Development Paludiculture on Tropical Peatland for Productive and Sustainable Ecosystem in Riau

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Abstract. There are 2 million hectares of tropical peatland that are critical and must be restored by the Indonesian Government to reduce the greenhouse effect until 2020. The clear-cutting of peat swamp forests has changed from natural ecosystems into degraded ecosystems. When peat was dried for monoculture, it will stimulate forest fires. Peatland forest fire in 2015, caused Indonesia as one of the largest CO\textsubscript{2} emitters in the world. The magnitude of the increase in CO\textsubscript{2} emissions due to land use change caused peatland degradation. Paludiculture is an alternative technique for managing productive peatlands for food crops while maintaining ecological functions. Rewetting in peatland could reduce the emission of carbon, while food crops increase the quality and quantity of biomass. The plasticulture system can produce biomass on wet peatland conditions, maintain the sustainability of ecosystem services and can increase carbon accumulation. The principle in paludiculture is to restore the sustainability of the peat ecosystem while still paying attention to economic interests. Development of paludiculture of peat swamps land in Kepulauan Meranti Riau is very suitable to be implemented because could support their function of the hydrological buffer in natural peat swamp forest and source of food.

1. Introduction

Peatland ecosystem management in Indonesia is one of the hot issues in recent years. It is related to the function of peat ecosystem and the increase or decrease of environmental quality. The area of peatland is about 200 million ha worldwide. Indonesia is ranked 4 (± 20 million ha) after Canada, Russia and the United States of America. In 2000-2012, Indonesia lost 2.6 million ha of natural peat forest. In average, 217 ha natural forest of wetland vanishes in Indonesia each year. This ecosystem change causes deficient ecosystem. For more than 90\% of peat forest has been converted or degraded which lead to the decrease of biodiversity, carbon emission as 700 million CO\textsubscript{2}/year, subsidence and social conflict [10].

Forest fire in peatland had been occurred since the 1980s and recurs every year and it was aggravated due to Elnino occurrence in 1997 and 2015. This fire was caused by the huge amount of drainage in peatland so that the peat is easily washed out and burnt. Drainage causes peat material to be decayed and washed out to the river which causes subsidence. When peatland is flooded, it means that it is no longer productive [8;19]. Therefore, the function of the formed environment needs to be repaired by following natural rules. One of the way to repair the ecosystem is by implementing ecology principles. To overcome this problem, paludiculture is implemented in peatland.

In the attempt of peat ecosystem recovery, Indonesia government has targeted ± 2 million ha restoration activity in peatland up to 2020 [16]. Riau is one of the seven-province included in peat restoration because of it prone to fire forest. The data shows that about 2.3 million ha or 59.54\% of total area in Riau has been degraded including in Kepulauan Meranti District which is 75\% of its area consist of peatland with the depth of >3 meters [23].
By considering that most of the area in KHG Pulau Tebing Tinggi, Kepulauan Meranti District is a peatland, the policy of swamp area management based on sustainable natural resource development is necessary. Based on conservation principle, peat swamp land as the ecosystem has to be protected but also as potency which can be improved as utilized. The management of peat swamp land in Kepulauan Meranti District also aimed to achieve the improvement of food production, so that the utilization of peat swamp land has a high prospect.

Paludiculture is swamp-based plant cultivation which does not need drainage before the peatland is destroyed. Drainage-based soil management into nondrainage management is using plant which suitable for the wet area. The selection was also based on economic consideration. Kepulauan Meranti District has the potency of several local plants which suitable with the criterion of paludiculture, those are sago, areca nut, coffee, and coconut.

The activity of peatland ecosystem recovery can be fit to local government program namely national food development to achieve national food security. The combination of agriculture plant and forest tree in this swamp area called paludiculture-based agroforestry. One factor affecting the success of paludicultur-based agroforestry implementation is the correct choice of plant type. This study presents how the characteristic of land utilization and paludicultr-based agroforestry model worked which implement in KHG Pulau Tebing Tinggi, Kepulauan Meranti District, Riau.

2. Method
The study Location was in KHG Pulau Tebing Tinggi, Kepulauan Meranti District, Riau. This study was conducted in August 2018. The objective of this study was paludicultur and agroforestry model in KHG Tebing Tinggi. In this study, the method used was the study of information and the result of research which related to paludiculture with the development of paludicultur-based agroforestry. Primary data was obtained through survey and interview with related stakeholder particularly paludicultur-based agroforestry models in KHG Pulau Tebing Tinggi.

3. Results and discussion

3.1. Results
From the survey it was known that area utilization in KHG Pulau Tebing Tinggi used as paludicultur-based agroforestry is shown in table 1.

| No | Village          | Land Use    | Commodity type | Information           |
|----|------------------|-------------|----------------|-----------------------|
| 1  | Tanjung Sari     | Community Garden | Cococnut       | Plant Age > 40 year   |
| 2  | Lukun            | Community Garden | Sago           | Plant Age >20 year    |
|    |                  |             | Rubber         | Plant Age ± 7 year    |
| 3  | Sendanu Darul Ikhsan | Community Garden | Sago           | Plant Age > 20 year   |
|    |                  | Small Garden | Rubber         | Plant Age ± 7 year    |
| 4  | Sungai Tohor Barat | Community Garden | Rubber  | Plant Age > 40 year |
|    |                  |             | Rubber         | Plant Age > 40 year    |

Source: Primary Data, 2018

The result of the survey shows that in general the utilization of area in KHG Tebing Tinggi was sago plantation, rubber plantation, and coconut plantation. Every type of area utilization gave different economic contribution to the community with ecology value for peatland conservation. It was the consideration of government which is Badan Restorasi Gambutto choose the vegetation rehabilitation suitable for the initial purpose which was peatland recovery [16].

In Kepulauan Meranti District, coconut plantation was the priority in peatland ecosystem rehabilitation because most of the coconut tree was not productive (>40 years old) and needed
rejuvenation. The same condition was for rubber plantation, it was >40 years old and monoculture. Some of the rubber plants were young ± 7 years old but most of them are not harvested due to its age, meanwhile, sago plant in KHG Pulau Tebing Tinggi was monoculture so that it needs to be diverted with the wood-based plant.

Peatland restoration is a long process to restore the function of peatland and improve social welfare that gets the impact of peatland degradation. Based on WRI analysis, forest conservation can decrease 7 billion metric ton of CO2 which is equal to 1.5 billion cars’ emission. During 2017, restoration done by KHG Tebing Tinggi were paludiculture-based agroforestry development established by Pusat Studi Bencana of UNRI collaborated with Badan Restorasi Gambut. The restoration was conducted by making paludiculture-based agroforestry model in the determined plot. Every plot was 0.5 ha except in yard area which was 0.15 ha. Paludiculture-based agroforestry model can be seen in Table 2.

### Table 2. Species and Composition of Agroforestry based paludiculture models in KHG Tebing Tinggi

| Model | Land Use       | Composition of species     | Information                      |
|-------|----------------|---------------------------|----------------------------------|
| A     | Sago Plantation| Sago + Wood plants        | Enrichment                       |
| B     | Rubber Plantation | Rubber+ Wood plants   | Enrichment                       |
| C     | Gardens        | Yard + Wood plants        | Enrichment                       |
| D     | Coconut Plantation | Coconut                  | Enrichment with Coffee + Bee   |
| E     | Coconut Plantation | Coconut                  | Enrichment with Areca + Bee   |
| F     | Coconut Plantation | Coconut+ Bee             | Enrichment with Coffee  |
| G     | Coconut Plantation | Coconut+Coffee+Areca   | Enrichment with Bee             |

Source: Pusat Studi Bencana UNRI, 2018

From the study result, it shows that Meranti Island community has cultivated peatland-based plants such as sago, coffee, rubber, and areca nut. Rubber plant was planted with a quite wide distance between plants with the drainage of 60-80cm. Vegetation rehabilitation in sago plantation, rubber plantation and yard was conducted by diversification of wood-based plants such as Selumar (Jackia ornata), Geronggang (Cratoxylum spp) and Punak (Tetramerista glaba). In coconut plantation, it was implemented paludiculture-based agroforestry model which was honey bee cultivation in the space area of a coconut plantation. In a mono-cultured coconut tree, the diversification of areca nut tree aimed to increase the population of the honey bee and to provide food for a bee to increase the honey.

Regardless that the program was in the trial stage, the success of paludiculture-based agroforestry has been shown in several provinces such as Jambi, Sumatera Selatan, and Kalimantan Barat. The success of paludiculture-based agroforestry implementation has been shown in Tanjung Jabung Barat, Jambi in areca nut, coconut, and liberica coffee. The community had felt the economic and ecological impact of coffee-based agroforestry [4].

In the presentation of Hesti Tata Lestari in Pojok Iklim, several patterns of peatland management which have been successful in paludiculture-based agroforestry system were coconut + areca nut, coconut+ coffee, coconut + coffee+ areca nut, rubber + pineapple, jelutung + rubber and so on [7].

### 3.2. Discussion

Peat swamp forest ecosystem is a good forest because it is a balanced ecosystem. In stable and balanced ecosystem the reciprocal relationship among biotic and abiotic component has interdependence each other. This stability generates water balance and conserves flora and fauna. Peat swamp ecosystem function as an area to hold and to store water and balance the water in that area. Peat swamp ecosystem is absorbent and storage of water during rainy season and in the dry season it releases water slowly. More than 300 types of plants can be found in peat swamp forest, there are types of plants that have a high value of wood such as ramin, jelutung, and meranti. Various forest product can be exploited with certain limitation without reducing ecology process of peat swamp ecosystem formation. The process of natural peat swamp ecosystem is normal so that it is called as a good and stable ecosystem because of no disturbance [9].
Considered from climate change, peat swamp forest ecosystems has functioned as carbon storage and emitters of CO2 and CH4. Global warming due to CH4 is 3.7 times greater than CO2 but CO2 emissions are 1000x greater than CH4 emissions [11]. Due to a greater level of CO2 absorption than emissions, thus tropical peatland was very large carbon storage. The level of carbon absorption in Sumatra and Kalimantan tropical peatland varies from 0.3 - 6 t C/ha/year [18;21] but anthropogenic disturbances increase the level of tropical peatland emissions. Deforestation transforms peatland ecosystems into sources of flux C 9.9 - 15.4 t C/ha/year [14]. The repeated forest fires in the dry season cause large amounts of C emissions from tropical peat ecosystems. Peat fires in 1997 in Sumatra and Kalimantan contribute emissions of 280 - 330 t C/ha [17]. The high amount of the increase in CO2 emissions due to the conversion and fires of peatland has caused disturbances in peat stability.

In Industrial Forest area, subsidence due to the drainage establishment was 0.119 – 0.159 cm/month or 14.28 – 19.08 cm/year [1]. The damage of peatland with the depth of 10 cm/ha because of a forest fire can decrease the water storage for 650 m3/ha. If the peatland was burned as 3000 ha it is equal to the loss of water of 1.950.000 m³ [15]. Therefore there was unbalance in ecosystem function of swamp area as a hydrological regulator so that drainage and fire forest can lead to the damage of hydrological function or peat swamp land. The entry of exotic plant in plantation forests such as akasia, palm tree, and rubber plant is not recommended because it increases CO2 significantly [25].

Deforestation and degradation of peatland is a consequence due to the drainage. Greenhouse gas emission, the vanished biodiversity, and fire forest were the impacts of peatland drying. Almost all degraded peatland was greenhouse gas emission contributor. The increase of greenhouse only can be overcome by elevating land water surface. Therefore the action of wetting and restoration can decrease greenhouse gas emission, peatland fire and return the biodiversity in peatland. By rewetting, wet land based on drainage will lose its productive land but paludiculture can return land productivity [26].

Paludiculture is one of the method of planting of endemic peat swamp land plant by (a) restoring peatland condition become wet by covering drainage canal, (b) planting local type plant which produces high quality and quantity of biomass. (c) Making peatland ecosystem function as it was. Paludiculture is an alternative to land usage especially for the area where the increase of land demands lead to drainage. Because the peatland ecosystem is fragile the peatland has to be protected. If the land usage cannot be avoided, paludiculture has to be the reference of drainage-based land usage [12].

The principle in paludiculture is restoring ecosystem conservation of peatland. In natural peatland ecosystem, the existing plant was the plant which can survive in extreme condition such as adapting with a puddle, high acid of land and limited nutrition of soil. The plant type selection has to consider that this type technically and economically can be implemented. By revitalization, the society is empowered to manage peatland as a cultivation area of the paludiculture plant [13].

Malaysia and Indonesia peatland have ±1.473 species peat swamp species including tree, shrub, and bush. The high number of species has a function but the main commodity is wood (222), medicine(221) and food (165)[25]. The type of areca nut, sago, coffee bean, and coconut can grow in peatland well. Areca nut can be a sign of border and can grow in the inner side of peatland, meanwhile, sago (Metroxylon spp) can be cultivated in the inner part of peatland because it needs no drainage to retain productivity, harvesting needs no canal and was conducted by using railways. Sago only needs one of planting because its reproductive system is through vegetative reproduction dan needs to be taken care.

The potential of sago in peatland management is highly possible, consider that Meranti Island District was one of the National Food Security Area because it produces the highest amount of sago in Indonesia. Sago plantation area in Kepulauan Meranti was 44.657 ha which equals to 2,98% of Sago plantation in Indonesia [3]. Sago plantation in Meranti had become main source income for 20% of Kepulauan Meranti people. Sago (Metroxylon spp) is species which can be considered in the paludiculture program. Sago also can be a part of the restoration program after deforestation and fire forest in Kepulauan Meranti District.
Switching from the peatland management based on drainage into paludiculture is a strategy to the minimized the impact of climate change. Peatland was degraded which uses exotic species which need drainage can be replaced by species which can adapt in peatland. Before the existence of rubber plants in Asia in the early 20th century, sap from Ficus elastica was the main source of rubber plant in this region. Rubber plants are not recommended because this plant requires drainage so that it is not considered a form of sustainable agriculture and not as true paludiculture [12]. A number of rubber replacement options depend on market needs such as Jelutung (Dyera spp) latex-producing species can replace rubber as a candy product.

From the description above it can be seen that the process of managing peatlands with a pluricultural-based agroforestry model can create a healthy ecosystem through the mechanism:

a) Carbon and Greenhouse Gas Balance. Rewetting will reduce greenhouse gas emissions by 15 tons CO2 eq/ha/ year significantly reducing decomposition of peat, not including additional energy savings from fossil fuels released. Of one hectare of reeds, 12 tons of dry biomass /ha/year and calorific value of 17.5 MJ /kg of dry reeds /ha biomass can replace fossil fuels in factories that emit 15 tons of CO2 eq. With emissions of factory operational activities 2 t CO2eq /ha/year, then the paludiculture reeds will avoid emissions of 30 t CO2 /ha/year [24].

b) Complexity. The complexity of paludiculture-based agroforestry is indicated by a land use system consisting of a mixture of tree crops, plantations, and agriculture. The combination of forestry plants that function in forest conservation for ecological purposes while agricultural or plantation crops are more focused on income during the period of maintaining the forest.

c) Soil Protection, water, and forest fires. Vegetation diversity is the best land cover in erosion protection and prevention. The pattern of paludiculture-based agroforestry increases the complexity and diversity of the types of constituents of the ecosystem. Stratified canopy layers or a combination of annual crops (forestry and agricultural crops) are able to cover the soil perfectly so that it is effective against the stability of the water in the peat. Rewetting will restore the degraded peatlands in long term. By keeping the peat always wet it also reduces the danger of fire.

d) Restoration of habitat for endangered species. Rewetting the drained peatlands is useful for conservation because the land that has been drained and degraded has decreased biodiversity. The diversity of formed vegetation provides a habitat for extinct species. Paludiculture-based agroforestry will protect rare species and almost extinct due to the decline in previous peat swamp habitat. The formation of an ecosystem that is similar to its natural condition after being watered will provide new habitat for rare species. Species monitoring after wetting needs to be conducted for subsequent peatland management.

e) Adaptation. Paludiculture-based agroforestry model improve resilience to environmental changes if these types have different responses to disturbances through (1) mixing of timber-producing trees with agricultural crops (2) mixing species based on tolerance characteristics namely canopy and understorey (3) mixing age differences (harvesting based on mixing) (4) combining social and socio-cultural values so that changes in vegetation will go hand in hand with socio-cultural changes gradually (5) can be used as a model to facilitate changes in vegetation groups into new groups (adaptation).

f) Protection from pests. Climate change is a threat of forests condition because it can trigger pest outbreaks and change insect distribution patterns that cause plant vulnerability. Vegetation mixing techniques reduce pest attacks. The complexity of structure and diversity can restore the process of checking and balance between organisms so that there is no population explosion of pests and diseases. The selection of types that are suitable for the local environment, setting the stand and determining the harvest can prevent pest and disease attacks.

g) Product utilization. In addition to ecological benefits, the pattern of pluricultural agroforestry can act as a natural forest that provides a variety of increasingly rare and expensive commodity such as wood, food, medicinal plants and so on. The combination of paludicultural agroforestry products can be harvested in the long and short term. The paludicultural model can reduce the risk
of crop failure. If a plant fails to harvest because of the season, the risk of market development or other causes, other plants can still be expected.

4. Conclusions and Recommendations

Peat swamp forest in Kepulauan Meranti District had been converted into productive land to fulfill the need of food. The area dominantly used for sago plantation, rubber plantation and coconut plantation area. There were 4 types of land usage and 7 model of vegetation by paludiculture with the need of food. The area dominantly used for sago plantation, rubber plantation and coconut plantation.

Conclusions and Recommendations

Paludiculture method was suitable to be implemented in Kepulauan Meranti District because most of the area consists of peat swamp land. The implementation of paludiculture was limited to the level of the model so that it needs further study to obtain paludicultural which is most suitable to be implemented in Kepulauan Meranti District.

References

[1] Ratnaningsih A T and Prastyaningsih S R 2017 Dampak Kebakaran Hutan Gambut Terhadap Subsidesi di Hutan Tanaman Industri. Jurnal Wahana Forestru. 12(1) Januari 2017.
[2] Margono B A Potapov P V Turubanova S Stolle F and Hanse M C 2014 Primary Forest Cover Loss in Indonesia over 2000-2012 Natural Climate Change 4: 730-735.
[3] BPS 2011 Badan Pusat Statistik Kabupaten Kepulauan Meranti. Kabupaten Kepulauan Meranti Dalam Angka Year 2011.
[4] Waluyo E A Nurlia A 2017 Potensi Pengembangan Kopi Libericca (Coffea libericca) Pola Agroforestry dan Prospek Pemasaranannya untuk Mendukung Restorasi Lahan Gambut di Sumatera Selatan. Pengembangan Ilmu dan Teknologi Pertanian Bersama Petani Lokal Untuk Optimasi Lahan Sub Optimal. Proc. Seminar Nasional Lahan Sub Optimal. Palembang.
[5] Agus F and Subiyaksa I G M 2008 Lahan Gambut. Potensi untuk Pertanian dan Aspek Lingkungan. (Balai Penelitian Tanah dan Word Agroforestry Centre (ICRAF) Bogor).
[6] Tanneberger F and Witchmann W (eds) 2011 Land use options for rewetted peatlands. In Carbon Credit from Peatland rewetting. Climate Biodiversity Land Use: 107-132.
[7] Lestari H T 2018 Paludikultur: Praktek Pengelolaan Lahan Gambut Berkelanjutan. Pojok Iklim. https://www.pojokiklim.menlkk.go.id.
[8] Subiyaksa I G M Agus F Wahyunto E E Ananto 2010 Mitigasi dan Degradas lahan Gambut. Membalik Kecenderungan Degradasi Sumber Daya Lahan. (Badan Penelitian dan Pengembangan Pertanian).
[9] Wibisono I T C and Adu D 2016 Panduan Teknis Revegetasi Gambut (Badan Restorasi Gambut).
[10] Jikalahari 2016 Alternatif pengembangan Lahan Gambut Berkelanjutan Berbasis Masyarakat dengan Pendekatan Paludikultur. http:// www. Jikalahari.or.id.
[11] Inubushi K Furukawa Y Hadi A Purnomo E Tsuruta H 2003 Seasonal changes of CO2 and NO2 fluxes in relation to land-use change in tropical peatlands located in coastal area of south Kalimantan. Chemosphere 52:603-608.
[12] Joosten M L Bistrom H T Tol S (eds), 2012. Peatland-Guidance for Climate Change Mitigation Through Conservation, Rehabilitation and Sustainable Use. Food and Agriculture Organization of the United Nations, Rome, 100 pp. On line at https://www.fao.org/docrep/o15/an762e.pdf.
[13] KLHK 2015 Pedoman Pemulihan Ekosistem Gambut (Kementrian Kehutanan dan Lingkungan Hidup: Jakarta).
[14] Melling L Hatano R Goh K J 2005 Soil CO2 fluxs from three ecosystems in tropical peat of Sarawak, Malaysia. Tellus 57(B):1-11.
[15] Barchia M F 2006 Gambut. Agroekosistem dan Transformasi Karbon. (Gadjah Mada University Press: Yogyakarta).
[16] Peraturan Presiden Republik Indonesia No 1 Year 2016 tentang Badan Restorasi Gambut.
[17] Page S E Siegert F Rieley J O Boehm H-DV Jaya A Limin S 2002 The amount of carbon released from peat and forest in Indonesia in 1997 Nature 420: 61-65.
[18] Neuzil S G 1997 Onset and rate of peat and carbon accumulation in four domed ombrogenous peat deposits, Indonesia. In: Rieley JO, Page SE (eds) Biodiversity and sustainability of tropical peatlands. (Samara Publishing Limited: Cardigan) pp 55-72.
[19] Najiyati S Muslihat L and Suryadiputra I N N 2005 Panduan Pengelolaan Lahan Gambut untuk Pertanian Berkelanjutan (Wetland Internasional Bogor).
[20] Shimada S Takashi H Osaki M 2016 Tropical Peatland Ecosystems. (Springer: Japan). pp. 354-365
[21] Sieffermann R G, Fournier M, Triutomo S, Sadelman M T, Semah A M 1988 Velocity of tropical peat accumulation in Central Kalimantan Province, Indonesia (Borneo). In: Proc. of the 8th International Peat Congress, Leningrad I, pp 90-98.
[22] Kolb T E Wagner M R and Covington W W 1994 Utilitarian and Ecosystem Perspective. Concept of Forest Health. Journal of Forestry. 92(2) : 10-15.
[23] Turmudi 2017 Pengelolaan Lahan Gambut Dengan Pendekatan Hidrologis (KHG). Pengelolaan Sumber Daya Wilayah Berkelanjutan pp.625-635.
[24] Wichtmann W Joosten H 2007 Paludiculture; Peat Formation and Renewable Resources from Rewetted Peatland. Newsletter. Issue 2007/3. Agust. 2007 International Mire Conservation Group (IMCG). German.
[25] Giessen W 2013 Paludiculture: Sustainable Alternative on Degradated Peatland in Indonesia. QANS Report on Activity 3.3. (Bapenas dan Ditjen Sumber Daya Air Government Indonesia Partners for Water Programme the Netherland).
[26] Witchman W Schoder C Joosten H 2016 Paludiculture is an Inclusive Solution. Paludiculture- Productive of Wet Peatlands. Climate Protection. Biodiversitas Regional Economic Benefits. (Swhweizerbart : Sciece Publisher).
[27] WRI 2018 Pelestarian Hutan Dapat Mengurangi Emisi Karbon Setara dengan Emisi Semua Mobil di Bumi. https:// www.wri-indonesia.org.