of the study plots.

Results and Discussion

Dynamics of the characteristics of peatlands. The sustainability of peatland is inseparable from the dynamics of land biophysical conditions due to changes in the land use and management systems. In the past five years the dynamics of the biophysical characteristics of peatland have occurred in the Kampar Peninsula, Riau, due to very rapid changes, mainly from forests to plantations and industrial (pulp wood) plantations. The peatland area is 29,590 ha, covered primarily (25,203 ha) with forest in 1991. By 2017, about 17,357 ha of the primary forest changed to plantations and forest plantation; the rest being secondary forests, shrubs, mixed gardens, field crops, and settlements (Table 3; Figure 1). These changes followed by changes in the biophysical characteristics of the land.

Table 3

Changes of land use on the Kampar Peninsula, Riau

Land use	*Year*			
	1991	*2001*	*2010*	*2017*
	Area (ha/%)			
Primary forest / peat swamp	25,203	9,161	927	
	91.53	33.27	3.36	
Secondary forest, Bush, Shrub, mix garden, dryland food crop	1,975	6,592	8,442	9,823
	7.17	23.95	30.66	35.67
Settlement		254	349	355
		0.92	1.27	1.29
Plantation, Industrial forest (HTI)	357	11,528	17,818	17,357
	1.30	41.87	64.71	63.04

المنارة للاستشارات
www.manaraa.com

Peat soil in the Soil Taxonomy classification system called Histosols (Soil Survey Staff 2014) and in the Indonesian National classification system called Organosol (Subardja et al 2016). Histosols tend to have greater dynamics of change than mineral soils. Within five years, the more mature Histosols expanded. In five years, there have been changes in the distribution and characteristics of peat soil in the research area. In addition, there were also changes in some soil biophysical characteristics, including the maturity and the stability of peat structures.

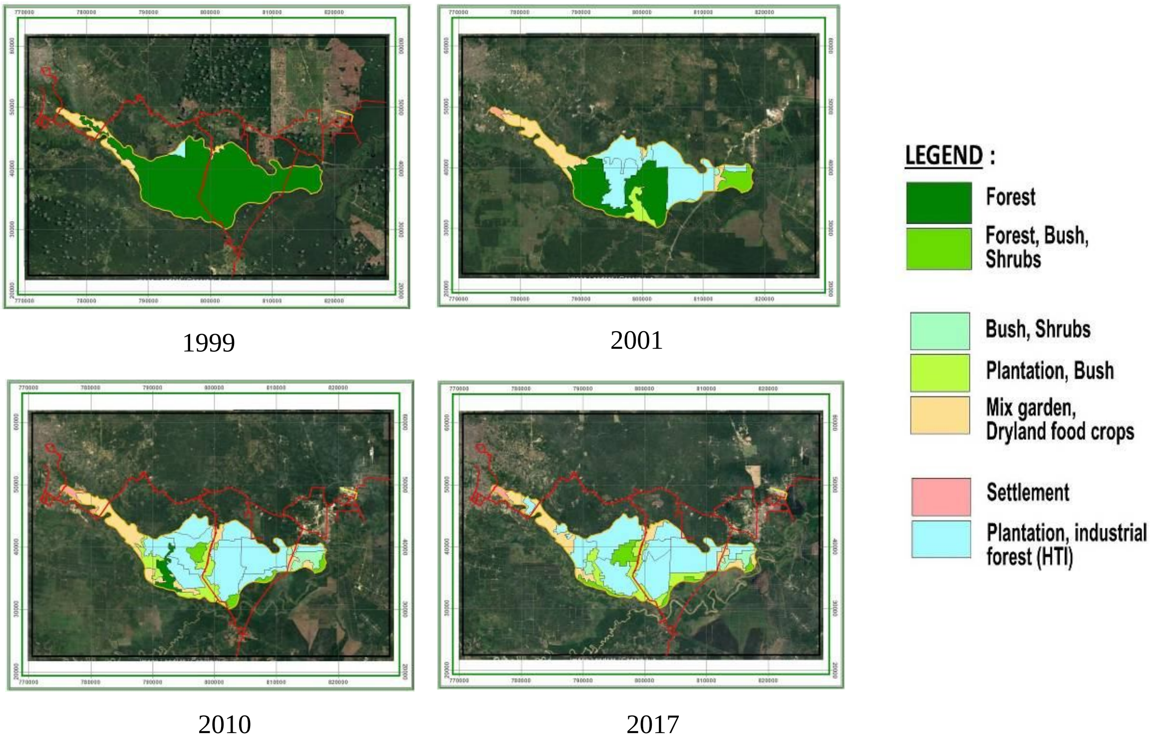

Figure 1. Changes of land use in the research area (BBSDLP 2011, 2017).

Changes in the level of decomposition of peat. Changes in the level of decomposition of peat or the level of maturity of peat are evidenced by lower fibre content, increased ash content, and tends to lose organic C content, shown in Figure 2. The lower the fibre content indicates that the peat is getting more mature. Peat with a low decomposition level is called raw peat or fibric peat, with the fibre content of > 75%. Peat with moderate decomposition rate is called semi-mature or hemic peat, with the fibre content between 17 and 75%. Peat with an advanced maturity is called sapric peat with the fibre content of < 17% (Soil Survey Staff 2014). The greatest decrease in fibre content from 40 to 20% was observed in oil palm plantation, the lowest from 30 to 28% (negligible change) was in forests and shrubs.

Ash content indicates the enrichment of mineral materials on peatlands. The enrichment of mineral materials can support the level of decomposition of organic matter or the maturity of peat (Bogacz et al 2017; Suratman et al 2013). The results showed that ash content increased. A high increase occurred in land with intensive management. On land where there is no management, the ash content is more stable or lower.

The organic C level shows the carbon content resulting from the breakdown of organic matter from peat soil. The decomposition process on peat produces greenhouse gas (GHG) emissions. The main GHG is CO_2, so that in the process of decomposition the peat will lose Carbon (Agus & Subiksa 2008). The decomposition is influenced by microbial activity and conducive environmental conditions. In general the factors that greatly influence the microbial activity that emits CO_2 are temperature, depth of ground water level, mineral content, pH, cations and salinity (Blodau 2002; Bertrand et al 2007; Handayani et al 2010; Hooijer et al 2011). However, there is no guarantee that emission could be reduced by raising water levels in the plantation area (Rieley et al 2008). Our

www.manaraa.com

of peatland is necessary, considering the peatland is one of the land important as an ecological buffer for the future, if managed properly. According to Thamrin et al (2007) some of the key principles of sustainable peatland use are (1) legal aspects that support peatland management, (2) spatial planning that is based on hydrological system units, (3) appropriate water management, (4) development approach based on soil characteristic minerals under the peat layer, (5) increased stability and decreased toxic properties and peat material, and (6) development of plants suitable with the land characteristic. The main lever attributes of ecological dimension sustainability are efforts of maintain Carbon stock and groundwater level.

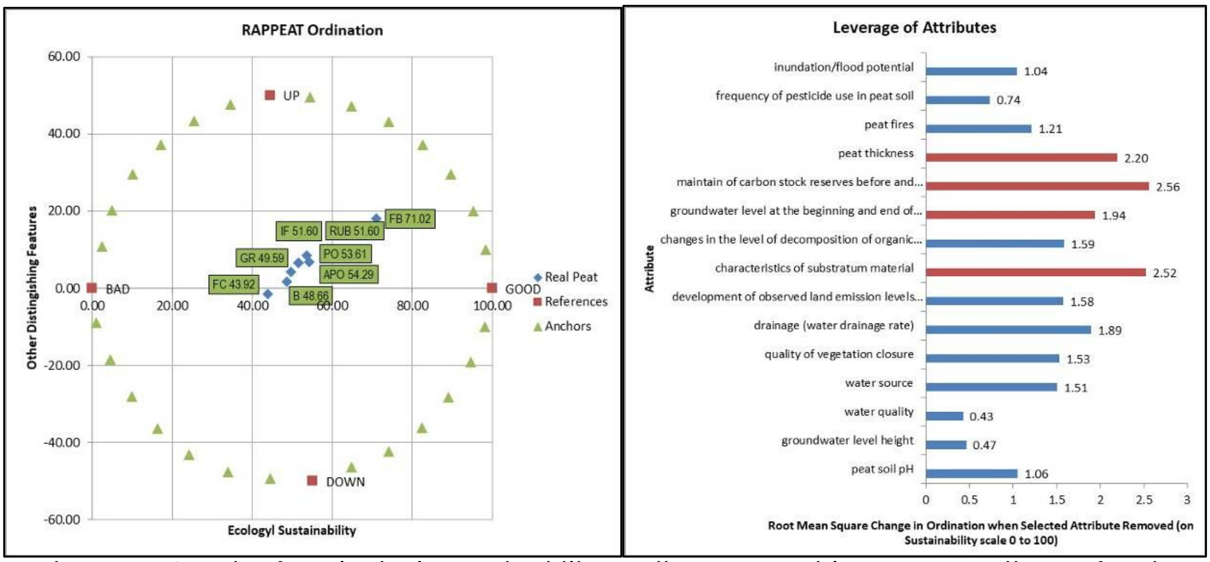

Figure 4. Graph of ecological sustainability ordinances and leverage attributes for the field condition as of 2017.

Sustainability status of social dimensions. Social dimension sustainability is an indicator of the sustainability of peatlands related to social aspects. The social aspect is one indicator of the sustainability of development.

The Rappeat analysis results related to the sustainability of social aspect indicate that the influence of land use types on peatlands have different effect on social aspect. Figure 5 shows that the rubber had the highest social sustainability value of 51.26% or is categorized as sufficiently sustainable, while the degraded forest had the lowest ecological sustainability index, of 40.06% or categorized as less sustainable. The same condition also occurred for grassland, industrial forest/Jabon, abandoned oil palm with the same value of sustainability idex of 46.27%, oil palm with the sustainability index of 48.90%, and field annual crop with sustainability index of 50.72%. This condition shows that the six types of land use were relatively unsustainable, with respect to social aspects. Social aspect is one of the main aspects in sustainable development. This aspect is very important given the very high function of peatland. Utilization of peatland for livelihood such as oil palm, rubber and other crops makes the accessibility of peatlands high and open. One of the fundamental problems that currently exist on peatland is the conflict between effort to improve the palm oil plantation quality and protection peat ecosystem from the threat and damaged caused by fire. On the other hand, land conflicts which constitute social conflicts in resource use are still a major problem on peatland. The main lever attributes of social dimension sustainability are knowledge and experience about peatland management.

www.manaraa.com

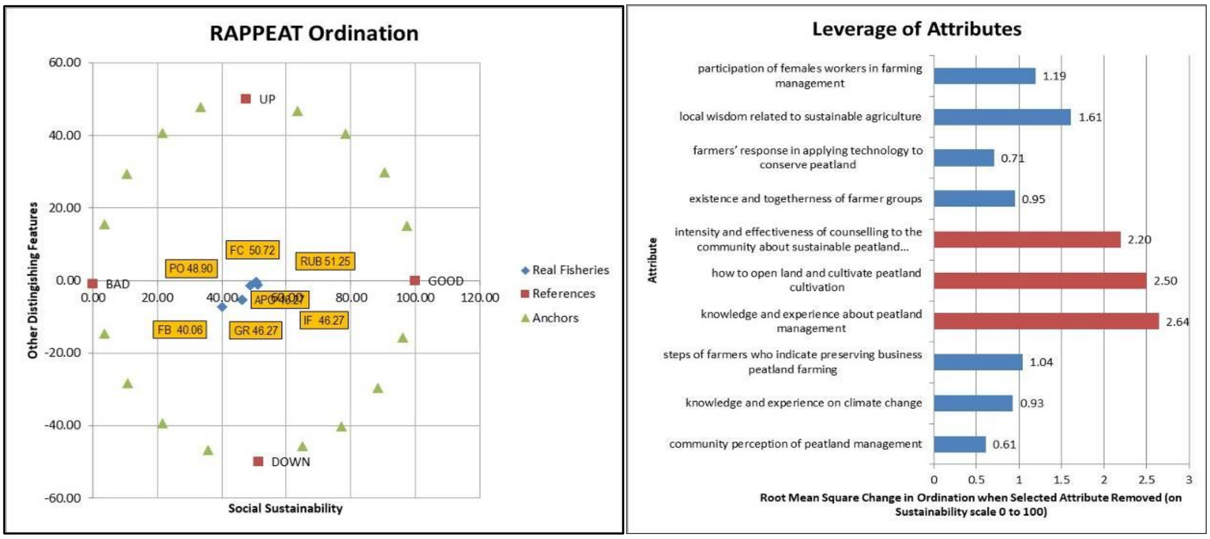

Figure 5. Graph of social sustainability ordinances and leverage attributes for the field condition as of 2017.

Sustainability status of economic dimensions. Economic sustainability dimension is an indicator of the sustainability of peatland related to economic aspects. Economic aspect is important in managing peatlands, and is one aspect of sustainable development.

The Rappeat analysis result related to sustainability of economic aspect indicates that the land use types on peatlands were have different effect on economic aspect. Figure 6 shows that the rubber had the highest economic sustainability value of 64.47% or is categorized as sufficiently sustainable. The same condition also occurred for field annual crop with the Sustainability Index of 55.95% and oil palm with the Sustainability Index of 54.01%, while the grassland, shrub, and abandoned oil palm had the lowest economic sustainability index, with the same value is 41.88% or categorized as less sustainable. The same condition also occurred for industrial forest/ Jabon with the Sustainability Index of 43.40% and degraded forest with the Sustainability Index of 42.28%. This condition shows that the five types of land use, were relatively unsustainable, with respect to economic aspects. Economic aspect is very important given the high economic function of peatlands. The peatland utilization into livelihood such as oil palm, rubber and other crops makes peatland one of the potential lands that can be developed towards food self-sufficiency. The main lever attributes of economic dimension sustainability are price stability of farm products.

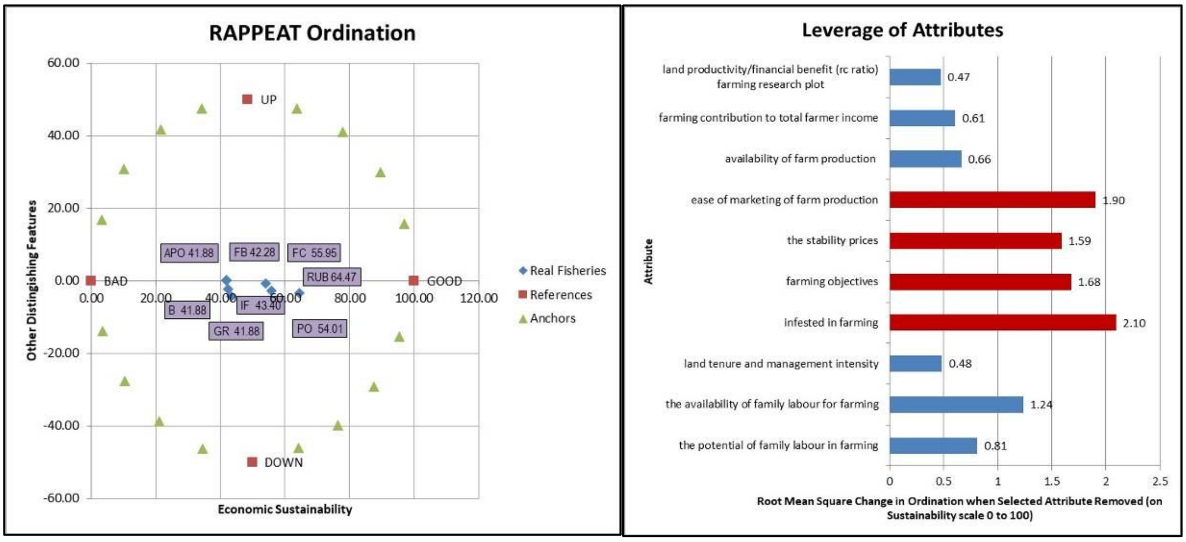

Figure 6. Graph of economic sustainability ordinances and leverage attributes for the field condition as of 2017 (PO = oil palm, RUB = rubber, IF = industrial forest/Jabon (*Anthocephalus cadamba*), FC = field annual crop, APO = abandoned oil palm, B = shrub, GR = grassland, FB = degraded forest).

www.manaraa.com

Trade off peatland management sustainability. Peatland management must always pay attention to environmental rules, because the constraints in its utilization are quite large, so the use of peatland, especially for agriculture that does not pay attention to environmental rules causes damage and losses in term of the environment and from socio-economic conditions. Things that will result from proper management include; forest fires, smog, floods, land cannot be utilized, loss of endemic and protected species, and loss of livelihoods of people who depend on peatlands. The following is trade-off for the sustainability of peatland management.

The Rappeat analysis results show that the sustainability values of the three peatland management dimensions are fairly even (Figure 7). However, there were two management dimensions which were categorized as less sustainable, namely; social dimension (47.01%) and economic dimension (48.22%). Meanwhile the environmental (ecological) management dimension level was 53.03%. Thus, it can be concluded that the two management dimensions, namely the social and economic dimensions were experiencing considerable pressure, where the value of sustainability was < 50%. While the ecological dimension is performed quite well with the value of sustainability of > 50%.

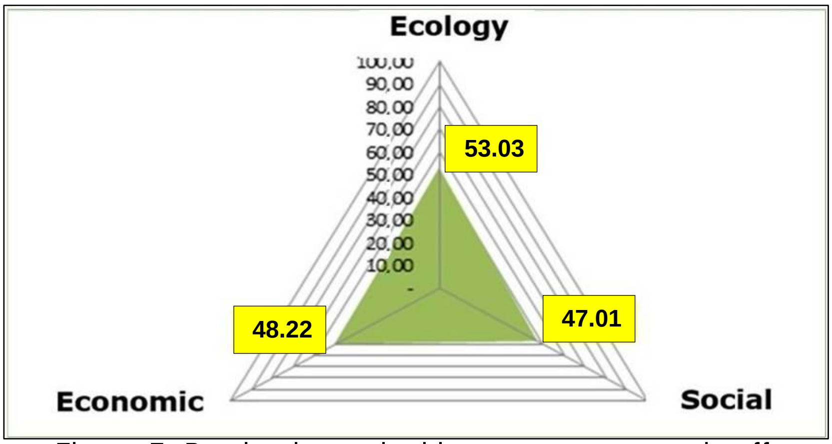

Figure 7. Peatland sustainable management trade off.

Conclusions. In the past five years, there has been a high dynamic of the biophysical characteristics of peatlands. Sapric (mature) peat is more widespread and the structure of the peat is more stable, as indicated by increased bulk density and lower rate of subsidence. The dynamics depend on the management pattern and type of land use. Increased decomposition or maturity is indicated by the decrease of fibre content, increased ash content, and decreased organic C content. High bulk density occurs in land with more intensive management. We found that the average rate of subsidence ranged between 2 to 5.65 cm yr^{-1}, with the highest one was found under rubber plantation. The status of sustainability of peatlands in various types of land uses shows that in general it is categorized as unsustainable with an average MDS value of 49.42% consisting of the ecological dimension of 53.03%, the social dimension of 47.01%, and the economic dimension of 48.22%. The main lever attributes of the peatland sustainability management were a) carbon stock and groundwater level, b) knowledge and experience on peatland management, and c) price stability of farm products. Sustainable peatland use and management with the MDS value greater than 50% can be achieved by raising ground water level, improving the land manager knowledge on peatland management and choosing the commodities with more stable price.

Acknowledgements. Special thanks to Postgraduate Program of Environmental and Resources Management, IPB University, Indonesia. Thanks to Dr. Maswar (Soil Research Institute, Indonesia Agency for Agricultural Research and Development) and the Team who have provided active role in giving advice and input in this research.

www.manaraa.com

References

Agus F., Subiksa I. G. M., 2008 [Peatlands: potential for agriculture and environmental aspects]. Soil Research Center, Agricultural Research and Development Agency, 78 pp. [in Indonesian]

Alder J., Pitcher T. J., Preikshot D., Kaschner K., Ferriss B., 2000 How good is good? A rapid appraisal technique for evaluation of the sustainability status of fisheries of the North Atlantic. Sea Around Us Methodology Review, pp. 136-182.

Andriesse J. P., 1988 Nature and management of tropical peat soils. FAO Soils Bulletin 59, Rome, 179 pp.

Arikunto S., 2006 [Research procedure]. Rineka Cipta, Jakarta, 243 pp. [in Indonesian]

BBSDLP (Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian/ Indonesian Centre for Agricultural Land Resources Research and Development), 2011 [Map of Indonesia peatland]. Indonesian Centre for Agricultural Land Resources Research and Development, Indonesia Agency for Agricultural Research and Development, Bogor, Indonesia, 11 pp. [in Indonesian]

BBSDLP (Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian/ Indonesian Centre for Agricultural Land Resources Research and Development), 2017 [Atlas of Indonesia peatland]. Indonesian Centre for Agricultural Land Resources Research and Development, Indonesia Agency for Agricultural Research and Development, Bogor, Indonesia, 32 pp. [in Indonesian]

Bertrand I., Delfosse O., Mary B., 2007 Carbon and nitrogen mineralization in acidic, limed and calcareous agricultural soils: apparent and actual effects. Soil Biology and Biochemistry 39(1):276-288.

Blodau C., 2002 Carbon cycling in peatlands – a review of processes and controls. Environmental Reviews 10(2):111-134.

Bogacz R., Usher M., Zhang J., McClelland J. L., 2007 Extending a biologically inspired model of choice: multi-alternatives, nonlinearity and value-based multidimensional choice. Philosophical Transaction of the Royal Society of London. Series B, Biological Sciences 362(1485):1655-1670.

Dawson J. J. C., Billett M. F., Hope D., Palmer S. M., Deacon C. M., 2004 Sources and sinks of aquatic carbon in a peatland stream continuum. Biogeochemistry 70:71-92.

Dikici H., Yilmaz C. H., 2006 Peat fire effects on some properties of an artificially drained peatland. Journal of Environmental Quality 35(3):866-870.

Eviati, Sulaeman, 2012 [Technical guidelines for soil chemistry analysis, water and fertilizers]. 2nd edition, The Indonesian Agency for Agricultural Research and Development-Ministry of Agriculture, Indonesia, ISBN:978-602-8039-21-5. [in Indonesian]

Fauzi A., Anna S., 2005 [Fisheries and marine resource modeling for policy analysis]. Gramedia Pustaka, Jakarta, Indonesia, 221 pp. [in Indonesian]

Grace Gerda R., 2013 [Implementation of reducing emissions from deforestation and forest degradation + (REDD+) in Kapuas Regency, Central Kalimantan]. eJournal Hubungan Internasional 2(1):451-462. [in Indonesian]

Handayani E. P., Van Noordwijk M., Idris K., Sabiham S., Djuniwati S., 2010 The effects of various water table depths on CO_2 emission at oil palm plantation on West Aceh Peat. Journal of Tropical Soils 15(3):255-260.

Hikmatullah, Suparto, Tafakresnanto C., Sukarman, Suratman, Nugroho K., 2014 [Technical guidelines: semi details soil survey and mapping scale 1:50,000]. Indonesian Agency for Agricultural Research and Development, Bogor, Indonesia, 34 pp. [in Indonesian]

Hooijer A., Page S., Jauhiainen J., Lee W. A., Lu X. X., Idris A., Anshari G., 2011 Subsidence and carbon loss in drained tropical peatlands: reducing uncertainty and implications for CO2 emission reduction options. Biogeosciences Discussions 8(5):9311-9356.

Hora S. C., 2004 Probability judgments for continuous quantities: linear combinations and calibration. Management Science 50(5):597-604.

المنارة للاستشارات
www.manaraa.com

Istomo, 2006 Phosphorus and calcium contents in soil and biomass of peat swamp forest – a case study at the concession area of PT. Diamond Raya Timber, Bagan Siapi-api, Riau Province, Sumatera.Jurnal Manajemen Hutan Tropika 12(3):38-55.
Kavanagh P., 2001 Rapid appraisal of fisheries (Rapfish) project. University of British Columbia, Fisheries Centre, 36 pp.
Kavanagh P., Pitcher T. J., 2004 Implementing Microsoft Excel software for Rapfish: a technique for the rapid appraisal of fisheries status. Fisheries Centre Research Reports, University of British Columbia, Canada, 75 pp.
Malhotra N. K., 2006 Marketing research: an applied orientation. Pearson Education Australia, 912 pp.
Munasinghe M., 1993 Environmental economics and sustainable development. World Bank Environment Paper Number 3, The World Bank, Washington DC, 112 pp.
Nasution S., 2011 [Research methods]. Bumi Aksara, Jakarta, 154 pp. [in Indonesian]
Nazir M., 1988 [Research methods]. Ghalia Indonesia, Jakarta. [in Indonesian]
Pitcher T. J., 1999 Rapfish, a rapid appraisal technique for fisheries, and its application to the code of conduct for responsible fisheries. FAO Fisheries Circular No. 947, FAO, Rome, 47 pp.
Preikshot D., Nsiku E., Pitcher T. J., Pauly D., 2005 An interdisciplinary evaluation of the status and health of African lake fisheries using a rapid appraisal technique. Journal of Fish Biology 53(Suppl A):381-393.
Rachim A., 1995 [The use of polyvalent cations in relation to phosphate availability to increase corn productivity on peat soil]. Postgraduate Dissertation, IPB, Indonesia, 138 pp. [in Indonesian]
Rieley J. O., Wüst R. A. J., Jauhiainen J., Page S. E., Wösten J. H. M., Hooijer A., Siegert E., Limin S. H., Vasander H., Stahlhut M., 2008 Tropical peatlands: carbon stores, carbon gas emissions and contribution to climate change processes. In: Peatlands and climate change. Strack M. (ed), Jyväskylä: International Peat Society, pp. 148-181.
Ritung S., Suparto., Suryani E., Nugroho K., Tafakresnanto C., 2017 [Technical guidelines for landform classification guidelines for land mapping in Indonesia]. Center for Agricultural Land Research and Development, Agricultural Research and Development Agency, Bogor, 49 pp. [in Indonesian]
Ritung S., Suryani E., Yatno E., Hikmatullah, Nugroho K., Sukarman, Subandiono R. E., Tafakresnanto C., Suratman, Hidayat H., Sudrajad D., Suryana U., Supriyatna W., Hartadi A., 2019 [Map of Indonesia peatland, scale 1:50.000]. Edition December 2019, Indonesian Centre for Agricultural Land Resources Research and Development, Indonesian Agency for Agricultural Research and Development, Bogor, Indonesia, 203 pp. [in Indonesian]
Salampak, 1999 [Increased productivity of peat soil which is offered by the administration of high-iron mineral soil ameliorants]. Postgraduate Dissertation, IPB, Indonesia, 236 pp. [in Indonesian]
Schipper L. A., McLeod M., 2002 Subsidence rates and carbon loss in peat soils following conversion to pasture in the Waikato Region, New Zealand. Soil Use and Management 18(2):91-93.
Serageldin I., 1996 Sustainability and the wealth of nations: first steps in an ongoing journey. Environmentally Sustainable Development Studies and Monographs Series No. 5, The World Bank, Washington DC, 21 pp.
Soil Survey Staff, 2014 Keys to soil taxonomy. 12th edition, USDA-Natural Resources Conservation Service, Washington, DC., 112 pp.
Stevenson F. J., 1982 Humus chemistry: genesis, composition, reactions. John Wiley and Sons Inc., New York, Chichester, Brisbane, Toronto, Singapore, 443 pp.
Subardja D., Ritung S., Anda M., Sukarman, Suryani E., Subandiono R. E., 2016 [Technical guidelines for national land classification]. Center for Agricultural Land Research and Development, Agricultural Research and Development Agency, Bogor, 67 pp. [in Indonesian]

www.manaraa.com

Subiksa I. G. M., Agus F., Wahyunto., Ananto E. E., 2010 [Mitigation of the rate of damage to agricultural land on peatlands]. In: [Reverse the trend of degradation of land and water resources]. Suradisastra K., Pasaribu S. M., Sayaka B., Dariah A., Las I., Haryono, Pasandaran E. (eds), Badan Litbang Pertanian-Dapertemen Pertanian, pp. 113-139. [in Indonesian]
Sugiyono, 2010 [Statistics for research]. Bandung: Alfabeta, 203 pp. [in Indonesian]
Suratman, Hariyadi, Sukarman, 2013 [Optimization of peatland management using mineral soil ameliorants and cover crops on oil palm plantations in Central Kalimantan]. IPB University, Bogor, Indonesia, 154 pp. [in Indonesian]
Thamrin, Sutjahjo S. H., Herison C., Sabiham S, 2007 Sustainability analysis of West Kalimantan-Malaysian border for the development of agropolitan region (Case study of a sub-district at the area border of Bengkayang Regency). Jurnal Agro Ekonomi 25(2):103-124. [in Indonesian]
[WCED] World Commission on Environment and Development, 1987 Our common future. Oxford University Press, South Melbourne, Australia, 168 pp.
Widjaya-Adhi I. P. G., 1995 Land and water management in swamp land resource development for sustainable and environmentally friendly farming. Paper presented at the training of prospective trainers for agricultural development in the tidal areas of Karang Agung Ulu, South Sumatera Selatan, 26-30 June 1995, 62 pp.
Widjaya-Adhi I. P. G., Sudjadi M., 1998 Distribution and potential for developing peatland for agriculture in Indonesia. The First Congress of the Indonesian Peat Association and the Peat I National Seminar. Gadjah Mada University, Yogyakarta, Indonesia, 45 pp.
Yusuf M., 2017 [Training of decision support system applications (Decision Support System)]. Material of MDS Rapfish, Bogor, Indonesia, 18 pp. [in Indonesian]
Yusuf M., Daris, 2018 [Analysis of research data. Theory and applications in the field of fisheries]. 210 pp. [in Indonesian]

Received: 02 December 2019. Accepted: 26 January 2020. Published online: 28 February 2020.
Authors:
Suratman, Indonesian Centre for Agricultural Land Resource Research and Development, Bogor, Indonesia, e-mail: ratman_end@yahoo.co.id
Widiatmaka, Postgraduate of Environmental and Natural Science, Bogor Agricultural University, Bogor, Indonesia, e-mail: widi.widiatmaka@yahoo.com
Bambang Pramudya, Postgraduate of Environmental and Natural Science, Bogor Agricultural University, Bogor, Indonesia, e-mail: bpramudya@yahoo.com
Muhammad Yanuar Jaswadi Purwanto, Postgraduate of Environmental and Natural Science, Bogor Agricultural University, Bogor, Indonesia, e-mail: yanuar_tta@yahoo.com
Fahmuddin Agus, Indonesian Soil Research Institute, Bogor, Indonesia, e-mail: fahmuddin_agus@yahoo.com
This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.
How to cite this article:
Suratman, Widiatmaka, Pramudya B., Purwanto M. Y. J., Agus F., 2020 The dynamics of biophysical characteristics and sustainability of peatland management under various types of land use. AES Bioflux 12(1):53-65.

المنارة للاستشارات
www.manaraa.com

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.

www.manaraa.com