Restoring Degraded Peatlands through Improving Land Suitability and Cultivating Native and Non Native Plants of Peatlands

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Abstract. Peatlands as natural resources can be utilized for agriculture in a broad sense (such as fisheries, animal husbandry, smallholder agriculture, plantations, energy, and forestry). Most current users have forced peatlands, resulting in degradation, oxidation, soil subsidence, and an increased risk of peat fires. This peatland degradation requires developers to look for suitable plants that supporting local communities to earn a living while protecting the peatlands. The research aimed how to carry out restoring degraded peatlands through improving land suitability and cultivating native and non-native plants of peatlands. The research resulted that four permanent limiting factors (natural condition and difficult to repair) were found in the research area, namely oxygen availability (oa); root media (rc); peat (pe); and flood (fh). Two non-permanent limiting factors (be improved by giving soil ameliorant) were nutrient retention (nr) and available soil nutrients (na). The improvement in class from actual to potential changed maximally to be one level better. Improvement efforts to increase peatlands productivity included: managing ground water table by making drainage; fertilize soils with lime and NPK fertilizers; do not burn biomass; manage forests and land fires; maintain organic matters in the soils; and maintain peat depths and maturity. Scenarios to achieve sustainable management of peatlands can be done by the gradual elimination of oil palm plantations and other crops that require drainage over time and replacing them with crops that do not require drainage in combination with forestry including timber and non-timber production forests in the peatlands.

Keywords: Degraded peatlands, land suitability, cultivated plants

1. Introduction

Restoration of degraded peatlands is the key to preventing further degradation of peatlands. In the long-term restoration of peatlands, we are faced with two main problems, namely the less types of suitable plants for peatlands and ensuring the livelihoods of local communities who rely heavily on peatlands [1][2][3]. The level of plant suitability to the peatlands ecosystem was limited, thus the alternative choices of plant species to be cultivated by farmers were also limited[4][5][6]. This is because peatlands have low fertility, high acidity, poor drainage, and the fragile nature of the peatlands ecosystem [7][8][9]. Great care is needed, so that the degradation of the peatlands function can be minimized, so it is necessary to look for suitable plant species with the peatlands ecosystem [10][11].

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Classification of land suitability was carried out by evaluating the soil properties and matching it with the growing requirements of the superior species being assessed, so that the land suitability class can be determined[12][13]. The research aimed how to carry out restoring degraded peatlands through improving land suitability and cultivating native and non-native plants of peatlands.

2. Materials and Methods

This research was carried out in the Talang Sepucuk peatlands swamp which is included in the Peatlands Hydrological Unit of Sibumbung River – Komering River, OKI Regency, South Sumatra (Figure 1). The location of this research is a physiographical type of Lebak Peatlands swamp which was not affected by tidal water, either from river tides or sea tides. The steps involved in evaluating land for suitability include evaluating land quality through evaluating plant growth requirements, and evaluating land suitability for each agricultural species. The principle of land suitability analysis was to match plant growth requirements with land quality.

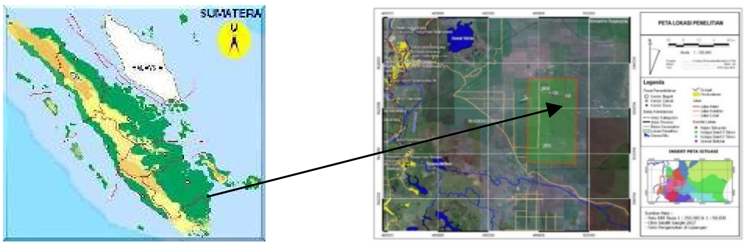

Figure 1. The map of research location in Talang Sepucuk OKI

3. Results and Discussions

3.1 Cultivated Plants on the Degraded Peatlands

Farmer's motivation, some reasons of farmers why they utilized degraded peatlands, namely:

1) Their profession in the future is as farmers, thus they need to work on processing peatlands for agriculture, animal husbandry and fisheries.
2) Peatlands make it possible to produce and to meet family food needs if they can be managed properly.
3) Agricultural production can reduce the cost of living and the remaining part can be used for other purposes, such as education and others.

Utilization of the degraded peatlands, historically farmers were less interested in utilizing peatlands because peat farming was similar to gambling. The faced challenges were high, such as far from residential areas, no road access, and river boats for transportation, peatlands were not suitable for any plant cultivation. Over time, more and more farmers were interested in owning peatlands. The buying and selling of peatlands occurred and continued to this day. Those who can afford can have extensive peatlands (more than 10 ha).

Condition of the degraded peatlands, around 85% of the peatlands were classified as deep peatlands (> 300 cm) and about 32% of the deep peatlands were currently being cultivated. In the dry season, these peatlands were vulnerable to fire, and in the rainy season there were frequent floods. This was exacerbated by the drainage canals that were deliberately built to drain the peatlands. Cultivated plants (especially those that were not adapted to stagnant water) have experienced stress due to water inundation. Forest and land fires and water inundation were heavy constraints making many farmers reluctant to work on the peatlands.

Cultivated plants on the degrade peatlands, more than 52% of farmers grow jelutung, ramin, pulai and pineapple, nearly 28% of farmers cultivated belangeran, geronggang, medang, pelawan, and tengkawang and 20% cultivated oil palm, rubber, acacia, coconut, fruit trees and vegetables (Table 1). The peat endemic species (jelutung, belangeran, ramin, geronggang, pulai, medang, pelawan, tengkawang, and gemor) were planted with purpose for investment. The endemic species to mineral soils were planted with hope that they can be used for self-sufficiency and commercial purposes.

Floods Challenge, Floods occurred each year with varying frequency, depth and duration of inundation. In 1990, inundation occurred around 10.18%, the average depth of inundation was 10-15 cm with its duration of 1-2 hours. Floods in the rainy season of 2020 have caused many fruit trees that were ready to harvest to have stress. In 2021, floods occurred around 2-4 times. Floods in November 2021 lasted a long time (> 4 days). The extensive inundation occurred increase to 23.54%, and the average inundation depth increased in range of 30-150 cm and longer duration of inundation slightly increased to 3-5 hours. Water inundation was predicted to expand to more than 200 % (around 51.29%) with a depth of inundation increased more than 100% (>150 cm) and duration of inundation increased to > 5 hours (Table 2).

Table 1. Cultivated plant species and their suitability on peatlands

Plant Name	Plant native to		Plant type
	Peatlands	Mineral soil	
Plantation Plants			
Acacia *(Acacia Mangrum L.)*		√	Tree
Coconut *(Cocos nucifera L.)*		√	Tree
Oil palm *(Elaeis guineensis* Jacq.)		√	Tree
Rubber (*Hevea brasiliensis Muell. Agr.)*		√	Tree
Forest/Non Timber Forest Trees			
Jelutung (*Dyera costulata* (Miq.) Hook.	√		Tree
Belangeran *(Shorea balangeran L.)*	√		Tree
Ramin (*Gonystylus bancanus*)	√		Tree
Geronggang (*Cratoxylon arborescens* (Vahl.)	√		Tree
Pulai *(Alstonia scholaris L.)*	√		Tree
Medang (*Litsea* spp. L.)	√		Tree
Pelawan (*Tristania* sp)	√		Tree
Tengkawang *(Shorea spp. L.)*	√		Tree
Gemor (*Nothaphoebe coriacea* Kosterm.)	√		Tree
Petai (*(Parkia speciosa L.)*		√	Tree
Mahoni (*Swietenia mahagoni (L.) Jacq.*)		√	Tree
Sengon (*Albizia chinensis* Merr)		√	Tree

Fruit Plants/Trees			
Avocado (*Persea americana* Mill.)		√	Tree
Banana *(Musa paradisiaca L.)*		√	Bush
Citrus *(Citrus sphaerocarpa L.)*		√	Bush
Durian *(Durio zibethinus L.)*		√	Tree
Mango (*Mangifera indica L.)*		√	Tree
Pineapple *(Ananas comosus L.)*		√	Bush
Rambutan *(Nephelium lappaceum L.)*		√	Tree
Vegetable Plants			
Chilli *(Capsicum annuum L.)*		√	Bush
Eggplants *(Solanum melogena L.)*		√	Bush
Maize *(Zea mays L.)*		√	Bush
Spinach *(Amaranthus hybridus L.)*		√	Bush

Source: Results of field survey and laboratory analyses (2022).

Table 2. Flood and inundation status in years of 1990-2050*/

Flood parameters	1990 [a]/	2021 [b]/	2050 [c]/
Inundation area (%)	10.18	23.54	51.29
Inundation depth (cm)	10-15	30-150	>150
Inundation duration (jam)	1-2	3-5	>5
Total river length (km)	5.24	2.10	1.60
Canal lengths (km)	1.30	10.38	17.28

Note: [a]/ before land clearing of peatlands, [b]/ existing condition, [c]/ predicted data
Source : */ Interpreted based on the land use map (1: 250,000 scale), field survey (2022)

3.2 The Ultimate Challenge of Farming on the Degraded Peatlands

The main challenges in farming on peatlands were how to choose plants that are suitable for the peatland ecosystem, able to adapt to floods and drought. The total river lengths were progressively shortened around 5.24 km (in 1990) becoming 2.10 km (in 2021) and was predicted around 1.60 km (in 2050). The opposite condition happened that lengths and acreages of man-made canals were growing year to year, namely 1.30 km (in 1990), increased to 10.38 km (in 2021) and was predicted to increase further to 17.28 km (in 2050). The increase in lengths and acreages of canals was intentionally done by the private large companies and government in order to anticipate the decline sharply in lengths and acreages of rivers. The conditions of the canals were less maintained, thus the canals could not drain water perfectly due to high sedimentation and pollution by illegal logging and domestic waste.

Drought Challenge, The peatlands area now had few fires due to strict supervision by the Fire Care Village Group (FCVG) and the dry seasons (2020 and 2021) were humid. Various actions taken by farmers:

1) Peatlands around the farmer's house become dry causing vegetable crops to dry out easily. They had to water their vegetable crops at least once a day and difficult to get water.
2) The first time for land preparing was difficult and challenging due to overgrown with dense shrubs and many roots needed to be removed. The government prohibits burning,

making it more difficult to prepare land. Some crops require drainage before planting, it is costly.

3) Fertilization was carried out according to the dose and on time regularly, especially for fruit plants. They argued if the crop was not fertilized regularly, then the plant will not produce.

3.3 Limiting Factors for the Cultivated Plants on the Degraded Peatlands

Four permanent limiting factors were found in the research area, namely oxygen availability (oa); root media (rc); peat (pe); and flood (fh) presented in Tabel 3.

Table 3. Limiting factors for cultivated plants on the degraded peatlands

Class	Sub class*/	Limiting factors	Cultivated plants
S1	S1-na	Available soil nutrients	Jelutung, belangeran, ramin, gemor, pelawan, tengkawang, medang
S2	S2-nr, na, fh	Nutrient retention; available soil nutrients; flood	Mango, pineapple, and rambutan
S3	S3-oa, nr, na, fh	O_2 availability (drainage), nutrient retention; available soil nutrients; flood	Acacia, coconut, oil palm, rubber, petai, avocado, banana, citrus, and durian
N	N-rc, oa, nr, na, fh, pe	Rooting media, O_2 availability, nutrient retention; available soil nutrients; flood, peat depths and maturity	Mahoni, sengon, chili, eggplants, maize, and spinach

Note: */ rc: rooting media; oa : oxygen availability (drainage); nr: nutrient retention; na: low available soil nutrients; fh: flood (frequency & duration); pe: peat depths & maturity
Source: Results of field survey and laboratory analyses (2022).

Oxygen availability (oa), oxygen availability is caused by field stagnant water needing drainage. All land clearing areas have been over-drained resulting in the CO_2 and CH_4 gases release, peat subsidence and compaction, and irreversible drying, which can affect the greenhouse effect and global warming.

Rooting media (rc), determined by soil depths, where soil depths determined how far plant roots can grow. Most soil depths in the research area are shallow (< 50 cm) due to shallow ground water table in range -40 cm until + 100 cm.

Peat (pe), the sapric maturity is classified as marginally suitable, S3 and fibric classified as non-suitable, N for plants, while most of the peat depths ranged from 200-450 cm.

Flood/inundation (fh), the construction of drainage channels payed less attention to elevation maps, so they were unable to predict how to facilitate hydrodynamics of water. The average height and duration of inundation was 25 cm with inundation duration of > 4 days, this can cause plants to experience inundation stress.

There are two non-permanent limiting factors, namely nutrient retention (nr) and available soil nutrients (na). Both of these limiting factors can be improved by applying soil ameliorant.

Nutrient retention (nr), pH 3.5 was classified as low soil; organic C content 40-46%, and low base saturation (S3). It can be overcome by liming to increase soil pH. As pH increased, the value of base saturation was also improved due to soil pH was closely related to base saturation.

Available soil nutrients (na), the average content of total N 1.75-1.80%, classified as very high; available P_2O_5 5-15 ppm, very low; K_2O 8-14 mg/100g, very low to low. Available soil nutrients were the simplest limiting factor to be corrected and have the lowest negative impact if fertilization was carried out at the right time and dose.

Most of the endemic cultivated species in peatlands were classified as very suitable (S1-na) with the limiting factor being low available soil nutrients, while other plant species (endemic plants in mineral soils) were classified as order/class S2 (moderately suitable); S3 (marginally suitable); and N (not suitable) followed by at least more than three limiting factors (Table 3).

3.4 Improving Land Suitability for the Cultivated Plants

The improvement in class from actual to potential changed maximally to be one or two levels better, but in this study the improvement was only one level better (Table 4).

Table 4. Efforts to increase land capability for cultivated plants

Land suitability class		To increase land capability for cultivated plants from actual suitability to potential land suitability
Actual[1]/	Potential[2]/	
S1-na	S1-na	Manage ground water table; manage forest and land fire; and do not burn biomass
S2-nr, na, fh	S2-nr	Manage ground water table by making drainage; fertilize soils with lime and NPK fertilizers; and do not burn biomass
S3-oa, nr, na, fh	S2-oa, nr	Manage ground water table by making drainage; fertilize soils with lime and NPK fertilizers; do not burn biomass; manage forest and land fire; and maintain organic matters in the soils
N-rc, oa, nr, na, fh, pe	N-rc, oa, na, pe	Manage ground water table by making drainage; fertilize soils with lime and NPK fertilizers; do not burn biomass; manage forest and land fire; maintain organic matters in the soils; and maintain peat depths and maturity

Note: */ rc: rooting media; oa : oxygen availability (drainage); nr: nutrient retention; na: low available soil nutrients; fh: flood (frequency & duration); pe: peat depths and maturity

Source: Results of field survey and laboratory analyses (2022).

Actual Land Suitability, Actual land suitability is defined as land suitability class in natural conditions (not yet considering improvement efforts). The research area had four land suitability sub-classes:

1) S1-na (classified as very suitable with the non-permanent limiting factor), available soil nutrients (na), such as jelutung, belangeran, ramin, geronggang, pulai, medang, pelawan, tengkawang, and gemor. Farmers cultivated this crop for investment purposes.
2) S2-nr, na, fh (moderately suitable), the limiting factor of nutrient retention; available soil nutrients; and floods, namely mango, pineapple, and rambutan.

3) S3-oa, nr, na, fh (marginally suitable with limiting factors of oxygen availability, nutrient retention; available soil nutrients; and floods), such as acacia, coconut, oil palm, rubber, petai, avocado, banana, citrus, and durian.
4) N-rc, oa, nr, na, fh, pe (not be suitable with the limiting factors of rooting media, oxygen availability, nutrient retention; available soil nutrients; flood, depth and maturity of the peatlands), namely mahoni, sengon, chili, eggplants, maize, and spinach.

Potential Land Suitability, Potential land suitability is the desired land suitability to increase land productivity by making efforts to improve the peatlands, such as manage ground water table; fertilize soils with lime and NPK fertilizers; do not burn biomass; manage forests and land fires; maintain organic matters in the soils; and maintain peat depths and maturity.

3.5 Needed Priorities for the Degraded Peatlands

The scenarios are called for the gradual elimination of oil palm plantations and other crops that require drainage over time and replacing them with crops that do not require drainage in combination with forestry including timber and non-timber production forests in the peatlands (Table 5). The research area was with peatlands depths of 100-450 cm, therefore conservation and restoration measures need to be carried out by cultivating peatlands endemic plants.

Table 5. Needed priorities for degraded peatlands

Peatlands	Uses in agriculture	Uses for forest & conservation
Drained	To apply paludiculture technology and to stop oil palm plantation needing drainage over time; to minimize strategic areas needing intensive drainage because drainage influenced strongly non-drained areas and their surrounding; to control forest and land fire	Maintain remaining forests; conserve and restore peatlands by rewetting and blocking drainage canals; and control forest and land fire
Non-drained	Do not drain anymore; to cultivate paludiculture plants; to control forest and land fire control	Conserve remaining forests in degraded forest, reforestation, and forest and land fire control
Other uses	Increasing peatland control, namely drainage, land uses, and land cover Increasing control of local peatland uses connected to peatland policies Improving law enforcement for peatland	

Source: Results of field survey and laboratory analyses (2022).

4. Conclusions

Farmers planted endemic species to peatlands for investment. Planting endemic species to mineral soils with hope that they can be used for self-sufficiency and commercial purposes. The main challenges in peat farming were how to choose plants that are suitable for the peat ecosystem, able to adapt to floods and drought. Four permanent limiting factors were oxygen availability (oa); root media (rc); peat (pe); and flood (fh). Two non-permanent limiting factors were nutrient retention (nr) and available soil nutrients (na). The improvement in class from actual to potential changed maximally to be one level better, namely managing ground water table; fertilizing soils with lime and NPK fertilizers; doing not burn biomass; managing forests and land fires; maintaining soil organic matters; and maintaining peat depths and maturity. Scenarios to achieve sustainable peat management are by the gradual elimination of oil palm plantations and other crops that require drainage over time and replacing them with crops that do not require drainage in combination with forestry including timber and non-timber production forests in the peatlands.

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