

Tropical Peat Swamp Management Options: A Case Study Using System Dynamic in Southern Aceh

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Abstract

Tropical peat forest ecosystems have multiple benefits as regulating hydrological system, carbon storage, timber and non-timber products, and protecting the biodiversity. Lack of understanding of these functions, short-term economic benefits is more preferable despite reducing its ecological benefits. This study proposed a system dynamics model of tropical peat forest ecosystem in determining its optimum management for extractive utilizations (timber and non-timber forest products), environmental services, and biodiversity. A dynamics model was used to describe changes in peatland and forest cover, biomass accumulation and carbon storage, and total economic value of tropical peat forest ecosystem in Trumon and Singkil, Southern Aceh. The projection showed that peat forest ecosystem benefits would decline in the long term if degradations continue at the same rate over last decade. Efforts to change the primary peat forest to plantation would reduce the total economic value of ecosystem and biodiversity values at level -19.63% and -26.28% from current conditions. Carbon emissions were increased at 117.32 ton CO₂ eq ha⁻¹ year⁻¹, higher than average of carbon losses from peatland oxidation. Preserving 50% of forest vegetation on moderate depth and protection very deep peatlands would reduce emission -6.96% to -35.06% and increase forest carbon storage at significant rate +15.06% to +63.32%, respectively. These mitigation schemes would improve the biodiversity and hydrological function. Forest rehabilitation with agroforestry practices will enhance carbon uptake, especially on degraded lands.

Keywords: system dynamics, tropical peat forest, carbon storage, environmental services, total economic value

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Introduction

Over the last decade, one of ecosystem that became global concern is tropical peat swamp forest. This is related to multi-functionality of these ecosystems in global climate regulation, water resource preservation, reducing floods, supporting of biodiversity, and providing of timber and non-timber for community welfare (Sudip *et al.* 2005; Blumenfeld *et al.* 2009; Hooijer *et al.* 2010; Hirano *et al.* 2014).

Lack of understanding of these functions lead to the short-term economic benefits was more likely to be considered. During period 2000–2009, approximately 2 million ha tropical peat forest were deforested, the highest in Sumatra which 0.98 million ha due to conversion to oil palm plantations and pulpwood plantations. Until 2009, a total of 10.77 million ha or 51% of Indonesia's peat forests were degraded (Forest Watch Indonesia 2011). Land conversion and deforestation contributed more than 25% of total CO₂ emissions (Murdiyarso *et al.* 2013). Carbon losses from

peatland degradation reached 65 ton CO₂ eq ha⁻¹ year⁻¹ (Hooijer *et al.* 2010).

Degradation of peat ecosystem release of greenhouse gases, disrupt hydrological function and loss of biodiversity (Holden *et al.* 2004; Blumenfeld *et al.* 2009; Hooijer *et al.* 2010; Miettinen *et al.* 2012; Murdiyarso *et al.* 2013; Hirano *et al.* 2014; Hommeltenberg *et al.* 2014). The intensities of floods and thick smoke haze from peatland fire were increased in surrounding degraded peatlands (Holden *et al.* 2004; Erwin 2008; Basyuni *et al.* 2015). The level of vulnerability hundreds of flora and fauna species also increased (Wich *et al.* 2008; Posa 2011). These ecological disasters were estimated trillion rupiah in economic losses annually (Rijksen *et al.* 1997; Hooijer *et al.* 2010).

Peat ecosystem function degradation due to the utilization exceeds the carrying capacity. Disturbance of land cover and excessive drainage increase the difficulty of ecosystem recovery. Increased soil acidity, hydrophobic, and irreversible drying characteristics induce low nutrient

availability, therefore growth of peat forest regeneration is inhibited. Shrubs preclude succession so that restoration efforts take a long time, huge cost, and low extent of success (Page *et al.* 2008; Wösten *et al.* 2008). Therefore, based on their marginal and vulnerable characteristics, peat forests management require a proper planning. The principles of equilibrium between utilization and carrying capacity are indispensable.

The objectives of this study was to build a system dynamics model to determine alternatives of peat forest management on timber and non-timber, carbon sequestration, environmental services, and the total economic value of tropical peat forest ecosystem in southern Aceh. The study proposes various alternative policy that support sustainable peat swamp forests management and enhancement of community welfare.

Methods

Research framework Peat swamp forest is dynamic and complex ecosystem (Blumenfeld *et al.* 2009; Miettinen *et al.* 2012; Murdiyarso *et al.* 2013). A holistic approach is needed to understand the behavior and overcome limitations in estimating the impact of policies. One approach that could be used is system dynamics. This approach helps in understanding the behavior and complexity of ecosystem in spite of limited information (Sterman 2001; Ghaffarzadegan 2011; Mousavi & Sadeghian 2015). By simulations, dynamics of system interest could predict behavior of the system as a result of a policy or its management scenarios (Sterman 2001; Ghaffarzadegan 2011).

A system dynamics approach in this study is used to describe dynamics of peat forest biomass accumulation, carbon stored, and economic value of timber, non-timber product, and environmental services. System dynamics were

constructed to integrate variety of these benefits. Dynamic of peat forest ecosystems were shown in Figure 1. The long term projections were used to determine impact of changes in peatland on multiple benefits of ecosystem. Allocation of peatland forest ecosystem was determined by examining different management scenarios. Optimum allocation was a policy that reduced GHGs emission, increased carbon sequestration, protection of biodiversity and hydrological functions, and increased monetary values of various benefits of these ecosystems.

Research was conducted on peat swamp forest ecosystem on Singkil Watershed in District of Aceh Singkil and South Aceh, Province of Aceh since May 2014 until June 2015. Geographically, it is locate between N2°15'25"–N2°43'48" and E95°39'22"–E97°54'48" in Southern Aceh (Figure 2). The ecosystem that covers an area of 144,512.50 ha represents tropical coastal shallow to deep peat typology and various types of land cover. These is habitat for protected wildlife and endangered species such as the sumatran tiger (*Panthera tigris sumatrae*), orangutan (*Pongo abelii*), sumatran elephant (*Elephas maximus sumatranus*), and the sumatran rhino (*Dicerorhinus sumatrensis*). Various timber forest products found in peat swamp forests as *jelutung* (*Dyera* spp.), *meranti* (*Shorea* spp.), *rengas* (*Gluta renghas*), *medang* (*Litsea* spp.), and others. Non-timber forest products such as honey, tree bark, rattan, and medicinal substance were harvested by local communities. Considering the high conservation value, these area was designated as one of the key biodiversity areas in Sumatra (Conservation International 2007).

Research procedures The research consisted of (a) measurement of changes in peat forest and land cover and carbon dynamics, and (b) development of system dynamics

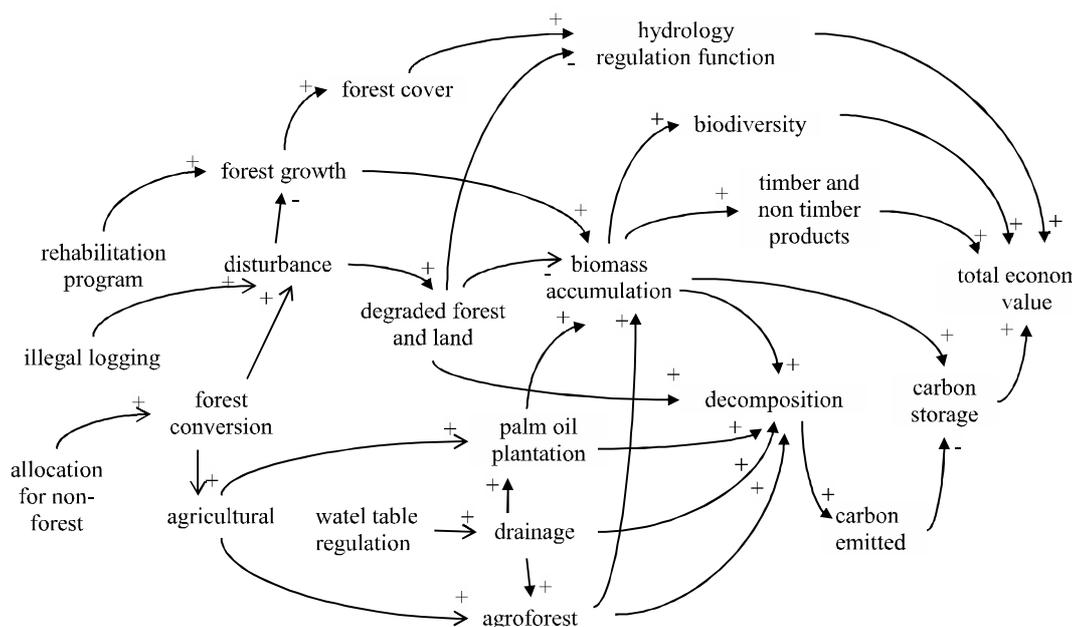


Figure 1 Clausal loop of peat forest ecosystem dynamics.

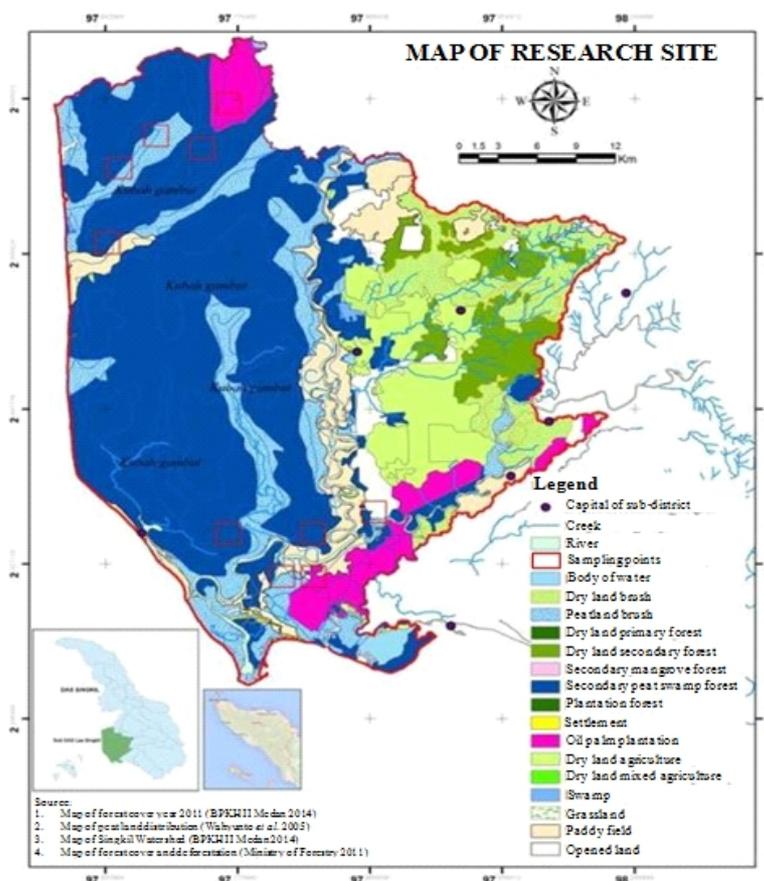


Figure 2 Research site on tropical peat forest ecosystem in Trumon and Singkil, Southern Aceh.

model. Peatland and forest changes were identified using a geographic information system approach based on maps of forest cover in 2003, 2009, 2011 (BPKH II Medan 2014), and maps of peat and forest degradation (Wahyunto *et al.* 2005; Forest Watch Indonesia 2011). Carbon estimation was conducted using a non-destructive method for 3 carbon pool, i.e. above and below-ground carbon, and soil organic carbon (Kenzo *et al.* 2009). Some types of peatland cover measured were primary and secondary peat forest, brush, mixed plantation/agroforestry, and oil palm plantations. In each type was built 3 plots @0.25 ha (50 m × 50 m). Stand parameters measured were tree diameter and height. Above and below-ground carbon were estimated using allometric equations (Krisnawati *et al.* 2012). Peatland carbon was calculated based on area of land, peat depth or thickness, bulk density, and C-organic content (Wahyunto *et al.* 2005). Carbon loss was calculated based on elevated levels of ash (Gronlund *et al.* 2008; Maswar *et al.* 2009). Valuation of total economic value of peat ecosystem was conducted on direct use value and indirect use value (Carson 2011). Direct use in form of timber harvesting, non-timber forest products (honeybee, rattan, etc.), the cultivation of agriculture and farming, and fishing were evaluated using market price. While indirect use values of ecosystem as flood control and water provider were evaluated using the avoid damage cost and replacement cost method (Carson 2011). Data collected

by structured interview of 30 respondents, i.e. farmers, fishermen, firewood collector, and also community associated with peat swamp forests.

Steps of a system modeling include (a) identification of issues, objectives and constraints, (d) conceptual model formulation, (c) model specification, (d) model evaluation, and (e) use of model (Grant *et al.* 1997; Purnomo & Mendoza 2011). The conceptual models were constructed by identifying all components and their relationship with software Stella 9.0.1. Some peat forest cover types measured consist of secondary peat forests, bushes, mixed plantation/agroforestry, oil palm plantations, and primary peat forest. Model were evaluated by observing their rationality and sensitivity and compared with real world or similar reliable models (Grant *et al.* 1997; Purnomo & Mendoza 2011). Model was validated by comparing the results of projection with forest cover change in year 2003, 2009, and 2011 (BPKH II Medan 2014). The forest growth based on stand structure dynamic of logged peat swamp forest which consists of ingrowth, upgrowth, mortality, and increment functions (Aswandi 2007).

The model ran by 5 scenarios by varying the driving variables such as the rate of peat forest conversion, the proportion of peat forests can be converted, rate of rehabilitation, and forest growth. The 1st scenario ran at similar condition in the last 12 years. The 2nd scenario were

quantified as Figure 3. Peatland forest cover dynamics influenced by the intensity of disturbance and forest growth. Forest disturbances include forest conversion and deforestation due to encroachments and fires. This land changes were also affected by the conversion rate and the proportion of suitable land for agricultural and plantations development. In contrast with degradation, forest cover was increased as a result by logged forest growth, succession, and rehabilitation of degraded peatlands (Wösten *et al.* 2008; Gunawan *et al.* 2012).

Sub model of biomass accumulation and carbon storage describe dynamics of biomass accumulation, carbon storage in soil, peat forest, and other peatland covers. Biomass accumulation is result of vegetation growth in peat forests and restoration of degraded lands (Wösten *et al.* 2008; Gunawan *et al.* 2012; Hommeltenberg *et al.* 2014). The ecosystem carbon storage is carbon content in vegetation biomass and carbon accumulation as result of litter

decomposition. Carbon contents of peatland were determined based on average level of decomposition, levels of carbon, and land area (Wahyunto *et al.* 2005). The highest soil carbon is stored in primary peat forest by 3,929 ton C ha⁻¹, followed by agroforestry and secondary peat forest of 3,713 and 3,612 ton C ha⁻¹, respectively. Oil palm plantations store 3,232 ton C ha⁻¹. The lowest is in brush of 3,098 ton C ha⁻¹. Onrizal (2010) reported that carbon content of the soil in the Singkil Swamp Wildlife Reserve in range of 496.54 to 2,587.86 ton C ha⁻¹. Carbon stock in primary peat forest vegetation reached 154.12 ton ha⁻¹ or a total 4083.12 ton ha⁻¹ including soil carbon. Secondary peat forest stored 43.00 ton C ha⁻¹, followed by oil palm plantation and agroforestry reached 33.59 and 31.80 ton C ha, respectively. Shrub vegetation just saved 6.82 ton ha⁻¹ of carbon. While Onrizal (2010) reported average of carbon stock in peat forest vegetation is 87.69 ton of C ha⁻¹. Carbon dynamics were influenced by accumulation of biomass and amount of

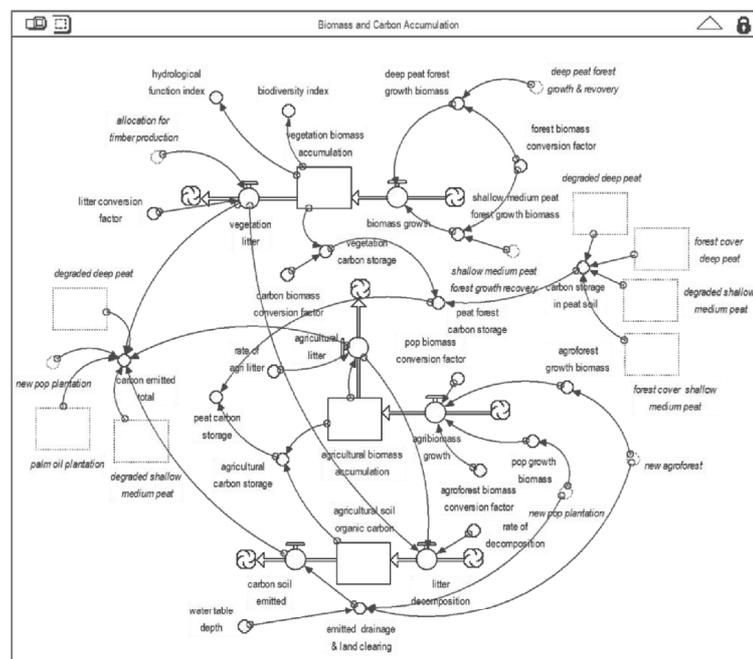


Figure 4 Model specification of system dynamic on biomass accumulation and carbon storage on peat forest and land.

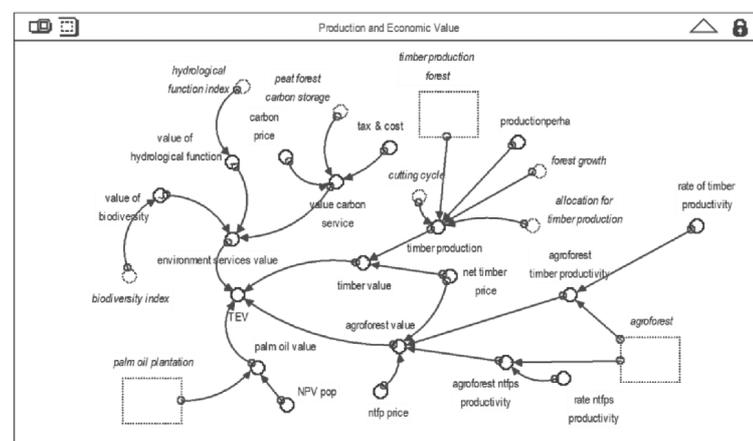


Figure 5 Model specification of productivity and forest resources economic valuation.

carbon emitted. While carbon emissions were influenced by rate of land and forest clearance and decomposition rate of organic matter. Primary peat forest conversion and land clearing for plantations were eliminated 817.53 ton ha⁻¹ carbon stored in vegetation. Carbon fixation 33.59 ton C ha⁻¹ in biomass of oil palm plantations is not enough to cover this loss. The highest soil carbon loss was in bushes 44.99 ton ha⁻¹ year⁻¹. Deforestation of peat primary forest into scrub was removed average 978.30 ton C ha⁻¹. Inter-relationships between these components were quantified as Figure 4.

The value of peat forest resources consist of direct use values, environmental services and biodiversity benefits. Direct use values such as extractive utilization of timber and non-timber forest products, plantation, agricultures and fisheries value were appraised by market prices. One of non-timber forest products is honey bees. Direct use values of these based on the market price is IDR180 million year⁻¹. Net present value (NPV) of oil palm plantations is IDR2.895 million ha⁻¹ year⁻¹ (Buttler & Conway 2007). Direct use values of agricultural and fishery on peatland based on market prices is IDR36 billion year⁻¹ (Rijksen *et al.* 1997).

Environmental service benefits in regulating hydrological function were calculated from the cost of lost revenues (Engel *et al.* 2008). The benefit of carbon storage of peat protection activities were appraised based on carbon credit scheme. Cost of management was calculated 10%, taxes 7% and carbon price USD3.5 ton⁻¹ (Buttler & Conway 2007; Guzick & Robinson 2013). Biodiversity benefits were calculated as value of existence which appraised using contingency approach with willingness to pay for protection of these resources. Existence value of peat ecosystem biodiversity in Trumon and Singkil reached IDR1.08 trillion year⁻¹ (Rijksen *et al.* 1997). Inter-relationships of these components were quantified as Figure 5.

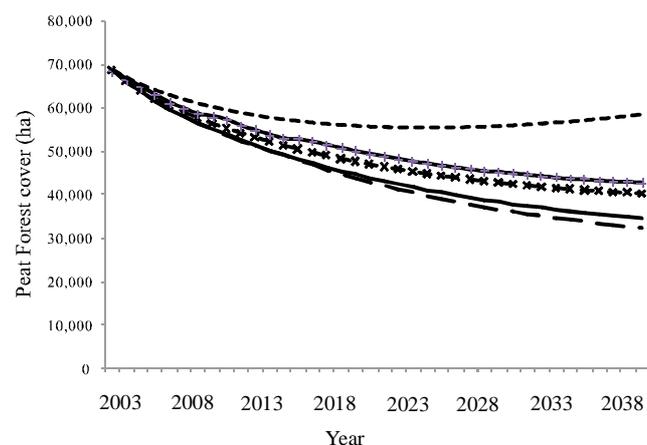


Figure 6 Projection of peat forest cover under various management policy options. Policy #1 (baseline) (—), policy #2 (---), policy #3 (-*-), policy #4 (-+-), policy #5 (.....).

Projection of policy options Model was executed by changing model equations to create various management scenarios. Forest resource allocations were determined by analyzing rate of emission reduction, direct use values and protection of biodiversity and hydrological function values. The model simulated with five management scenarios with length of simulation from year 2003 to 2040.

The 1st scenario ran at similar rate and conditions in the last 12 years. The projection next 30 years based on current conditions showed unsustainable peat forest management. These were shown by declining of peat forest cover projection (Figure 6). Compared with year 2015, peat forest cover in 2040 would reduce to 33.99 % (Table 1). Conversion into oil palm plantations and forest encroachment induced the forests and peatlands cover reduction. Changes on peatland cover affect benefits and functions of wetland ecosystem (Blumenfeld *et al.* 2009; Gunawan *et al.* 2012). Figure 7 and Figure 8 showed ecosystem benefits depression in carbon storage, and increasing carbon emission, conversely. Although economic benefits of oil palm plantation expansion and agroforestry practices were increased, these benefits under this policy option unable to reduce total economic value depression as a consequent of forest degradation (Table 2).

The 2nd scenario where was executed with option to improve the short term economic benefits by converting shallow moderate depth peat into oil palm plantations at rate twice of current conditions. This policy would raise economic benefit of plantation, but total economic value decline in long term. Deforestation would reduce total economic and biodiversity values at level -19.63% and -26.28 from current conditions. Carbon emissions were increased at 117.32 ton CO₂ eq ha⁻¹ year⁻¹, higher than average of carbon losses from peatland oxidation (Hooijer *et al.* 2010).

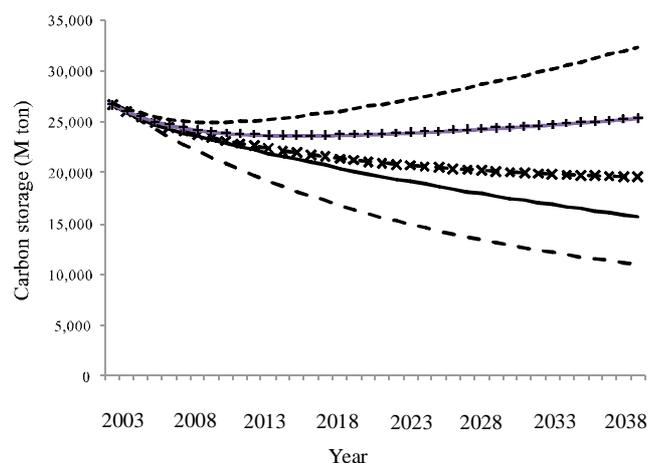


Figure 7 Projection of carbon storage in peat forest ecosystem under various management policy options. Policy #1 (baseline) (—), policy #2 (---), policy #3 (-*-), policy #4 (-+-), policy #5 (.....).

Table 1 Projection of peat forest cover, carbon storage and emitted based on various policy options

| Policy option | Peat land cover | | | | Carbon storage dynamics | | | |
|------------------------|-----------------|------------|------------------|-----------------|-------------------------|----------------|---|---|
| | Forest (ha) | Forest (%) | Non-forest* (ha) | Non-forest* (%) | Ecosystem (M ton) | Forest (M ton) | C emitted (CO ₂ M ton year ⁻¹) | C emitted (CO ₂ eq ton ha ⁻¹ year ⁻¹) |
| 2015 | 49,011 | 44.24 | 61,775 | 55.76 | 22,780.28 | 19,120.12 | 1,735.90 | 35.42 |
| Policy 1 st | 32,352 | 29.20 | 78,434 | 70.80 | 13,693.24 | 18,598.03 | 2,398.13 | 74.13 |
| | - (33.99) | | (+) 26.97 | | -(39.89) | - (2.73) | (+) 38.15 | |
| Policy 2 nd | 29,974 | 27.06 | 80,812 | 72.94 | 9,351.40 | 18,326.17 | 3,516.53 | 117.32 |
| | - (38.84) | | (+) 30.82 | | - (58.95) | - (4.15) | (+) 102.58 | |
| Policy 3 th | 39,199 | 35.38 | 71,587 | 64.62 | 19,263.14 | 20,167.94 | 2,881.23 | 73.50 |
| | - (20.02) | | (+) 15.88 | | - (15.44) | (+) 5.48 | (+) 65.98 | |
| Policy 4 th | 40,118 | 36.21 | 70,668 | 63.79 | 26,636.61 | 21,999.64 | 1,615.14 | 40.26 |
| | - (18.14) | | (+) 14.40 | | (+) 16.93 | (+) 15.06 | - (6.96) | |
| Policy 5 th | 62,761 | 56.65 | 48,025 | 43.35 | 36,429.27 | 31,226.66 | 1,127.32 | 17.96 |
| | (+) 28.05 | | - (22.26) | | (+) 59.92 | (+) 63.32 | - (35.06) | |

Non-forest* consist of agricultural land, oil palm plantation and agroforestry

Policy 1st. Projection on current condition

Policy 2nd. Projection based on scenario convert swallow –moderate depth peatlands to agriculture

Policy 3th. Projection based on scenario 25% peat forest cover protection

Policy 4th. Projection of peat forest cover, total economic value, oil palm plantation value, carbon emitted, and carbon storage based on scenario 50% peat forest cover protection and agroforestry development

Policy 5th. Projection based on scenario peat forest moratorium and followed by degraded peatland rehabilitation and agroforestry development

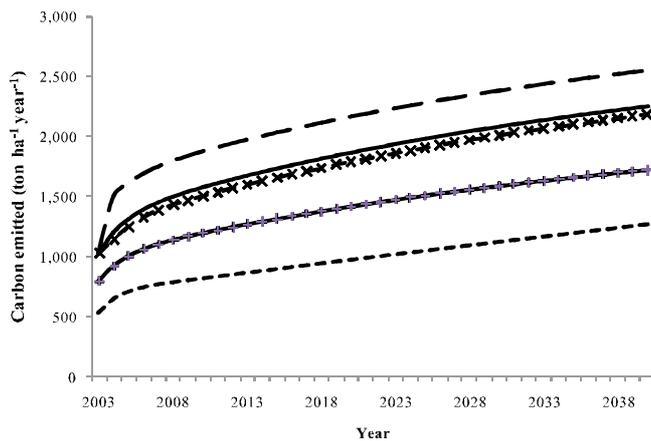


Figure 8 Projection of carbon emitted from peat forest ecosystem under various management policy options. Policy #1 (baseline) (—), policy #2 (---), policy #3 (- · -), policy #4 (—◆—), policy #5 (·····).

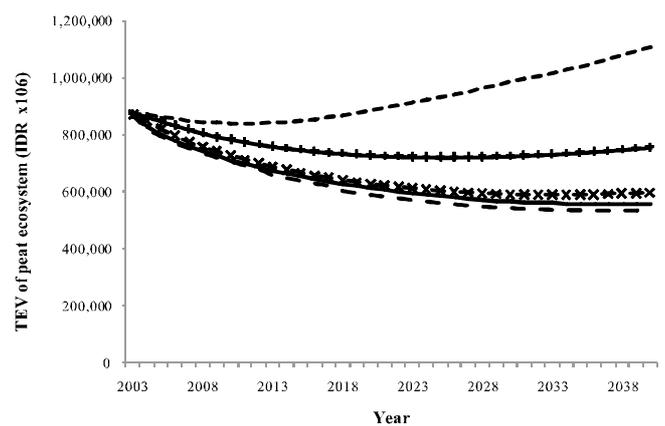


Figure 9 Projection total economic value of peat forest ecosystem under various management policy options. Policy #1 (baseline) (—), policy #2 (---), policy #3 (- · -), policy #4 (—◆—), policy #5 (·····).

Table 2 Projection of total economic value on peat forest ecosystem based on various policy options

| Policy option | Total economic value | Extractive direct use benefits | | | Environmental benefits | | |
|------------------------|----------------------|--------------------------------|---------------------|--------------|------------------------|-----------------------|--------------------|
| | | Timber | Oil palm plantation | Agroforestry | Carbon storage | Hydrological function | Biodiversity value |
| 2015 | 664,310 | 60,863 | 2,040 | 52,664 | 2,969 | 956 | 544,818 |
| Policy 1 st | 587,139 | 52,386 | 3,112 | 61,258 | 3,211 | 930 | 466,242 |
| | - (11.62) | - (13.93) | (+)52.55 | (+)16.32 | - (8.15) | - (2.72) | - (14.42) |
| Policy 2 nd | 533,907 | 55,761 | 3,876 | 68,307 | 3,409 | 916 | 401,638 |
| | - (19.63) | - (8.38) | (+)90.00 | (+)29.70 | - (14.82) | - (4.18) | - (26.28) |
| Policy 3 th | 618,439 | 52,967 | 2,030 | 61,258 | 3,201 | 1,008 | 497,975 |
| | - (6.91) | - (12.97) | - (0.49) | (+)16.32 | - (7.81) | (+)5.44 | - (8.60) |
| Policy 4 th | 819,115 | 75,271 | 1,332 | 61,149 | 3,211 | 1,100 | 677,052 |
| | (+)23.30 | (+)23.67 | - (34.71) | (+)16.11 | (+)8.15 | (+)15.06 | (+)24.27 |
| Policy 5 th | 1,144,053 | 107,109 | 2,896 | 53,623 | 3,839 | 1,561 | 975,025 |
| | (+)72.22 | (+)75.98 | (+)41.96 | (+)1.82 | (+)29.30 | (+)63.28 | (+)78.96 |

economic value = value 000.000,- (IDR)

The 3rd scenario was executed with preserving 25% of forest cover on shallow moderate depth peat and convert its remaining to agricultural plantation. The projection showed that these policies insufficient to reduce level of carbon emitted from forest and land degradation. Carbon emission reached 73.50 ton CO₂eq ha⁻¹ year⁻¹ or increased 65.98% from current condition. These level still higher (Hooijer *et al.* 2010). As a consequence, total economic value of ecosystem benefits would decline in long term (Figure 9). Compared than year 2015, peat forest cover in year 2040 would decrease to 20.02%.

Similar to the 3rd, the 4th scenario was executed by protecting a half (50%) forest cover on shallow-moderate depth peat, followed by agroforestry development on degraded peatlands. It is necessary to preserve peatland forests function as a hidrology unitary. Referring to 2nd scenario, although forest cover has reserved 25%, it is not enough to overcome rate of emissions and environmental service benefits declining in the long term. The projection is showed that the 4th policy would reduce rate of forest cover degradation on peat, although the remaining forest area still narrow (18.14%) (Table 1). This reduction would decrease the level of carbon emitted in year 2040 at 40.26 ton CO₂ eq ha⁻¹ year⁻¹ or -6.96% from current condition, and enhance forest carbon storage up to 15.06%. This emission is lower than average of oxidation level from tropical peatland drained which reached 65 ton CO₂ eq ha⁻¹ year⁻¹ (Hooijer *et al.* 2010). Increasing proportion of peat forest cover would enhance the benefits of hydrological function and biodiversity (Dommain *et al.* 2010; Onrizal *et al.* 2010) while providing short-term benefits of agroforestry practices. These schemes escalate total economic value of ecosystem (Figure 9).

The 5th policy scenarios ran with moratorium (suspending) primary peat forest clearance and followed by degraded peat forest rehabilitation with agroforestry development and oil palm plantations. This policy would increase peat forest cover up to 28.05% of current conditions. This scheme also reduce rate of carbon emission (-35.06%) and increase forest carbon storage at significant rate (+63.32%). Increasing proportion of peat forest cover through moratorium of primary peat forest clearance and rehabilitation of degraded peatland enhance benefits of hydrological functions and biodiversity up to 63.28% and 78.96%, respectively (Table 2). Preservation the peatlands for their carbon value would generate income from carbon credits market. A study done in Central Kalimantan indicate that value of carbon credit from a 1,000 ha area would be worth USD6.32–9.02 million, which would be greater than net income from a oil palm plantation (Hemanath & Tisdell 2009). Butler and Conway (2007) demonstrated that this mitigation scheme is more economically profitable than using the land to produce palm oil.

Allocation and policy implication Forest and peatland management policies at various intensities provide diversity on economic and environmental services benefits. Efforts to generate short-term benefits by changing peat forest function will enhance higher direct economic value, but deflate their environmental benefits. First policy option projection showed that peat forest management on current condition would not fulfill the principles of sustainability. Even though concession benefits were higher, utilization of ecosystems provide lower economic value for community. Environmental services in regulation of hydrological

function and biodiversity protection would decline in long term. Increasing intensity and economic losses due to floods are indications of ecosystem function degradation (Blumenfeld *et al.* 2009; Dommain *et al.* 2010). The 4th and 5th scenarios allowed maximum environmental services benefits, but the latter were more take side for community. Both of schemes support the Presidential Instruction Number 6/2013 on *moratorium or suspension on granting of new licenses and improvement of natural primary forest and peatland governance* and the United Nations' program on Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD). This program is being intensively discussed as a key framework in international conventions on climate change (Stern 2006).

The opportunities from non-timber forest products and agroforestry development on degraded peatlands will escalate community welfare. Community involvement in restoring ecosystem function would diminish their dependence on forest-damaging practices (Keenleyside *et al.* 2012). Rehabilitation of degraded peatland with agroforestry and oil palm plantations and preservation the peatlands for carbon trading would generate income from operation of concession, non-timber forest product harvesting for community welfare, and revenue from carbon market.

The results showed that current forests and peatlands management are must be reorganized, particularly in planning and monitoring conditions in long-term. Forest criticality assessment which applied the Regulation of Minister of Forestry (*Permenhut*) Number P.32/2009 revised *Permenhut* P.12/2012 need to be improved by considering criteria and indicator impacts, so that its application in peat swamp forests more appropriate. Peat ecosystem should be managed as a holistic hydrological systems management. Collaborative management schemes are indispensable for multiple stakeholders involved such as Watershed Management Agency (BPDAS) of Wampu Ular, Gunung Leuser National Park (TNGL), Forestry and Plantation Services (*Dinas Kehutanan dan Perkebunan*), local government and plantation companies. Considering peat utilization as multiple benefits management, clarity of roles and responsibilities of each party are indispensable. Simulations based on dynamics of the system can be used to determine impact of certain policy as long-term

consequences of system interest.

Peatland ecosystems is proposed as a protected area or adaptive management and intensive, with consideration the criticality criteria and their physiological characteristics (Aswandi *et al.* 2015). Peat dome and very deep peatlands should be protected and rehabilitated when degraded. If the right policies and institutional structures were in place, preventing further deforestation would be cheaper than other types of mitigation strategies for greenhouse gas emissions (Stern 2006). Adaptive management allowed on uncritical edge shallow peat to moderate depth only with water table regulation. Meanwhile, intensive management is permitted in very shallow peat and uncritically edge peat. Various alternative designations of forest and peatland are showed in Table 4.

Adaptive management is conducted for limited timber production limited with selective logging and potential NTFPs development such as aloes, rattan, honey, and bark. Agroforestry patterns are developed without much changing forest cover to reduce malfunctioning of hydrology and biodiversity. Water level regulation is a requirement. The water level should not be deeper than 60 cm in drained peatlands (Aswandi *et al.* 2015). Excessive drainage would dry out the peat thus changing its characteristics, peat becomes vulnerable to fire and unable to absorb water. The escalation of flooding intensity and smog hazard from peat fires are evidence of these changes (Holden *et al.* 2004; Erwin 2008; Hooijer *et al.* 2010). Intensive management is allowed by maintaining forest cover at least 50%. Management schemes such as timber production with selective logging, plantations and agricultural development proportionally. Opportunities of NTFPs management and agroforestry development on degraded land would improve the community welfare and reduce the dependence on forest-damaging practices indirectly.

Understanding of processes and impacts of policy options on the system dynamic are important factors in utilizing the model as a learning tool (Stern 2001; Purnomo & Mendoza 2011; Mousavi & Sadeghian 2015). If the processes could be understood, built model would improve the capabilities of policy-makers to set proper policy options and make the right decisions to increase community welfare and reduce forest degradation.

Table 3 Economic and environmental services benefit based on various peatlands management policy

| Policy option | Community income | Government income | | Concession income | Biomass accumulation | Carbon emitted | Hydrological function | Biodiversity |
|------------------------|------------------|-------------------|---------|-------------------|----------------------|----------------|-----------------------|--------------|
| | | Local | Central | | | | | |
| Policy 1 st | Low | Low | Low | High | Low | High | Low | Low |
| Policy 2 nd | Low | Higher | Higher | Higher | Lower | Higher | Lower | Lower |
| Policy 3 th | Low | Lower | Lower | Lower | Higher | Lower | Lower | Lower |
| Policy 4 th | High | Lower | Lower | Lower | Higher | Lower | Higher | Higher |
| Policy 5 th | High | Higher | Higher | Higher | Higher | Lower | Higher | Higher |

Table 4. Criteria and alternatives sustainable allocation of peat forest ecosystem

| Depth | Physiology | Criticality | Allocation | Management strategy | |
|----------------------------|------------------------|---------------|----------------------|---|--|
| Very deep–deep (> 3 m) | Peat dome | Critical | Protection | Restoration with endemic and non-invasive species, protection/conservation | |
| | | Not disturbed | Protection | Protection/conservation | |
| | Peat edge | Critical | Protection | Restoration with endemic and non-invasive species, protection/conservation | |
| | | Not disturbed | Protection | Protection/conservation | |
| Moderate (1–3 m) | Peat dome | Critical | Protection | Restoration with endemic species, protection/conservation | |
| | | Not disturbed | Protection | Protection/conservation | |
| | Peat edge | Critical | Adaptive management | Rehabilitation with endemic and non-invasive species/ protection 50% forested area | |
| | | Not disturbed | Adaptive management | Limited production (selective logging), plantation with water table management and protection 50% forested area | |
| Shallow (0.5–1 m) | Peat dome | Critical | Adaptive management | Rehabilitation using non-invasive species, limited production (selective logging), plantation with water table management, and protection 50% forested area | |
| | | Not disturbed | Adaptive management | Limited production (selective logging), plantation with water table management, and protection 50% forested area | |
| | Peat edge | Critical | Adaptive management | Rehabilitation using non-invasive species, limited production (selective logging), plantation with water table management, and protection 50% forested area | |
| | | Not disturbed | Intensive management | Limited production (selective logging), plantation with water management, and protection 50% forested area | |
| | Very shallow (< 0.5 m) | Upstream peat | Critical | Intensive management | Rehabilitation using non-invasive species, timber production (clear cutting and pulp plantation), agroforestry development |
| | | | Not disturbed | Intensive management | Timber production (clear cutting and pulp plantation), agricultural/plantation, agroforestry development |
| Very shallow (< 0.5 m) | Peat edge | Critical | Intensive management | Rehabilitation using non-invasive species, intensive production (clear cutting and pulp plantation), plantation, agricultural and agroforestry development | |
| | | Not disturbed | Intensive management | Timber production (clear cutting and pulp plantation), intensive production, plantation, agricultural and agroforestry development | |

List Abbreviation:

BPDAS: Balai Pengelolaan Daerah Aliran Sungai, BPKH: Balai Pemantapan Kawasan Hutan, GHGs: Greenhouse gases, IDR: Indonesian Rupiah MoF: Ministry of Forestry, NTFPs: Non-timber forest products, OPP: Oil palm plantation, REDD: Reducing Emissions from Deforestation and Forest Degradation in developing countries, TEV: Total economic value, TNGL: Taman Nasional Gunung Leuser, USD: United State Dollar

Conclusion

The system dynamics can be used as a tool to develop various scenarios of forest management by analyzing impact of policies. Changes primary peat forest to oil palm plantation would reduce value of ecosystem benefits. Carbon emissions were increased at 117.32 ton CO₂ eq ha⁻¹ year⁻¹, higher than average of carbon losses from peatland oxidation. Preserving 50% of forest vegetation on moderate depth and protection very deep peatlands would reduce emission - 6.96% to -35.06% and increase forest carbon storage at significant rate +15.06% to +63.32%, respectively. These

mitigation schemes propose maximum environmental service benefits, optimum total economic value, higher ecological preservation and short-term benefits value, and favor to community development. Forest rehabilitation with agroforestry practices will enhance carbon uptake, especially on degraded lands. Model developed can be applied in determining the peat ecosystem management decisions. Understanding the process and impact of these policy choices would help policy makers to optimize the peat forest management. Validation is required when applied to similar ecosystems elsewhere.

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