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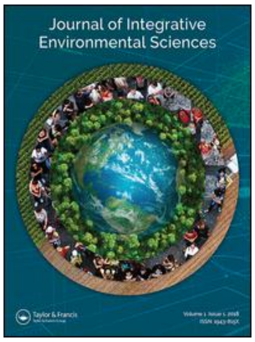

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Are peatland farming systems sustainable? Case study on assessing existing farming systems in the peatland of Central Kalimantan, Indonesia

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ABSTRACT

Economically, peatland plays an important role since they can be reclaimed for agriculture. Shallow peat (<100 cm) can be used to grow food crops including vegetables. Peatland has also become attractive for development of large-scale oil palm and rubber plantations. However, peatland has a number of constraints in terms of greenhouse gas (GHG) emission, especially CO_2 emissions in the degraded peatland. These arise from decomposition of peat. Common sense suggests three alternatives to manage GHG emissions from degraded peatland: conservation and restoration, natural recovery, and agricultural use. In this context, the challenge is to utilize degraded tropical peatland for agriculture while avoiding the negative impacts, and ensuring its environmental sustainability. This research attempts to contribute toward developing better management plans. Results of this study show that rice farming has highest sustainable score in degraded peatland. Rice farming secured a 52.14% sustainability score, while oil palm and rubber farming exhibited 47.55 and 47.67% sustainable scores, respectively. Therefore, rice farming can be considered as the first alternative for development of degraded peatland. Improved oil palm and rubber farming systems may also be subsequently considered if their sustainability can be improved.

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Peatland; sustainability; rice; oil palm; rubber; Central Kalimantan

Introduction

Indonesia has approximately 14.9 million hectares of peatlands (Mulyani 2012) which equal to 80% of peatland in South East Asia and 50% of the globally tropical peatland (Page et al. 2011). However, indiscriminant exploitation of peatland with improper management such as logging activities, conversion to plantations, and expansion of small-holder agriculture has caused degraded peatland (Silvius and Diemont 2007).

Economically, peatland plays an important role since they can be reclaimed for agriculture. Shallow peat (<100 cm) can be used for growing food crops, several vegetables, and perennial crop (Sabiham 2008). This peat has a relatively higher fertility and lower environmental

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risk than deep peat (BBSDLP 2008). BBSDLP (2008) also reported that 33% of Indonesian peatland which is spread among the islands of Sumatra, Kalimantan and Papua, is suitable for agriculture. Considering limitations in the availability of highly productive arable land, development and optimization of peatland for food production is an option since to ensure national food security. 1.4 million ha of additional rice cultivation will be needed to ensure national food security (Haryono 2014). Currently, peatland has also become sites for development of large-scale oil palm plantations. An estimated 1.3 million ha oil palm plantations in Indonesia are on peatland (Page et al. 2011) and it is predicted that this area will increase to 2.5 million ha in Sumatra and Kalimantan by 2020 (Hooijer et al. 2006; Page et al. 2011). Utilization of peatland for palm oil plantations is promising and brings equitable benefits but development of large-scale oil palm plantation on peatland needs serious consideration to minimize negative impacts to the environmental and economic losses due to peat subsidence. Another plantation on peatland is rubber. The utilization of peatlands for rubber plantation has been done by communities since 1920 (Firmansyah et al. 2012). Rubber plantations have significant socio-economic importance to Indonesian society. They are a source of foreign exchange and employment. Suyanto et al. (2009) reported that in Kapuas district, specifically in the former Mega Rice Project (MRP) area, rubber was an important livelihood of farmers.

On the other side, peatland also has a number of constraints in terms of GHG emission. CO_2 emissions will increase due to acceleration of microbial (heterotropic) decomposition (Agus et al. 2010) and increase the number of fires (Gomiero et al. 2010) as peatland forests are drained for others purposes. It is estimated that around 55 tonnes CO_2 ha^{-1} $year^{-1}$ will be released into the atmosphere as land is drained to a 60 cm depth (Hooijer et al. 2010). Jaenicke et al. (2008) also stated that degraded tropical peatland predominantly shrubland, is a significant source of CO_2 emissions arising from decomposition of peat and fires. Therefore, peatland agriculture has been part of the debate on climate protection terms of their GHG emissions.

With this reality, answer must be sought how to manage degraded peatland to support food production and improve food security by avoiding the negative impacts on the natural resources especially CO_2 emission for achieving sustainability. Sustainable peatland management aims to optimize the functions of peatland for the welfare of farmers, and control GHG emissions without compromising the ability of future generations to meet their needs (Gandasasmita and Barus 2012). Assessing sustainability status of existing farming system in the peatland is important for developing better management plans. In this study, a modified Rapfish method is used to assess the sustainability of farming systems on degraded peatland based on ecological, economic, social, institutional and technology-infrastructure dimensions. This method offers rapid assessment of sustainability and does not require extensive data. It is based on ordinal score of ecological, economic, social, institutional and technology-infrastructure sustainability achieved, using multidimensional scaling (MDS) and includes uncertainty (Pitcher and Preikshot 2001; Kavanagh and Pitcher 2004; Cissé et al. 2014).

Case study

The MRP on peatlands in Central Kalimantan several years ago (Presidential Decree. 82/1995) is an example of agricultural peatland development. The project received mixed response, advocating both for and against the effort. The government argued that clearing a million hectares of peatland would lead to national food self-sufficiency. However, the peatland of the MRP was badly degraded. Floods occurred in the rainy seasons and droughts in the dry seasons due to decreased water discharge (Noor and Sarwani 2004). Degraded peatland diminished hydrological and ecological functions (Wahyunto et al. 2013). Fire is another danger in degraded peatland since dry peat can be easily burnt. Peatlands fires burn slowly and are very difficult to control since fire spreads below the peat surface. As such degraded peatland is a significant source of CO_2 emissions arising from decomposition of peat, which is generally accelerated by drainage and from fires.

Currently, only 1.52 million ha (57%) of the total 2.67 million ha peatland forest in Central Kalimanatan is categorized as pristine; the remaining 1.15 million ha is categorized as degraded (Wahyunto et al. 2013). Degraded peatland is predominantly shrubland. This area needs careful management for improved economic benefit and reduced GHG emissions such as conservation and restoration, natural recovery, and agricultural use. Therefore, the current study was conducted in Central Kalimantan as case study to assess the sustainability of existing farming systems in these most degraded peatland area.

Methodology

This research was conducted in Central Kalimantan, and focused on Kapuas and Pulang Pisau districts. Primary data were collected through in-depth interviews with experts and stakeholders, and Focus Group Discussions (FGD) at the district and village levels.

In the study area, there are three farming systems practiced in the peatland; they are rice, rubber and oil palm. Each was observed and evaluated using modified Rapfish software. Rapfish is a rapid appraisal technique that estimates fisheries status by using a scoring technique on attributes and puts these fisheries in rank order using a statistical technique (http://www.rapfish.org). The attributes that were used in evaluation described farming conditions and reflected sustainability of the corresponding specific dimension. To adapt the modified Rapfish analysis to this research, attributes were chosen from different sources (Zhen and Routray 2003; Nazam 2011; Ruslan et al. 2013). Furthermore, relevant variables on the peatlands farming system were identified through FGD at the District and village levels which involved related stakeholder on the peatlands farming system (researchers, district agency staffs of food crops, plantation and food security, agriculture extensions, and farmers) and in-depth interview with experts from research institute who had experience on the peatlands farming system.

Determination of all attributes scores was done by in-depth interview with nine related group stakeholders which is consist of farmers, field agricultural extensions, agricultural extensions specialist staffs, and agricultural district staffs, head of food security and agricultural extension agencies and researchers. An attribute score of '0' represents a bad condition while a score of '3' denotes good. The definitive score is the mode of that dimension, which is analyzed to reflect sustainability using statistical MDS ordination techniques.

In this research, the chosen sets of attributes (10 each) were grouped in to five dimensions, i.e. ecological, economic, social, institutional and technology and infrastructure, and were scored as shown in Table 1.

Modified Rapfish analysis was done using Microsoft Excel with the Rap 1.6 add-in installed (Kavanagh and Pitcher 2004). This program uses a statistical ordination technique, MDS. It

Table 1. Defined list of the attributes used in Modified-RAPFISH analysis.

Attribute	Bad	Good	Notes
Ecology			
Land suitability	0	3	Not suitable (0); marginally suitable (1); quite suitable (2); very suitable (3)
Land fertility	0	3	Percentage of fertile area: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Climate condition	0	3	Not supportive (0); less supportive (1); quite supportive (2); very supportive (3)
Drought occurrence	0	3	Drought area: increase (0); tend to increase (1); tend to decrease (2); decrease (3)
Flood Occurrence	0	3	Flood area: increase (0); tend to increase (1); tend to decrease (2); decrease (3)
Fire occurrence	0	3	Fire incident: increase (intentionally burning for land preparation) (0); slightly increase (1); remain unchanged (2); decrease (3
Potential of expansion area	0	3	Land potential: not available (0); limited (1); quite available (2); still extensive (3)
Expansion area	0	3	Development of new area: nothing (3); limited (2); quite extensive (1); very extensive (0)
Pest and disease attack	0	3	Frequency and intensity of pest and disease attack: increased rapidly (0); tend to increase (1); tend to decrease (2); decrease (3)
Peat subsidence	0	3	Decreasing of peat layer per year: very high (>6 cm) (0); high (4–6 cm) (1); low (2–4 cm) (2); very low (< 2 cm) (3)
Economic			
Land holding by farmer	0	3	Land holding: <1 ha (0); 1–2 ha (1); 2–4 ha (2); >4 ha (3)
Labor availability	0	3	Family labor: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Labor cost	0	3	Labor cost: very high (0); relatively high (1); reasonable (2); low (3)
Plant productivity	0	3	Productivity per ha: Rice: <1 ton (0); 1–2 ton (1); 2–4 ton (2); >4 ton (3) Rubber: <0.5 ton (0); 0.5–1 ton (1); 1–1.5 ton (2); >1.5 ton (3) Oil Palm (fresh fruit bunches): <1 ton (0); 1–3 ton (1); 3–6 ton (2) >6 ton (3)
Capital adequacy	0	3	Capital loan: >75% (0); 51–75% (1); 25–50% (2); <25% (3)
Product price	0	3	Product price during harvest season: unstable (0); less stable (1); relatively stable (2); stable (3)
Input availability	0	3	How to get production input: Very difficult (0); difficult (1); relatively easy (2); very easy (3)
Input price	0	3	Standard Maximum Retail Price: far above (0); above (1); almost similar (2); equal/same (3)
Financial benefit/BC Ratio	0	3	BC ratio: <1 (0); BC Ratio 1–1.25 (1); BC Ratio 1.25–1.5 (2); BC ratio >1,5 (3)
Contribution to farmer income	0	3	Contribution farm benefit to total farmer income: <25% (30); 25–50% (1); 51–75% (2) >75% (3)
Social			
Farmer household number	0	3	The number people in a farm household: drastically decreased (0); decrease (1); remain (2); increase (3)

(*Continued*)

Table 1. (*Continued*).

Attribute	Bad	Good	Notes
Farmer education	0	3	Education of farmer: not graduate from elementary school (0); graduate from elementary school (1); graduate from Junior High school (2); graduate from Senior High School and above (3)
Women participation	0	3	Women participation in peatland farming: Do not care (0); less attention (1); only some women are active (2); all women are active (3)
Communication access (cellular phone indicator)	0	3	Area covered by cellular phone: <50% (0); 51–70% (1); 71–90% (2); 91–100% (3)
Transportation accessibility	0	3	Area where affordable for vehicle transportation (4 wheel); <50% (0); 51–70% (1); 71–90% (2); 91–100% (3)
Farmer experience in the peatland farming system	0	3	Farmer knowledge and experience of peatland farming systems: Do not understand (0); it is new information (1); fair understand (2); clearly understand the details (3)
Farmer experience in the peatland GHG	0	3	Farmer knowledge and experience in peatland GHG: Do not understand (0); it is new information (1); fair understand (2); clearly understand the detail s (3)
Local indigenous technology/local wisdom	0	3	Local indigenous technology in the peatland area: not available (0); Available but not yet widely known by farmer (1); Available but not done by farmers (2); Available and applied by farmers (3)
Farmer response to sustainable management	0	3	Farmer response to sustainable management: No response (0); responds only when there is a project (1); quite responsive even when there is no project (2); very responsive and tries to apply (3)
Dissemination and discussion of sustainable peatland management among farmer	0	3	Dissemination and discussion of sustainable peatland management: not done (0); rarely done (1); done but not focused (2); done and focused on sustainable peatland farming systems (3)
Institutional			
Existence of farmer group	0	3	Existence of farmer group: Farmer groups do not exist (0); Farmer groups exist but no activity (1); Farmer group exist and rarely have activities (2); Farmer group exist and are active (3)
Advantage of farmer groups	0	3	Percentage farmer group member who get benefit from the group: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Capital institutional support	0	3	Percentages farmers who have access to institutional capital (government and private): <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Institutional technology support	0	3	Supported with institutional technology: No support (0); less support (1); good support (2); very good support (3)
Institutional extension support	0	3	Percentage of farmer who get access to extension: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Institutional seed support	0	3	Percentage of those needing superior seed who receive this material: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Institutional support for agricultural inputs	0	3	Percentages of agriculture inputs needed that can be met: <25% (0); 25–50% (1); 51–75% (2); >75% (3)

(*Continued*)

Table 1. (*Continued*).

Attribute	Bad	Good	Notes
Institutional support for integrated pest management	0	3	Percentage of pest and disease target can be fulfilled: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Institutional support for marketing agriculture products	0	3	Percentage of agricultural product can be easily sold: < < 25% (0); 25–50% (1); 51–75% (2); >75% (3)
Government policy support	0	3	Percentage of government policy that benefits farmers: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Technology & Infrastructures			
Condition water management infrastructure	0	3	Percentage of damaged irrigation canals: >75% (0); 51–75% (1); 25–50% (2); <25% (3)
Transportation infrastructure	0	3	Percentage of damaged roads: >75% (0); 51–75% (1); 25–50% (2); <25% (3)
Infrastructure for extension and technology dissemination (Extension office)	0	3	Not available (0); available but in damage condition (1); available, good condition but does not function well (2); available, good condition and functions well (3)
Infrastructure for agriculture product marketing	0	3	Village market: Not available (0); available but in damaged condition (1); available, good condition but does not function well (2); available, good condition and functions well (3)
Technology application for soil and water management	0	3	Percentage of farmers who applied soil and water technology: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Technology application for superior seed	0	3	Percentage of farmers who applied superior seed technology: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Application of agriculture mechanization technology	0	3	Percentage of farmers who applied agriculture mechanization: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Application of fertilizer technology	0	3	Percentage of farmers who applied fertilizer technology: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Application of Integrated Pest Management technology	0	3	Percentage of farmers who applied integrated pest and disease technology: <25% (0); 25–50% (1); 51–75% (2); >75% (3)
Technology Application of harvest and post harvest technology	0	3	Percentage of farmers who applied harvest and post harvest technology: <25% (0); 25–50% (1); 51–75% (2); >75% (3)

was used to represent sustainability of peatland farming systems on a scale from 0 to 100%. A value of '0% sustainability characterizes the worst possible score while 100% sustainability is the best possible score of all attributes' (Pitcher and Preikshot 2001; Cissé et al. 2014). The analysis was done in the following steps: (a) determination of attributes, (b) assessment of each attribute score on an ordinal scale by multidimensional sustainability criteria, (c) analysis of ordination to determine ordinate and value of stress, (d) indexing and determining the sustainability of the system in each dimension, (e) sensitivity analysis to determine the level influence of each attribute expressed as a Root Mean Square (RMS) value, where higher RMS values represent the greater influence upon the overall sustainability score, (f) evaluation of the effect of random error using Monte Carlo analysis.

Results

The peatland farming system sustainability is presented in Figure 1 for five dimensions on two-dimensional plots. These sustainability values are scattered along the *X*-axis between 0 and 100.

Figure 2 shows comparison of the three farming system scores in each dimension. Among the five dimensions, lower sustainability scores were obtained in the ecological dimension. They were 48.51, 40.97 and 42.83% for rice, oil palm and rubber farming, respectively. Higher scores for rice, oil palm and rubber farming were found in the social dimension. These were 56.71, 53.64 and 53.17%, respectively. Score of more than 70% is considered good, scores between 60 and 70% are considered acceptable but need improvement, while scores of 40% and less are poor. Others consider scores of 50% or higher as sustainable (Nazam 2011; Ruslan et al. 2013; Cissé et al. 2014).

Goodness of fit in MDS is reflected by the value of S-stress. A low stress value indicates a good fit, while a high value of S indicates bad fit. S-stress and Root Mean Square (RSQ) values of the five dimensions are shown in Table 2. The highest Kurkal's stress was for technology & infrastructure and the lowest was for the social dimension with values of 0.182 and 0.165, respectively. All dimensions had Kurkal's stress values lower than 0.25. This model is acceptable according to the stress value criteria of Pitcher and Preikshot (2001).

Leverage analysis was conducted to indicate the influence of each attribute on the ordination status of peatlands farming systems. This was indicated by RSQ value changing value when a specific attribute was dropped. The leverage results are shown in Figure 3. All attributes had values less than 10%, indicating that no specific attribute dominated the analysis (Tesfamichael and Pitcher 2006). The social dimension, as expected, has the widest range of leverage values, 0.40 and 3.73 for farmer education and farmer experience in peatland Green House Gas (GHG) emissions, respectively. Whereas, the technology and infrastructure dimension shows more homogeneous results, ranging from 0.46-1.22. The economic dimension had leverage results ranging from 0.55-1.84, with labor cost and plant productivity as the lowest and highest values, respectively. In the ecological dimension, leverage values varied from 0.42 to 1.41. The lowest leverage value was on the institutional dimension which referenced government policy support.

Farming system sustainability was derived from a combination of Rapfish analyses in different dimensions as presented in the kite diagram shown in Figure 4. It can be seen that the differences between farming system sustainability were related to the ecological and economic dimensions. Social, institutional and technology and infrastructure had similar

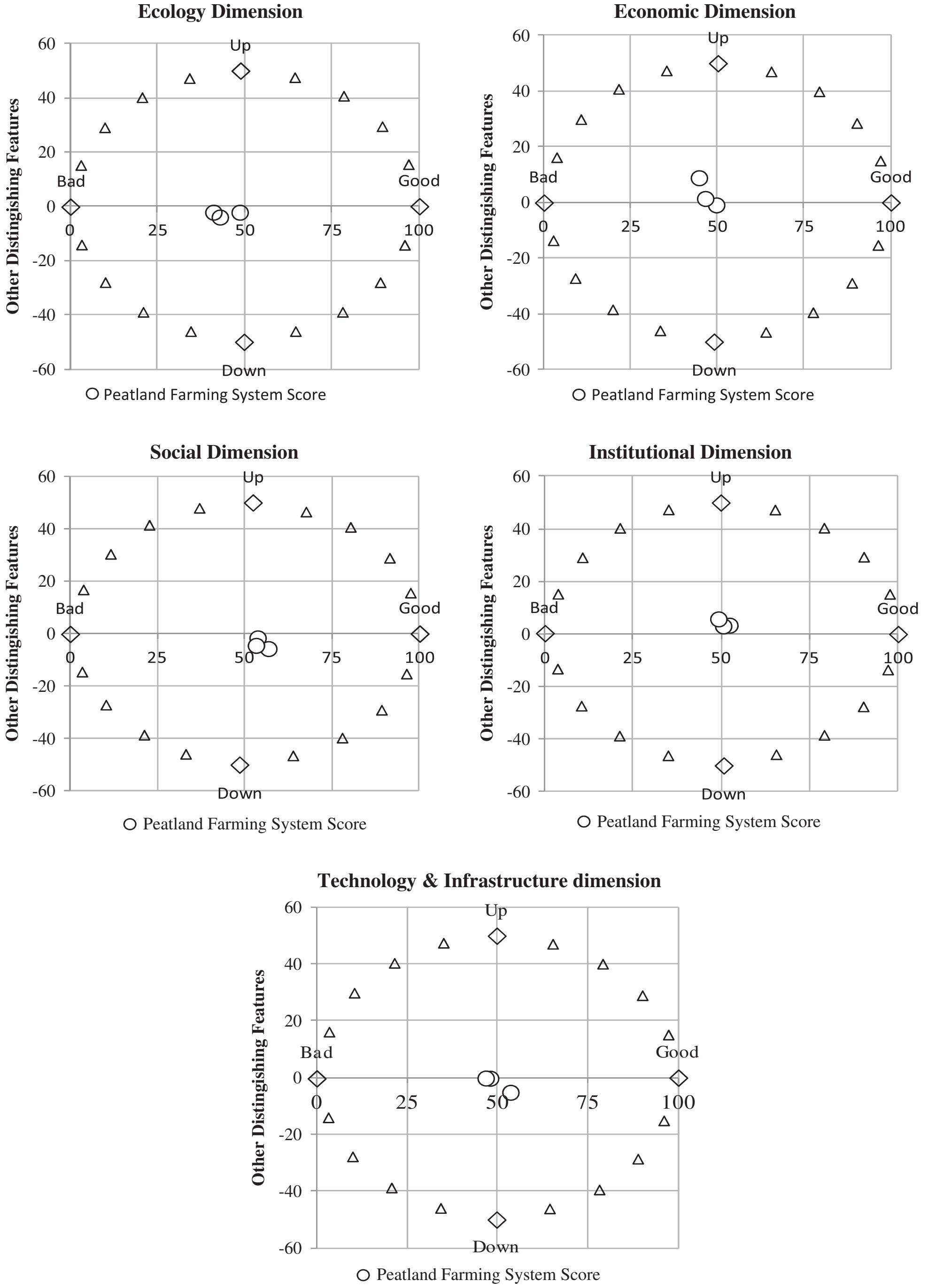

Figure 1. Two dimensional ordination plots from MDS analyses in different dimensions.

results. The kite diagram shows that rice farming has the highest score of sustainability index (52.14) followed by rubber and oil palm plantation with 47.67 and 47.55 sustainable scores.

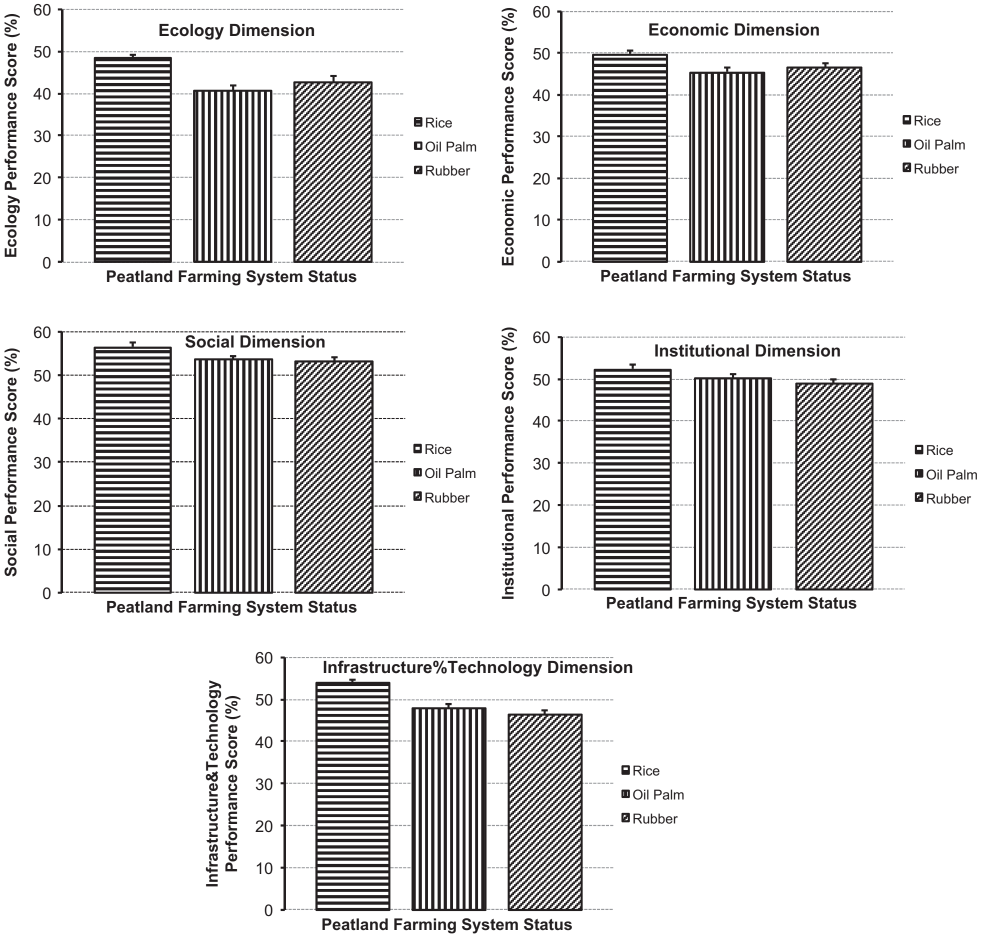

Figure 2. Sustainability of Peatland Farming Systems in ecology, economic, social, institutional and technology & infrastructure dimensions based on Monte Carlo analysis.
Note: Error bars represent mean ± S.D. *n* = 25.

Table 2. Kurkal's stress and RSQ for the different dimension.

Dimension	Kurkal's stress	RSQ
Ecological	0.175	0.941
Economic	0.175	0.940
Social	0.155	0.949
Institutional	0.165	0.944
Technology & Infrastructure	0.182	0.937

However, all farming systems score can deemed to be positioned in the mid-range of sustainability.

The results Monte Carlo analysis are expressed in index of Monte Carlo, which further distinguished by the results of the MDS analysis. According to Kavanagh and Pitcher (2004), indicating small difference of the index indicates that:

(a) Errors in scoring of each attribute are relatively small.

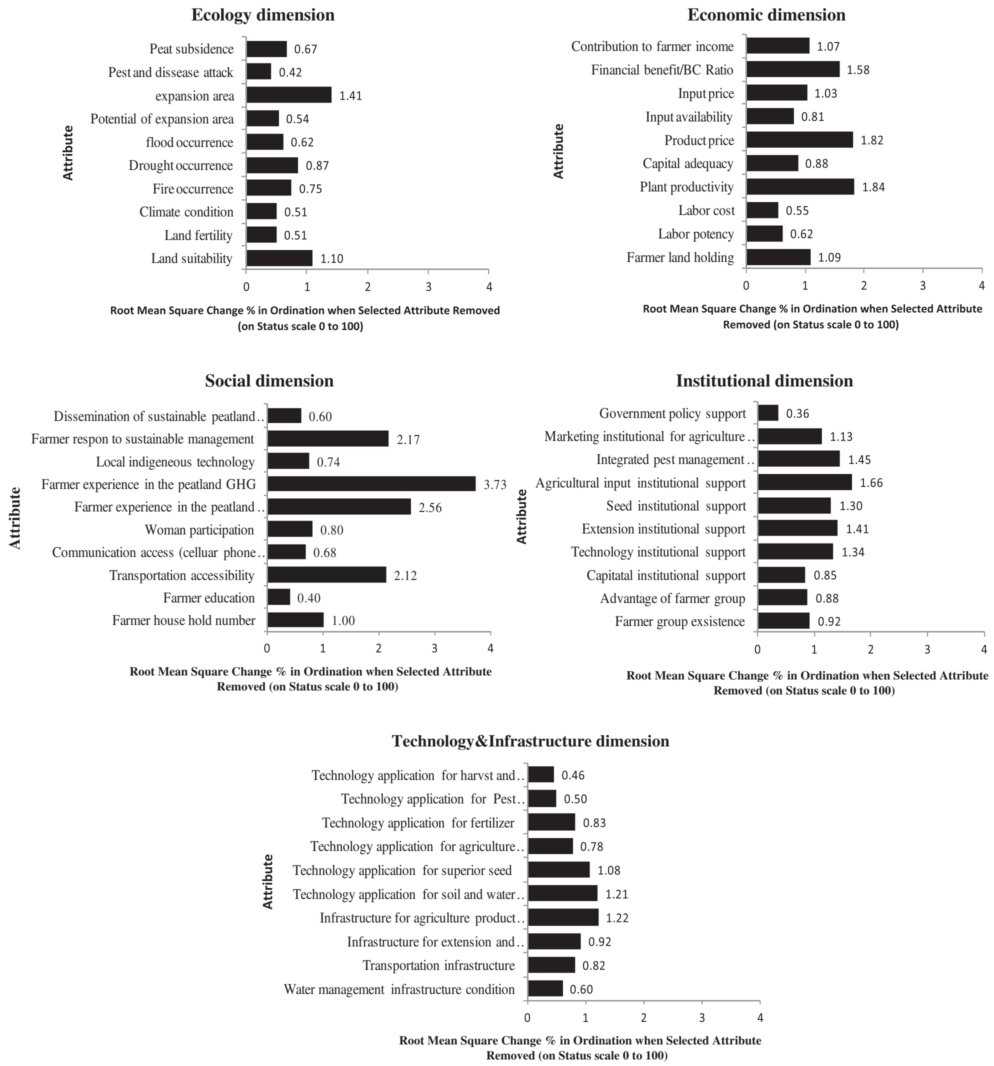

Figure 3. Leverage values of attributes in different dimensions.

(b) Variations in scoring due to the relatively small difference in opinion.
(c) The analysis process was carried out repeatedly (iteration) was stable
(d) Data entry errors and missing data can be avoided.

In this research, the differentiation of Monte Carlo analysis and MDS analysis can be shown in the Table 3.

The analysis also showed that at the level of 95% confident interval level, the highest differences between MDS and the Monte Carlo is 1.23% (less than 5%). This indicates that the simulation of the sustainability index in this rapfish analysis has a high confidence level (Kavanagh and Pitcher 2004).

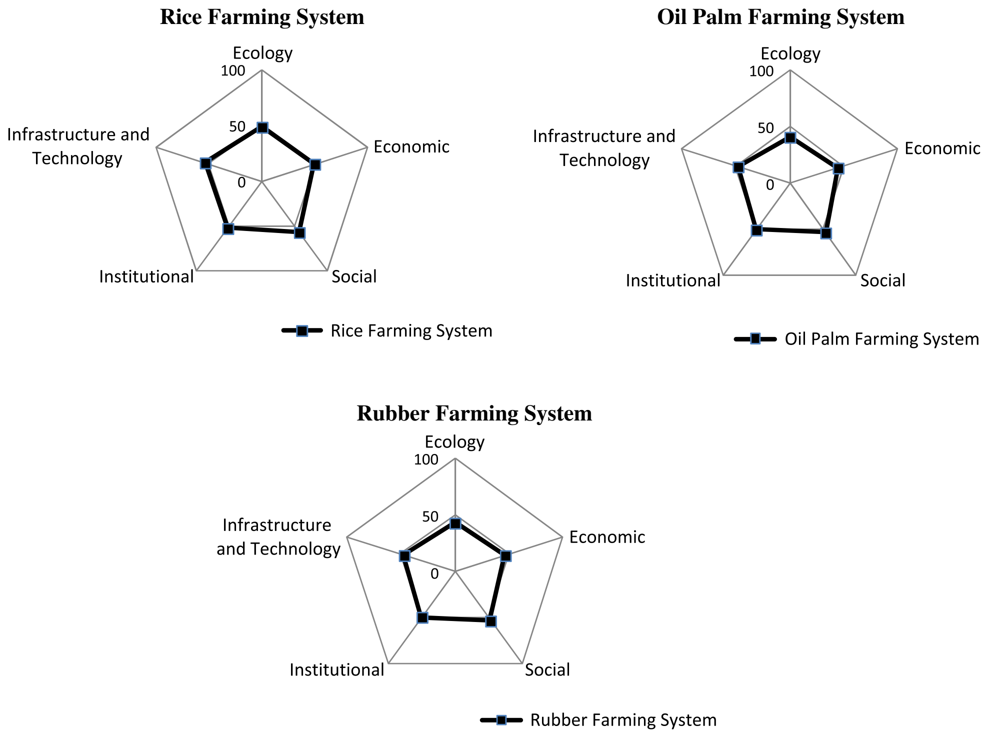

Figure 4. Kite diagram representing the sustainability of different peatland farming systems in five dimensions.

Table 3. Sustainability index from MDS analysis and Monte Carlo (MC) analysis.

	Rice			Oil Palm			Rubber		
Dimension	MDS	MC	Diff.	MDS	MC	Diff.	MDS	MC	Diff.
Ecology	48.51	48.44	0.07	40.97	40.60	0.37	42.83	42.78	0.05
Economic	49.65	49.52	0.13	44.68	45.23	0.55	46.48	46.69	0.21
Social	56.71	56.50	0.21	53.64	53.61	0.03	53.17	52.91	0.26
Institutional	52.25	52.06	0.19	50.49	49.99	0.50	49.12	48.64	0.48
Technology & infrastructure	53.59	53.6	0.01	47.98	47.9	0.08	46.74	46.28	0.46
Sustainability index	52.14	52.02	0.12	47.55	47.47	0.09	47.67	47.46	0.21

Discussion

Ecological dimension

Among others, the ecological dimension had the worst results in terms of sustainability. All farming systems had scores under 50%. Oil palm farming exhibited the lowest score, 40.97% followed by rubber and rice with 42.83 and 48.51%, respectively. Lowering ecology score for oil palm and rubber farming system were caused by low score in the land suitability attribute. However, all the scores were over 40%, so it is possible to improve the ecological dimension through better peatland management (Pitcher et al. 2009; Nazam 2011; Ruslan et al. 2013).

Based on the leverage results, expansion of arable area had highest value in the ecological dimension followed by peatland suitability. Wahyunto et al. (2010) stated that in general, development of agriculture area, especially on peatland in Indonesia, was not agronomically suitable. Only some peatland is suitable for food crops, horticulture and plantations. Other areas are unsuitable due to their low peat maturity, obstructed drainage, flooding, organic acid content, low nutrient levels and extensive plant roots (Mulyani and Noor 2011). For example, rubber farming in the Jabiren village of Pulang Pisau District is categorized as marginally suitable (Firmansyah et al. 2012), but through a better management, land suitability can potentially be increased. Peatland has typical physical and chemical characteristics that maintain its environmental stability in the natural condition, but can cause environmental problems when destabilized by human activities (Agus and Subiksa 2008). Rapid development of oil palm plantations should be given attention. Oil palm plantation projects on peatland need to consider land suitability and land fertility. Drainage of peatland for oil palm plantation increases peat subsidence, CO_2 emissions and makes peat susceptible to fire (Agus and Subiksa 2008). To improve soil fertility problem in the peatland, fertilization can be done in order to increase nutrient levels. A complete fertilizer is needed, containing N, P, K, Ca, Mg and micro elements Cu, Zn and B (Subiksa et al. 2011). Subiksa et al. (2011) reported that using slow-release fertilizers such as natural phosphate and 'Pugam' (specific fertilizer for peatland) is better than other conventional fertilizer e.g. SP-36 because it is more efficient, less costly and can increase soil pH. Therefore, to improve the sustainability of the ecological dimension, peatland should be strategically managed accounting for land suitability and land fertility. Since peatland is a fragile resource, its sustainability for agricultural use will depend on the ability of its user to correctly manage it.

Economic dimension

The economic dimension was slightly better than ecological dimension. Yet, its sustainability scores were 49.65, 44.68 and 46.48% for rice, oil palm and rubber farming, respectively. Unsuitability of peatlands for oil palm and rubber farming system leads to low plant productivity. It causes low score in the plant productivity, B/C ratio and contribution to farmer income attributes.

According to leverage analysis, the most influential factors were plant productivity and product price which led to a low B/C ratio. Input cost was the next most influential factors, followed by the ratio of farm income to total income. The ecological and economic dimensions are related. Without conducive conditions, plant cannot grow well. For example, rice productivity decreases as peat thickness increases (Noor 2001) because thick peat layers are nutrient depleted (Wahyunto et al. 2010). Improved plant productivity in peatland can be accomplished through use of soil and water technology, amelioration, fertilization and appropriate planting (Subiksa et al. 2011). Another influential factor is product price. Price fluctuations make agriculture risky (Grega 2002). Oil palm and rubber commodities are export products. Therefore, the product price depends on the international price, making the farm price somewhat unstable. Alternatively, the government agencies could engage in price stabilization. Price fluctuations alter the B/C ratio and affect farm income, in the same way that plant productivity, product price, B/C ratio and the ratio of farm income to total income impact farmers. Better farm management is best key to improve sustainability in the economic dimension. It is as important as price stabilization.

Social dimension

Among the all dimensions evaluated, the social dimension of peatland farming had the highest scores, 56.71, 53.64 and 53.17% for rice, oil palm and rubber farming, respectively. The higher performance in the social dimension was possibly caused by established use of peatland for agriculture purposes. Some peatland has been arable for many years and has been using indigenous technology practices for peatland management.

Based on the leverage analyses, farmers' experience in GHG emission management was of the highest importance among all attributes. Therefore, increasing farmer capability in GHG emission should be implemented. Role of agricultural extensions as a source of information is important for improving farmers understanding in GHG emissions but it should be supported by their capability in the impact of GHG emission as well as access to information technology. Even though the social dimension of peatland farming can be categorized as sustainable, improvement should be made to increase farmers' knowledge and experience in mitigating peatland GHG emissions. To achieve sustainable peatland management, farmer training and supervision should be done continuously to increase land productivity and decrease CO_2 emissions (Herman 2012).

Institutional dimension

The institutional dimension exhibited slightly less sustainability than the social dimension, but was more homogenous among the three farming systems. Institutional sustainability scores were 52.25, 50.49 and 49.12% for rice, oil palm and rubber farming, respectively. Institutional support is crucial in the development of degraded peatlands management. It has roles as stimulant and facilitator for increasing peatlands productivity.

According to leverage analysis result, the most important attributes were related to institutional support beyond farmer groups. These included institutional support for agricultural inputs, agricultural capital, agricultural markets, integrated pest management, seed, technology, and agricultural field extension services. This is indicative of active farmer group in the study area. Farmer groups have a strategic role in term of helping their members to access government information about technology, markets and government regulations (Nazam 2011). Financial institutions are also important for farmer capital to improve farming systems since application of agriculture technology will tend to increase input costs. Respondents voiced that agricultural credit programs developed in last decade should be re-implemented. *Kredit Usaha Tani* (Farming System Credit) was a credit program in the last decade that helped farmers implementing new technology. For improving institutional sustainability, the government agencies have an important role in improving institutional support for farming, especially for technology and agricultural extension. By this way, the problems of crop productivity in the ecological dimension can be solved using agricultural technology at the farm level.

Technology and Infrastructure dimension

The technology and infrastructure dimension had scores of 53.59, 47.98 and 46.74% for rice, oil palm and rubber farming, respectively. Infrastructure support for rice farming in peatland seems more advanced than rubber and oil palm plantations especially for water management infrastructure. Rice is a main commodity for supporting food security in Indonesia and has long been cultivated in peatlands. Therefore, Government of Indonesia tends to improve irrigation infrastructure for rice farming as well as peatland rice farming. Similarly, development of innovation technologies for rice farming is also more advanced than oil palm and rubber plantation. Less soil fertility and water management are the key questions in the peatlands research and development. These technologies may help to solve the peatlands issues relating to GHG emissions and peatlands fertility.

Leverage analyses showed relatively homogenous values with agriculture marketing infrastructure and application of technology to soil and water problems as the most influential attributes. Farmers with good market access can store their product for longer periods of time to possibly earn higher prices (Ezealaji and Adenegan 2014). Therefore, development of marketing infrastructure is important to support agriculture production. Improving marketing infrastructure can also improve farmer income by decreasing transportation costs. Another highly influential attribute is application of technology to soil and water issues. Peatland is a marginally productive and fragile land. It has low fertility, is flammable in the dry season and is easily eroded (subsidence). Therefore, it should be used cautiously. Many appropriate soil and water technologies are available to improve soil fertility and maintain water levels. These include macro and micro water management, amelioration, fertilization, adaptive plant varieties, integrated pest management and agriculture mechanization (Suriadikarta 2009; Subiksa et al. 2011).

Comparison between farming systems

When the five dimensions of sustainability were assessed for the farming systems under consideration, among the three the farming systems evaluated in this research, rice farming has highest score of sustainability index. However, all farming systems score can be positioned in the mid-range of sustainability. Low score of sustainability index in oil palm and rubber farming system seem caused by low score in ecology and economic dimension. Lowered ecology score for oil palm and rubber farming system were caused by unsuitability of those plants in the peatlands. According to Firmansyah et al. (2012) rubber farming in the Jabiren village of Pulang Pisau district is categorized as marginally suitable, but through a better management, land suitability can potentially be increased. Similarly, Sumarga et al. (2016) stated that the flood-prone areas of peatlands were unsuitable for oil palm and other crops requiring drained soils. Unsuitability of peatlands for oil palm and rubber leads to lower plant productivity. It was also caused low score in economic dimension.

At present, Indonesia seems to have no other viable option for achieving national food security than to manage its available suboptimal lands for food production, including its peatland. There are several advantages of using peatland for expansion of agricultural production. These include: (1) abundant water, (2) relatively flat topography, (3) situated near rivers to facilitate water for irrigation, (4) ideal for development of agricultural machinery since land holdings are large and farming is done usually extensively (Noor 2001). Economically peatland is important due to its potential for rice farming. Shallow peat layers (<100 cm) are recommended for food crops. Shallow peat has relatively higher fertility and lower environmental risk than deep peat (BBSDLP 2008). Rice farming can be sustainable in degraded peatland, if appropriate measures are taken to increase its sustainability. According to the leverage results, improvement of farmer knowledge about mitigation of GHG emissions is the most influencing attribute. This can be possibly done by improving agricultural extension to disseminate information about this issue. Plant productivity is also a highly influential factor in the economic dimension. Rice productivity is still quite low. To increase rice yields, implementing innovation technology is considered a priority, which should be done by farmers under the supervision of agricultural field extension agents. Another important factor for supporting agricultural production is improving agriculture infrastructure. Better irrigation systems, farm roads and markets are needed. Local governmental agencies' support in this regard is crucial.

A recent development shows that peatland is attracting interest for development of large-scale oil palm plantations. Utilization of peatland for oil palm plantations is deemed arguably promising with equitable benefits. Currently, an estimated 1.3 Mha Oil Palm plantations are located on peatlands (Page et al. 2011) and it is predicted that this area will increase to 2.5 Mha in Sumatra and Kalimantan by 2020 (Hooijer et al. 2006; Page et al. 2011). Although utilization of peatlands for palm oil plantations is promising and brings equitable benefits, development of large-scale oil palm plantation on peatlands needs serious consideration to minimize negative impacts to the environmental and economic losses due to subsidence. Since utilization of peatland for palm oil plantations are growing rapidly in Riau Province and is followed in other areas such as Jambi, Sumatra South, West Kalimantan and Central Kalimantan, serious attention is needed in order to minimize negative impact to the environmental and economic loss with respect to the rate of subsidence of the peat. There is also a group of researchers claiming that converting peatland to oil palm plantations is a major source of GHG emission (Schrier-Uijl et al. 2013).

The worst sustainability scores of the farming system evaluated in this research study were in the ecological dimension, followed by economic, technological and infrastructure dimensions. According to leverage analysis, in addition to improving farmer knowledge about GHG emissions management, improvement in land suitability and increasing plant productivity should be undertaken to improve peatland sustainability. Implementation of Best Management Practices for oil palm plantation based on the Roundtable on Sustainable Palm Oil (RSPO) on peat is important to enhance its sustainability (Parish et al. 2012). Consideration needs to be given to effective water management to reduce soil subsidence, GHG emissions and fire risk (Schrier-Uijl et al. 2013).

Smallholder rubber plantations have been cultivated on peatland since the 1920s, especially in Kuala Kapuas, Central Kalimantan, Banjarmasin, and South Kalimantan (Noor 2001). However, limited information about rubber cultivation technology is a constraint in development of these plantations on peatland. The main constraint is peat thickness. If peat thickness is more than 50 cm, rubber trees are vulnerable to collapse since thicker peat layers cannot support rubber trees (Cahyo and Saputra 2014). Firmansyah et al. (2012), stated that the primary limiting factors in the development of rubber in tidal peatland are rooting medium, toxicity, nutrient retention, and fire hazards; therefore, rubber plantations are categorized as marginally suitable, especially in Jabiren, Central Kalimantan. According to sustainability score, rubber farming system on peat is categorized as less sustainable (<50%). Improved management will help to increase land suitability for rubber farming on peatland. Attention should be given to improvement of drainage and planting systems (Firmansyah et al. 2012) since land suitability is the most influential factor in the ecological dimension.

Conclusions

The result of sustainability assessment of peatland farming systems is only indicative of relative sustainability since the analysis is strongly affected by the choice of attributes. However, if done comprehensively, it examines the biophysical aspects of sustainability and is a powerful tool in projection of socio-economic impacts of sustainability. Therefore in the current research sustainability of peatland farming systems was evaluated from a multidimensional frame work (ecological, economic, social, institutional, and technological and infrastructure dimensions). These results enable the relevant stakeholders in project planning to improve the sustainability of peatland farming systems. Results of the leverage analyses suggest some key interventions which should be done by stakeholders are:

- Prevent massive agriculture expansion on peatland
- Improve land suitability of peatland by use of fertilizers, ameliorants and limestone application
- Improvement of plant productivity in peatland can be done by use of soil and water technology, amelioration, fertilization and selecting appropriate crops
- Improve farmers' knowledge about GHG through training and supervision
- Empower farm groups for improvement of agricultural inputs, capital, market and integrated pest management
- Improve market infrastructure
- Improve and disseminate technology for peatland farming systems, especially for soil and water technology

Since peatland is highly vulnerable and a major source of carbon emissions, an integrated ecological approach is crucial for improving sustainability of peatland farming systems. Some technologies for peatland management can be improved for better productivity and reduced environment impact.

Among the three the farming systems evaluated in this research, rice farming has highest score of sustainability index. However, all farming systems score can be positioned in the mid-range of sustainability. Therefore, it can be considered as the first alternative for development of degraded peatland. However, some improvements are still needed to be done especially in ecological dimension by strategically managing of peatland focusing on land suitability, improvement of farmer knowledge about GHG emissions and plant productivity, and improvement agriculture infrastructure such as irrigation systems, farm roads and markets.

Disclosure statement

No potential conflict of interest was reported by the authors.

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