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Can We Simultaneously Restore Peatlands and Improve Livelihoods? Exploring Community Home Yard Innovations in Utilizing Degraded Peatland

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Abstract: Peatlands support the daily needs of people in many villages in Indonesia, including in Central Kalimantan Province. They provide the natural resources to enable fisheries, agriculture, plantations, and forestry. However, peatland utilization comes with various challenges, including fire, soil acidity, inundation, low fertility, and limited choice of suitable species. Many of the current uses of peatland can result in its degradation, oxidation, and increased risk of peat fire. Avoiding further environmental degradation will require the development of new technology that allows the community to both earn a livelihood and protect the peatland. In this study we assessed a range of technologies applied by 14 farmers at Tumbang Nusa village, Central Kalimantan province, in managing degraded peatlands in their home yard for agricultural business. The study shows that for endemic peatland species, good success can be achieved if they are planted directly. However, for species endemic to mineral land, there are four technologies applied by farmers in managing degraded peatland. The choice of technologies is influenced by their economic capacity/cash flow flexibility and their understanding of peatlands. Technologies intended to adapt to land inundation include the use of polybags, development of raised beds, and making peat mounds with mineral soil in the centre. Technologies to address the acidity and soil fertility include amelioration with dolomite lime and fertilizer. The use of polybags filled with peat soil is the easiest technology to adopt and can be conducted by all family members. However, a farmer's choice of technology needs to always consider the potential environmental impacts in addition to increasing soil fertility so that peat conservation is maintained.

Keywords: degraded peatland; agroforestry; home yard; agricultural technology

1. Introduction

Indonesia has around 15 Mha of tropical peatlands (the largest area of any country), most of which is situated on the three islands of Kalimantan (5 Mha), Sumatra (6 Mha), and

Papua (3 Mha) [1,2]. Of the 17 provinces on these 3 islands, 7 have extensive peatlands, comprising around 2945 villages [3]. Peatland in its natural state functions as a large store of carbon [4,5] and water [6,7]. After being drained, they can be developed for agriculture, forestry, and energy [8–10], however, this can also result in loss of ecosystem services such as regulation of the hydrological cycle [4,9,10], hosting a rich biodiversity [11–13], carbon sequestration [14,15], and provision of livelihoods for the local people [16,17]. There continues to be new peatland development in many areas, including drainage and establishment of new oil palm plantations. Many existing developments are unsustainable and are leading to rapid peat depletion and loss through oxidation and susceptibility to fire [18]. Restoration of degraded peatland areas is key to preventing further degradation and reducing future emissions of CO_2. However, in trying to restore and maintain the long-term sustainability of peatlands, the Indonesian government has been confronted with two major issues: frequent fire that prevents effective revegetation and ensuring sustainable livelihoods for those people who depend on access to peatlands.

Repeated peat fires cause peatland degradation due to loss of peat soil as well as changes in its chemical and physical properties [19,20]. In addition, the choice of prospective species on peatland is limited [19] due to low fertility, high acidity, and poor drainage [10]. Another challenge is the suitability of existing agricultural technology on peatlands. Due to its fragility, and to avoid degradation of land function, careful and prudent management is required. For this reason, appropriate technological innovations are needed so that peatlands can be used sustainably [10]. Thus, the challenge is how to utilize degraded peatland for cultivation while at the same time reducing or avoiding its negative impact.

The use of peatlands for cultivation and production requires careful water management without the need for drainage. Paludiculture techniques can be applied for the cultivation and conservation of peatlands by selecting plant species that are native to the environment and also are economically viable. Even though paludiculture has not been fully developed in Indonesia [21], it offers some opportunities for sustainable peatland management [22]. Apart from paludiculture, a 'raised bed' support system can be adopted for peatland cultivation so that plants do not become inundated for a long time [23].

The home yard is a plot of land around the house that can be managed for cultivation of food crops, flowers, livestock, and fisheries [12,13]. Thus, it can provide various benefits if well managed, providing aesthetic value as well as providing additional family income and meeting household needs [12]. The home yard also has a cultural and social function [24]. Home yards can be developed by poor communities with smaller areas of land that can be managed intensively with available resources, using limited and natural production inputs such as waste and animal manure as natural fertilizers that are applied by low-cost and low-risk technologies. Palestine-González et al. (2021) suggested this could represent a sustainable agricultural system with the principles of diversity-resilience, self-management-autonomy, integration, and self-sufficiency [25]. The home yard is an opportunity to trial new systems and livelihood options such as paludiculture, agroforestry, or agrosilvofishery systems.

Home yards can be managed in such a way that they are a multi-level and multi-purpose food production system that is beneficial for households [26]. The yard can provide a source of fresh and nutritious food for the household and become a buffer for the household during the lean season when the household has a reduced income [27]. Home yards can be managed intensively and with low costs by applying simple technology according to the abilities and knowledge of each household.

The aim of this study was to examine the technologies currently being applied by a subset of villagers cultivating degraded peatlands in their home yard in Tumbang Nusa Village, Central Kalimantan. We studied the community experience of peatland management in their home yard, including understanding the planting system and plant species cultivated in peatland home yard, and the problems and advantages of the implementation of technologies by the community. This study can help to understand the capacity of local communities to transition to the use of wet peatlands or peatlands with moderate drainage. Learning from community practices can assist in solving broader problems associated with scaling up sustainable agricultural practices in peatlands. Learning from peatland management carried out by the community will be valuable for supporting further sustainable peatland management. With increasing pressure on peatlands [28–30], community involvement in peat restoration can provide many social and economic as well as environmental benefits. These benefits include providing knowledge and increasing public awareness about good management/use of peatlands, improving the quality of peatlands, and at the same time providing an income. Promoting sustainable livelihood options on peatlands is part of a livelihood revitalization approach to peatland restoration.

2. Materials and Methods

2.1. Study Location and Biophysical Characteristics

The study was conducted from 2019 through to early 2021 in Tumbang Nusa village, Jabiren Raya District, Pulang Pisau Regency, and Central Kalimantan Province. This village is located about 35 km southeast of the provincial capital, Palangkaraya and is one of the focus villages for BRG restoration efforts. As part of their restoration efforts, BRG has installed a small number of canal blocks and around 250 deep wells, as well as exploring some livelihood options with the Tumbang Nusa community. Approximately 21% of the respondents in this survey were directly involved in the BRG activities. This village occupies around 200 km^2; 90% of which is peat with a depth of more than 3 m. Approximately 20% of this peat area is currently under cultivation [31]. In the dry season, the village is very vulnerable to fires, and in the rainy season it often floods.

Peatlands in Tumbang Nusa experience inundation from tidal flows in the Kahayan River. This is exacerbated by the many artificial canals in Tumbang Nusa that have been intentionally built to drain peat. The number of artificial canals causes large areas, even those far from the river, to be inundated. These canals were part of the mega rice project (MRP, Kalimantan, Indonesia) where 1 million hectares were planned to be developed to grow food crops from 1995. On an area of 1,133,607 hectares, the following infrastructure was established:

a. 200 km-long main channel connecting the Kahayan River and Barito River.
b. an additional 1000 km long main channel connecting the blocks in the MRP area.
c. primary and tertiary canals for irrigation and drainage of rice fields along hundreds of kilometers with a total channel length of about 2000 km.

Both trees and agricultural crops, particularly those not adapted to waterlogging, experience severe stress when grown on peat. This, plus the risk of fire and inundation are obstacles that make many villagers reluctant to work on peat. Hence, only around 13% of village households living along the highway manage their home yard for farming.

2.2. Groundwater Level and Subsidence

The groundwater level in peatlands fluctuates based on rainfall and intensity of drainage. The ability of the peat to store water has decreased over time as it has become more degraded. The lowest groundwater level in 2013–2014 was 30.6 cm below the peat surface [32], while in 2020–2021 we found the lowest level to be 44.0 cm below the peat surface (Figure 1). Fluctuations in groundwater level are also influenced by land cover and peat soil conditions.

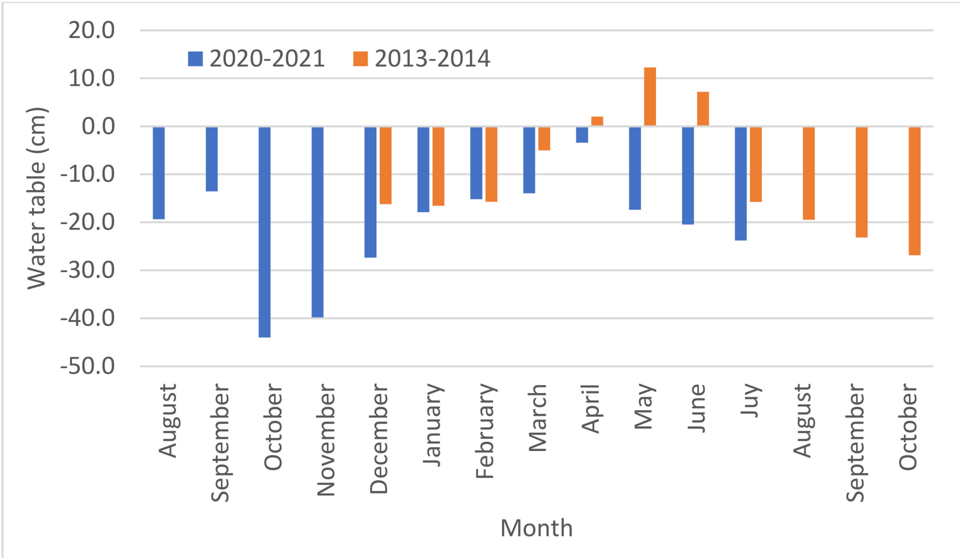

Figure 1. Water table depths measured in 2013–2014 and in 2020–2021.

Changes in peat soil conditions are also caused by the drying of peatlands due to the installation of many canals. These canals are designed to lower the groundwater level, which has also increased the vulnerability of the peatlands in Tumbang Nusa to fire. Land drying and fire incidents as well as land management activities for cultivation have resulted in a decrease in peat soil level (subsidence) [33].

2.3. Demography

In 2020 there were around 268 households in Tumbang Nusa, with the majority belonging to the Dayak ethic group. Each family tends to have more than one source of livelihood, with the majority (90%) earning a livelihood from fishing. Other livelihoods include rubber tapping, rattan collection and processing, purun collection and processing, timber harvesting, agarwood and resin collection, nursery production, oil palm plantation, raising livestock (swallows, ducks, chickens, goats, cows), and food and drink stalls. However, as of the time of study, rubber had not been tapped for 3 years and rattan not harvested for 5 years as the prices were low and unstable (US $420/tonne of latex and US $28/tonne for rattan). Purun is harvested from mineral soils on the river banks when water levels are high between January and May, but only if there is a request from a buyer. The price of purun is also low, at US $2.50/bunch.

About 60% of the families live along the Kahayan river on mineral soil, while the remaining 40% (107 households) live on peatlands, along the trans Kalimantan road that connects Palangkaraya, the capital of Central Kalimantan Province, with Banjarmasin, capital of South Kalimantan Province. The two settlements are 3 km apart.

Each of these 107 households along the highway have land holdings on peat that have been partially degraded by fires and/or current land management practices. Frequent fires and floods make most of these villagers hesitant to manage their land. However, around 14 households use the land for agriculture for their own consumption and/or to generate business income. They have adopted various technologies to overcome the challenges they face in managing their peatland.

2.4. Data Collection

This study was conducted from 2019 to early 2021 in Tumbang Nusa village, Jabiren Raya District, Pulang Pisau Regency, Central Kalimantan Province. We conducted a survey into people's preferences in the use of degraded peatlands in their yards and the technology applied to overcome various challenges, both natural and in the form of government policies that prohibit burning during land preparation.

The unit of analysis of this study was the family. Respondents came from 14 families who were selected purposively. Our sample reflected all of those households in Tumbang Nusa who utilised the peat land in their yards for agricultural activities.

Both primary and secondary data were collected. The primary data included quantitative and qualitative information on:

- Characteristics of respondents
- Existing uses of peatland in the home yard, including types of crops grown.
- Challenges in farming
- Farming technology

Secondary data was obtained from the study of documents that was relevant in this activity.

Primary data collection was carried out using interview techniques and field observations. Interviews were conducted using a list of in-depth questions that had been prepared to obtain further data/information on the research topic. Field observations allowed us to verify the responses and complete other information that respondents had accidentally omitted.

3. Results

3.1. Characteristics of Respondents

The 14 respondents had all previously lived on mineral soil along the Kahayan river. They began to move and settle along the highway after its construction began; and more followed after the inauguration of the Tumbang Nusa bridge (and completion of the road) in 2013. They made the move based on an expectation of improved economic opportunities arising from through traffic on the road and easier access to the big cities and markets.

Of the 14 respondents cultivating their home yard, 57% were indigenous people (Dayak) and 43% were migrants from Banjar-South Kalimantan, Lampung-Sumatra, and Java. Those who were migrants had been living in Tumbang Nusa village for some time and had married local people. The respondent ages were from 37 years old to 62 years old and their education also varied from elementary to undergraduate, with the highest proportion (35%) having achieved high school level and the lowest proportion (6%) elementary level.

Some of the reasons respondents nominated for utilising their home yard were:

- As farmers, their future is in their yards and livestock. They should not be easily discouraged from working in the yard.
- The home yard can at least guarantee the availability of family food needs if managed properly.
- The yields reduce family expenses, and if there is left over it can be saved for other purposes, like children's education.

Those who manage their home yard had other sources of livelihood, such as wages from employment and nursery workers for the Watershed Management Institution, employment with the Ministry of Environment and Forestry, traders, and/or other government employment. From time to time they still catch fish in the Kahayan river for additional income or for their own consumption. Some villagers are managing peatland in their home yard as a family business, while others are just managing it for supplemental income, but both involve family members in their implementation.

Their interest in cultivating peatlands in their home yard is supported by knowledge gained from training, work experience, internet (such as Youtube, San Bruno, CA, USA), family, neighbours, or personal experience. Training they have participated in includes development of a nursery, sowing seeds, planting seedlings, pineapple cultivation, pest control, how to make compost, technical guidance on handling forest and land fires, stingless bee cultivation, and swallow breeding. They also share knowledge on utilizing peatland with each other.

3.2. Existing Uses of Peatland in the Home Yard

Historically, the villagers were granted peatlands located along the trans-Kalimantan road by the village head, starting in 1975. They were granted an area of 2 ha (50 m × 400 m), with a letter from the village head providing proof of ownership. Only a small number of the villagers were interested in ownership of these peatland areas because, at that time, the peatlands were far from residential areas along the river, there was no road (the trans Kalimantan road had not been built), the main transportation was river boat, and residents believed that peatlands were not suitable for cultivation. Over time, more and more people became interested in owning peatlands. The sale and purchase of peatlands occurred and continues to this day. Those who can afford it can have large holdings of peatland (up to 10 ha or more). However, now that the government has deemed peatland deeper than 3 m to be protected, it will not issue certificates of ownership of these peatlands to the community. However, they can continue to utilize it without ownership.

The home yard of the Tumbang Nusa respondents along the trans-Kalimantan highway can be quite extensive, ranging from 0.8 ha to 10 ha, with an average of 3.5 ha. Some of the yards are partially inundated during the rainy season. To mark land ownership, land owners made small (0.5 m wide) canals around their land. The respondents had built a house and cultivated areas from 0.2 ha to 5 ha in their yards. The average cultivated area was 1.6 ha or 45% of their home yard.

An inventory of plant species in the village home yards revealed that villagers were growing a wide range of plants, including plantation crops, forestry species, fruit trees/plants, and agricultural crops (Table 1). Typical livestock found in the home yard included chickens, ducks, goats, and swallows. Stingless bees (*Trigona* sp.) were also being cultivated. Chicken, duck, and swallow farms are community initiatives, while goats and stingless bees were initiated by BRG and Banjarbaru Environmental and Forestry Research Institute, respectively.

Swallow nest production is very capital intensive, requiring between US $10,700 to US $28,600 to build one swallow house. Therefore, only respondents who have access to this capital, or who have regular income (such as civil servants) can cultivate swallows for their nests. They can fund the upfront cost through a bank loan that is repaid in installments from their monthly salary. Nest prices received at the farm level range from US $500/kg for low quality to US $1071/kg for good quality nests. When they are successful, they can harvest 0.5 kg to 1 kg/building/month.

The Banjarbaru Environmental and Forestry Research Institute, in 2020, conducted an experiment in cultivating *Trigona* sp honey bees in community yards. The Trigona bee box measuring 30 cm long × 20 cm wide × 10 cm high, was placed under a Geronggang stand (*Cratoxylon arborescens)* between 10 and 15 years old, belonging to one of the respondents. In respondent' yards, honey can be harvested within 2 months after installing the box containing the bees. The first harvest of seven boxes yielded 1.7–2.5 L of honey and sold for US $10–14 per 460 mL. Subsequently, Trigona honey can be harvested every month with a yield of 0.5–1 L per box. The respondent then learned through Youtube to break up the Trigona bee colony and the number of Trigona bees has grown to 10 boxes. Trigona honey cultivation is considered not difficult. Other communities began to show their interest in raising Trigona bees. In October 2021, the Forest Management Unit in Pulang Pisau District provided training to the community on Trigona bee cultivation.

One of the home yards was used for a broiler chicken business, producing healthy chickens to supply a restaurant in Palangkaraya. This family constructs chicken cages in their home yard and collects the manure as fertilizer for their nursery business.

Table 1. Plant species cultivated in peatland home yards in Tumbang Nusa.

Common Name	Scientific Name
Plantation crops	
Oil Palm	*Elaeis* sp
Rubber	*Hevea brasiliensis*
Cacao	*Theobroma cacao*
Calliandra	*Calliandra calothyrsus*
Coconut	*Cocos nucifera*
Forest/Non Timber Forest Trees	
Balangeran	*Shorea balangeran*
Sengon	*Paraserianthes falcataria*
Jelutung	*Dyera polyphylla*
Gaharu	*Aquilaria malaccensis*
Bintangur	*Calophyllum* sp.
Pete	*Parkia speciosa*
Geronggang	*Cratoxylon arborescens*
Pulai	*Alstonia scholaris*
Ramin	*Gonystylus bancanus*
Tumih	*Combretocarpus rotundatus*
Fruit plants/trees	
Rambutan	*Nephelium lappaceum*
Mango	*Mangifera indica*
Guava	*Psidium guajava*
Watery rose apple	*Syzygium aqueum*
Avocado	*Persea americana*
Durian	*Durio zibethinus*
Pineapple	*Ananas comosus*
Banana	*Musa* sp.
Lemon	*Citrus* sp.
Papaya	*Carica papaya*
Longan	*Dimocarpus longan*
Citrus	*Citrus aurantifolia*
Vegetable plants	
Chili	*Capsicum frutescens*
Water spinach	*Ipomoea aquatica*
Maize	*Zea mays*
Eggplant	*Solanum melongena*
Celery	*Apium graveolens*
Cassava	*Manihot utilissima*
Tomato	*Solanum lycopersicum*
Potato taro	*Colocasia* sp.
Green pepper	*Piper nigrum*

3.3. Agroforestry on Peat Land in the Home Yard

Of the various species planted, the respondents each identified up to 10 different plants that were considered important by them (Table 2).

Eleven of the species considered important (as shown in Table 2) were planted by between 21.4% to 85.7% respondents. The number of times each species was noted as being important (Figure 2) showed that more than 75% of the respondents were growing jelutung and rambutan, almost two thirds of the respondents were growing balangeran, and half of them were growing oil palm and vegetables. The other species present in Table 2 but not shown in Figure 2 were planted by only one respondent (7%) each.

Table 2. Summary of home yard plant species considered by the respondents to be important.

Common Name	Scientific Name	Plants Native to Peat Soils	Plants Native to Mineral Soil
Plantation crops			
Oil Palm	*Elaeis sp*		√
Rubber	*Hevea brasiliensis*		√
Cacao	*Theobroma cacao*		√
Coconut	*Cocos nucifera*		√
Forest/Non Timber Forest Trees			
Balangeran	*Shorea balangeran*	√	
Sengon	*Paraserianthes falcataria*		√
Jelutung	*Dyera polyphylla*	√	
Gaharu	*Aquilaria malaccensis*		√
Pete	*Parkia speciosa*		√
Geronggang	*Cratoxylon arborescens*	√	
Pulai	*Alstonia scholaris*	√	
Ramin	*Gonystylus bancanus*	√	
Tumih	*Combretocarpus rotundatus*	√	
Fruit plants/trees			
Rambutan	*Nephelium lappaceum*		√
Mango	*Mangifera indica*		√
Durian	*Durio zibethinus*		√
Pineapple	*Ananas comosus*		√
Citrus	*Citrus aurantifolia*		√
Vegetable plants			
Chili	*Capsicum frutescens*		√
Maize	*Zea mays*		√
Eggplant	*Solanum melongena*		√
Celery	*Apium graveolens*		√
Tomato	*Solanum lycopersicum*		√

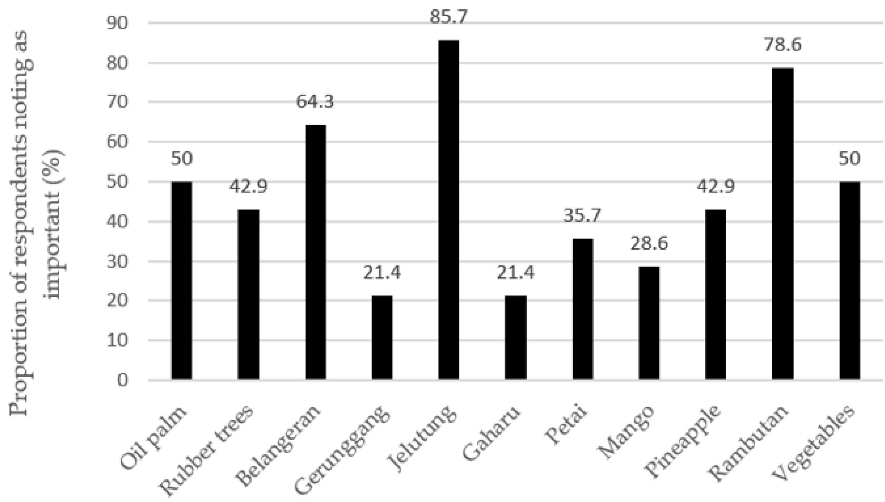

Figure 2. Proportion of times each species was noted as being important by the respondents. Note that species with only one mention in Table 2 were not included in this figure.

Respondents planted species that were endemic to both peatlands and mineral soils. The types of plants native to peatland included balangeran, jelutung, geronggang, pulai, ramin, and tumin. Other species are endemic to mineral soils, but the respondents tried to cultivate them on peatlands. The reasons for the choice of plant species cultivated in the yard (Table 3) shows that endemic peat species tended to be planted for investment purposes, while vegetables and rubber were to meet the family needs or provide income on a daily basis. Other crops met family needs and/or provided income on a monthly or annual basis.

The planting system varies between respondents, as well as the number of plants per species in one yard. For example, jelutong (Figure 3), balangeran (Figure 4), oil palm, and rubber plants are usually grown in clusters and the number varies. Four respondents had jelutung with a respective total of 100 stems, 200 stems, 300 stems, and up to 1000 stems. Three respondents planted rubber in their home yard with a total of 150, 1000, and up to 2000 stems.

Figure 3. Jelutung trees and stingless bees.

Figure 4. Balangeran and rambutan trees.

Table 3. Reasons noted by respondents for choice of species planted in their home yards.

Common Name	Investment		Fulfillment of Family Needs/Cash			Protection	Note
	Timber	Seeds for Seedlings	Daily	Monthly	Annually		
Plantation crops							
Oil Palm				√			
Rubber			√				
Cacao		√					
Coconut				√			
Forest/Non Timber Forest Trees							
Balangeran	√	√					
Sengon	√						
Jelutung	√	√					
Gaharu	√						
Pete					√		
Geronggang						√	
Pulai		√					
Ramin						√	
Tumih		√					
Fruit plants/trees							
Rambutan					√		Fruit prioritized to meet family needs, and if there are leftovers, they are sold to neighbors.
Mango					√		
Durian					√		
Pineapple				√			
Citrus			√				
Vegetable plants							
Chili			√				Vegetables prioritized to meet family needs, and if there are leftovers, they are sold to neighbors.
Maize			√				
Eggplant			√				
Celery			√				
Tomato						√	

Vegetables are planted in the ground or in polybags and placed under stands. Plants commonly grown in polybags include tomatoes, chillies, and celery. The number of plants that are cultivated is dependent on the capital and available family labour. In the family, the reliable labour is the head of the family and the wife. Children will provide help before or after school. If they have enough money, they will pay labourers to perform several types of work, mainly in land preparation (clearing land, shoveling, digging trenches, making planting holes, and land mounds). Other jobs include fertilizing, watering plants, cleaning grass, harvesting, and selling crop produce. They reported spending 2–7 days a week working in farming, for 2–6 h per day.

3.4. Challenges in Farming

Farming on peatlands is challenging, even under ideal conditions. Respondents faced many challenges from land preparation to harvesting, both in the rainy and dry seasons. Farming is considered high risk for the respondents. These challenges include technical and non-technical aspects.

1. Rainy season
    a. Flood: Every year the village of Tumbang Nusa is prone to flooding with varying frequency, flood height, and duration of inundation. Floods in the rainy season at the end of 2019 caused many rambutan trees of harvesting age to die. In 2021, from January to November 2021, floods occurred in Tumbang Nusa Village four times, in early April, early May, mid-September, and November. Floods in November 2021 lasted for 12 days, with the water level continuing to rise to 1.9 m on the riverbank, and 85 cm on peatland which is about 3 km away from the riverbank. Water not only inundated the plants, but also entered the houses. To date, the villagers have no way to prevent flooding.
2. Dry season
    a. Fire: Tumbang Nusa Village is one of the villages that is known to be prone to peat fires. Until 2019, peat fires occurred every year. The biggest fires occurred in 2015 and 2019. The 2015 fires burned thousands of hectares of the village [31]. Since that incident, villagers have been increasingly vigilant in protecting the village area from fire. They have established a Fire Care Village group that aims to prevent peat fires from occurring. Tumbang Nusa village had few fires in 2020 and 2021, partly because of the surveillance carried out by the Fire Care Village group, but also because the dry season in each of those years remained relatively wet and not conducive to fires.
    b. Drought. During the dry season, the peat land in the home yards becomes very dry and vegetable crops die easily due to drought. Respondents had to frequently water their vegetable gardens. They noted that vegetables required watering once or twice per day. The respondents found this to be time consuming because their vegetable garden is large and additionally there is not always enough water available during the dry season.
3. Land preparation when first clearing land for agricultural activities is very difficult. The land has substantial shrub growth with lots of roots that need to be removed. The prohibition on burning imposed by the government further complicates land preparation activities. Some respondents who have sufficient capital prefer to pay wages for agricultural land preparation activities. Certain crops need the land to be drained through canal installation, which is a high upfront cost.
4. Fertilizer must be applied regularly and in sufficient quantities, especially for fruit trees. According to one respondent's experience, if their rambutan trees are not regularly fertilized, they will not bear fruit.
5. Pests and snakes are quite prevalent, and as well as being a danger to humans, they also prey on livestock (chickens and ducks).

3.5. Farming Technology

Respondents did not face many obstacles in cultivating plants that were endemic to the peat, such as balangeran and jelutung in their home yard. Planting is done using seedling stock. They make a planting hole at a certain planting distance (e.g., 3 m $\times$ 3 m for jelutung), into which they plant the seedlings. It is critical to protect seedlings from fire. As long as the plants are protected from fire, they are likely to grow well. However, it is different for the cultivation of agricultural crops that are endemic to mineral soil but planted on peatlands. To grow these plants in their home yard, villagers apply various management technologies to overcome challenges of inundation, acidity, and soil fertility. They are: (1) use of polybags, (2) raised beds (locally called 'surjan' technology), (3) peat mounds with mineral soil, and (4) dolomite lime and fertilizers.

The first three technologies aim to overcome the problem of waterlogging on peatlands, and the use of dolomite lime and fertilizer is to overcome acidity and soil infertility.

The choice of technology is dependent on the economic capacity of the household, the knowledge they have, and the availability of labor in the family. If the home yard is run as a larger scale business, the economic capacity (capital) of the family becomes the main consideration. This is because they have to buy materials in large quantities and recruit outside labor for several activities, like preparing planting media and filling polybags with planting media.

3.5.1. The Use of Polybag

- Nursery Business

About 10 households conduct nursery businesses that market seedlings outside the village, including to other provinces. They use polybags for planting balangeran, sengon, jelutung, and agarwood seedlings. The seedlings are kept in wooden beds and covered with a plastic cap until they are ready to sell. The beds are built in the home yard, placed in a location that is not flooded and not far from the highway to facilitate transferring the seedlings to the roadside (Figure 5). To ensure that seedling is not submerged in water, some villagers construct shallow ditches to drain water out of the peat. They build wells or use the river water that flows on their land to water the seedlings.

Figure 5. Seedling nursery in Tumbang Nusa.

Beds for nurseries vary in size. Farmers running a nursery business construct more than one bed. One of the farmers had eight beds (each 20 m^2), with Jelutung, Balangeran, Pulai, and Sengon seedlings. He raises and sells 600,000–700,000 seedlings per year. They are ready for sale once they reach a height of more than 40 cm. Prices were US $0.08–0.11 per seedling for Jelutung, US $0.05 for Balangeran and Pulai, and US $0.07 for Sengon.

The nursery business does not occupy a large area of land, but they do require significant capital input of up to US $1400 to establish. These input costs are needed to cover the bed construction materials, nursery equipment and materials, and to pay labourers to fill polybags with seedling media. This initial capital does not include labour from family members involved in this activity, or electricity for pumping water to the seedlings. Beds are estimated to be serviceable for about 2 years.

Seedling media used by the nurseries is a mixture of peat soil, compost, mineral soil, and rice husks. Peat is the main component and is extracted locally by clearing the vegetation layer and collecting the topsoil material. The peat is then sieved to extract only the fine material. Some villagers conduct a business selling sieved peat soil for US $0.84 per bag (sufficient to fill 250 seedling polybags).

The use of peat soil as a seedling-growing medium is likely to be based on the experience of a project on Tropical Forest Reforestation and Management (ATA-267), which ran from 1984 to 1998 in South Kalimantan Province. The project was carried out by Enso Forest Development Ltd. (Helsinki, Finland) in collaboration with the research office of Banjarbaru Reforestation Technology (now called the Banjarbaru Environment and Forestry Research and Development Institute—BEFORDI, Banjarbaru, Indonesia). In this project they introduced a mixture of peat and husk in a ratio of 70:30 as a medium for growing fast-growing species to rehabilitate critical land. The BEFORDI researchers used this technology to develop nursery activities at the Tumbang Nusa, and it was then adopted by the Tumbang Nusa villagers.

The communities that have nursery business mostly sell seedlings outside the city, so that the use of peat as a planting medium in polybags for large-scale nursery businesses and in the long term can lead to thinning of the peat layer and loss of biodiversity along with the polybag media taken out of the area. Peat mining for nurseries will also change the physical properties of the peat surface to become undulating, with puddles forming in the swales due to peat exploitation

- Agricultural Crops

Some Tumbang Nusa villagers plant agricultural crops in their home yard such as chillies; tomatoes; eggplants; and celery using large black polybags, used plastic wrappers for rice or cooking oil, and other used items such as used buckets (Figure 6). This practice can be for their own use, for a business, or for both. Each bag is filled with either peat-only, or a mixture of peat soil with fertilizer as a growing medium. Each polybag is planted with one crop species. The villagers place the polybags in the home yard areas that are not flooded, in an open area, in between other plants (e.g., oil palm), or in a terrace or bench to avoid standing water during the rainy season. Although they are placed between oil palm plants, villagers select an area where the crops can get enough sunlight. They regularly irrigate the agricultural crops using plastic hoses.

The respondents stated that agricultural crops, such as chillies and tomatoes, planted in polybags generally last longer and grow more vigorously than those grown directly in the peat. They noted that agricultural inputs such as fertilizer can be fully absorbed by plants grown in polybags. Weeding and loosening of the soil is also easier compared to plants grown in the ground. For agricultural crops grown directly in peat soil, heavy rains and floods will wash away fertilizers, while weeding and loosening the peat are also more difficult.

Figure 6. Planting agricultural crops in polybags.

Polybag production has been noted as having several advantages:

- The costs can be managed to meet the economic capacity of the family, with potential for lower initial capital input as they can choose whether they want to procure polybags or use other receptacles like unused buckets or cleaned cooking oil plastics. They can choose to procure fertilizers or nutrients can come from their own livestock manure. Some of the farmers do not even apply fertilizer. If farmers only have a small number of polybags, they can often collect the peat for the media themselves.
- It can be used in plots that are submerged in the rainy season, as long as the inundation level is not high. This technique allows the plant to survive, but if the water reaches a certain height that floods the roots of the plant, the poly bag containing the plant can be moved to a safe place.
- It can be done autonomously by family members if it is on a small scale, with children also able to contribute. The number of polybags can be adjusted to account for the labor that is available in the family.
- It does not require a large area.

3.5.2. Raised Beds (Surjan Technology)

Some farmers adopted raised bed technology (Figure 7), that is planting into a mound of peat that extends to the height and width of the crops to be planted on it. Some of the topsoil is removed or excavated and then used to elevate the adjacent plot of land. This technology was adopted because they understand that it helps to keep the water table below the rooting zone so that more agricultural crops or species that are not native to peatland are able to grow better. Another important aspect to consider in making raised beds is the need to mitigate the possibility of inducing acid sulfate production from oxidation of pyrite in the peat or underlying substrate [34].

The crops planted on raised beds include water spinach, long beans, and pineapple. Some villagers also plant oil palm onto raised beds. Pineapple is planted between oil palm, or beside fruit trees to fill the empty space. The respondents noted that pineapple grows well on peatlands, but the price is quite low. Farmers receive between US $0.18 and $0.21 per pineapple.

So far, the use of the Surjan technology in Tumbang Nusa Village has been the choice of the community, which is considered friendly to peat ecology and provides optimal results without having to drain the peatland.

However, the construction of surjan must pay attention to the physical and chemical characteristics of peat soil in the form of pyrite and overflow of water so that there is no drying of the pyrite layer, which causes pyrite oxidation, which is toxic to plants.

Figure 7. Raised bed (Surjan) technology.

3.5.3. Peat Mounds with Additional Mineral Soil and Fertilizer

To plant fruit trees, some villagers make peat mounds with a hole in the middle that is filled with a small quantity of mineral soil and manure or mineral fertilizer (Figure 8). They plant the trees after leaving it to stabilise for 2 weeks. One of the farmers in Tumbang Nusa had used this technique to plant out 20 trees each of mango, *Syzygium aqueum*, guava, avocado, rambutan, durian, longan, mangosteen, and lansium. This required 7 m^3 of mineral soil, at a cost of US $140. These plants grew well, except that four of the mangosteen and lansium died. Using mineral soil in this way is quite capital intensive, and only a few of the farmers apply this technology. Other farmers have planted *Parkia speciose* (locally called 'petai') on peat home yard using this technique, which starts to produce after 7–8 years. The mounds in principle serve the same function as raised beds (increasing the rooting depth to the water table), but the addition of mineral soil and fertilizer also improves soil porosity and fertility. They found that this practice can lead to good crop yields.

Figure 8. Example of fruit tree growing on a peat mound.

3.5.4. The Use of Limestone and Fertilizer

The peat soil sampled from the cultivation area of Tumbang Nusa village was very acidic, with pH between 3 and 4. Lime, fertilizer, and ash from combustion are used as ameliorants [35–37]. They can increase soil fertility through improvement in physical and chemical conditions [38], and increasing the pH [35]. Respondents noted that peat soils are acidic, especially if they are not burnt. They understand that peat is unsuitable for many plants/crops, causing them to grow poorly or die. Pangaribuan (2018) [37] noted that the high acidity of peat soils reduces the bioavailability of phosphorus, which is an essential nutrient for many plant processes including photosynthesis, root development, flowering, fruiting, and seed formation [39]. To neutralize this acidity, one farmer in Tumbang Nusa applied dolomite lime after clearing his peatland. Dolomite can reduce the level of soil acidity and improve the nutrient balance so that nutrients can be taken up by the plants [36].

The method of dolomite lime and fertilizer application on peatlands deployed by this farmer was as follows:

a. Any remaining vegetation is cleared, including removal of the roots, and then dolomite is applied at a rate of up to 1.5 tonnes/ha.
b. The dolomite is cultivated into the peat and allowed to equilibrate. This operation takes about 1 week to complete.
c. If enough ash is available (from burning organic wastes), about 100 g of ash is applied into a planting hole.
d. Fertilizer is also added into the planting hole.

While this process can give good results, it takes care and time before the plants can be planted. The farmer learned the technique while working at the Arjuna Wiwaha timber concession in 1997. Other techniques used by this household included:

a. Land preparation, which includes manual clearing and spraying of herbicide (gramoxone) at a rate of approximately 2 L gramoxone/ha. This process takes approximately 5 days.
b. The dead plants are collected and stacked. This activity takes about 2 weeks.
c. The planting hole is made, with up to 1 kg of lime and organic fertilizer being added.

There are three main sources of organic fertilizer: chicken, cow, or swallow manure. Of the three types of materials, the farmer used swallow manure in a ratio of 4:1 (peat soil:swallow manure). Other farmers may use different ratios of peat:manure, depending on their economic situation, but importantly, they know that too much manure can kill plants, and that they need to wait 2–3 days after application before planting out with vegetables.

Villagers also neutralize soil acidity by using ash from burning grass, shrubs, or litter. One of the respondents generates their ash by piling several layers of litter and peat together for burning. Burning is done very carefully so that the fire does not enter the peat because of the risk of starting a peat fire. This technique for acidity amelioration is easy and practical to do, low cost, quick, and it can repel pests (such as rats). Burning on a scale of 1–2 ha for land preparation was the norm, but the prohibition on burning and the punishment/sanctions imposed by the government on those who do the burning, make the people of Tumbang Nusa Village afraid to do land preparation using fire. In fact, they object to the policy as they have no suitable alternative solutions.

Each farmer has their own technique for applying lime, fertilizer, and ash, and there is no standard application method. Most villagers rarely (if at all) take measurements, and rates of application are based on experience or economic ability of the family. There is substantial opportunity to work with farmers to improve their agricultural productivity through targeting their lime/ash and fertilizer applications. One study found that the application of 20 tonnes of ameliorant (80% chicken manure + 20% dolomite) per hectare gave the highest dry weight and nutrient uptake of NPK [36].

A small number of Tumbang Nusa farmers developed a unique way of making deep peat land suitable for planting horticultural crops. They understand that plants can grow well if their macro and micro nutrient requirements are met. Peatlands are acidic and have low concentrations of Ca, Mg, K, and Na. For this reason, they add slaked lime ($Ca(OH)_2$), as well as a small amount of detergent and cement to the peat. Detergents can function as surfactants that can increase the storage of K and Mg cations and restore the moisture of dry peat [40]. The results of a mixture of cement and lime as peatland stabilization on a laboratory scale have proven positive, although its effectiveness in the field is unknown [41]. Another way that has been reported to neutralize peatlands is by planting cassava (*Manihot utilissima*). According to respondents, cassava has the capacity to neutralize the acidity of peatlands and kill the grass around it, but the cassava cannot be eaten because the taste is bitter.

4. Discussion

Respondents use their home yards for various purposes, including meeting family nutrition needs, earning additional income, creating a shady environment around the house, and planting trees to stabilize the soil. Utilization of the home yard is carried out by growing various tree species, fruit crops, vegetables, and livestock, in the form of agroforestry. This pattern of using a home yard can provide additional daily, monthly, and/or yearly income, and even long-term savings.

4.1. Bridging the Gap between Sustainable Use of Peat and Ensuring Sufficient Income for Farmers

The people of Tumbang Nusa village cultivate degraded peatlands to support their livelihoods. In utilizing the peatlands, the government encourages sustainable practices on peatlands, including issuing a policy that prohibits burning and protecting peatlands with a depth of more than 3 m. For the respondents in this study, these provisions are not easy to follow because the peatlands in Tumbang Nusa are greater than 3 m deep, but are still being managed by the community for production.

Villagers applied a paludiculture system to grow tree species endemic to peat soil, such as balangeran, jelutong, and geronggang. This system is non-destructive and compatible with restoring the peatland. These tree species grow well and represent a form of long-term savings for the respondents. Even though these plants have not produced income from harvest yet, at least they have modified the microclimate and provided enough floral resources suitable for cultivation of stingless trigona bees. Utilization of space under stands with stingless trigona bee cultivation provides respondents with regular monthly income, so they can continue to support the growth of the endemic peatland species. This combination can help restore peatlands, as well as provide nutrition and additional income for respondents.

Respondents did not have a good understanding of how endemic peatland species can provide daily, monthly, and annual income. They were more familiar with the cultivation of plant species that are endemic to mineral soils. Seeing success, either in the neighbouring village or through friends/relatives, and armed with knowledge and great determination, they try to cultivate crops that are native to mineral soils. They understand that there are a number of risks and obstacles to successful peatland cultivation.

The agricultural technology adopted by the respondents for growing mineral soil species is primarily to avoid the key risks, namely not burning during land preparation and protecting their agricultural land from fire hazards, making raised bed or using polybags so that plant roots are not submerged in water when flooded, using fertilizers and dolomite lime, as well as cultivating fast-growing agricultural crops (such as tomatoes, chillies, etc.). This agricultural practice is relatively non-destructive. Their agricultural crops are produced for their own consumption, and if there is surplus they can be sold.

Agricultural practices on peatlands using the raised bed techniques have been tested in Bengkulu Tengah Regency, Bengkulu Province for agricultural crops, and in Kapuas Regency, Central Kalimantan Province for perennials at demonstration plot scale. These studies support the methods adopted by the Tumbang Nusa farmers; for agricultural crops, a rotation of cucumber, bitter melon and long beans on raised beds could return US $3781/hectare/year; and for a cucumber, squash, long bean rotation, farmers received US $3620/hectare/year [42]. For perennials, good survival was achieved in raised beds with mahogany (*Swetania mahagony*, 87%), petai (*Parkia speciosa*, 100%), and rubber (*Hevea brasiliensis*, 80%) [43].

The various agricultural technologies carried out by the community of Tumbang Nusa Village, each have their own advantages and suitability to the various characteristics of peat. Peat mining for polybag planting media will cause direct depletion of the peat layer [44].

Likewise, construction of surjans or raised bed must pay attention to the characteristics of the peat, including the depth of pyrite, the depth of the peat, and also the depth of the ground water table. Pyrite depth <50 cm from the peat surface if a surjan is made will be susceptible to pyrite oxidation, where pyrite oxidation occurs due to dry conditions in the pyrite layer. Pyrite oxidation will be toxic to plants and other biotans. Pyrite is not dangerous under flooded or aerobic conditions [45,46].

Long-term application of dolomite and fertilizer, especially chemical fertilizer, will contribute to the CO_2 and N_2O emissions arising from soil organic matter decomposition from agricultural land in tropical peatland [47]. Among other options, the establishment of mounding has the least impact on the peat. The challenge in making mounds is how to create a sufficiently solid mound that can withstand heavy rain and flooding for at least several years to enable the seedling to develop sufficiently strong roots and stem to support further development. Moreover, species tolerance to flooding and the susceptibility to flooding in the planting site should be considered when selecting mounds [48,49]. The choice of agricultural technology on peatland must consider peat physical and chemical characteristics. Agricultural technology can be applied as long as we keep the peat wet and ensure that it can be sustainability managed.

4.2. Adoption of the Agricultural Innovation

Around 13% of Tumbang Nusa villagers have used peat land in their yards for agricultural production. They have harvested the produce, either for their own consumption or for sale. Neighbouring villages that include more transmigrant populations have been intensively cultivating vegetables on peatlands to supply the city of Palangkaraya. Even though there are concrete examples and evidence, the adoption of peat land use in home yards in Tumbang Nusa village has been slow. This is because there is little interest from other villagers in cultivating peatlands. They do not have enough knowledge on peatland cultivation, and their predecessors did not farm on peatlands because they were considered infertile. Agriculture on peatland requires substantial capital, as well as strong will and willingness to accept high risk.

Raised beds require substantial labour input, from clearing of the undergrowth to creation of the mounds. The height of the mounds must take into account the height of the water that inundates their yards during floods. This work requires significant time and energy. They must ameliorate the peat soil, such as with dolomitic lime or irrigate with water that has been mixed with detergent and fertilizer, to ensure that the peat is ready to be planted with agricultural crops. Other jobs include weeding, ensuring plants are safe from pests and diseases, and protecting plants from floods and fires. Due to these high demands, the expansion of agricultural production has occurred slowly. The effort required and the limited market in Tumbang Nusa has resulted in a relatively small area of development.

Mounding aims to provide a depth of peat where plant roots can grow above the water table even under flood conditions [50]. This can aid survival even when the area has been inundated for more than 1 week [51]. However, [49] noted it is challenging to create a solid mound that can withstand heavy rain and flooding for several years to allow the seedlings to develop strong roots and stem. This technology is commonly used to plant trees that usually grow on mineral soils (like mango and rambutan), and they are usually planted out at one plant per mound. Mounding could reduce the mortality of seedlings planted in the peatland at the initial stage [48,52].

The practice of cultivation technology such as raised bed and mounding development has been found to increase a farmer's income 3-fold compared with conventional farming [53]. Similarly, [54] found that use of a raised bed system in Jambi, Sumatra, could increase the productivity of land and commodity diversification and improve a farmer's income by around 44%.

For the people of Tumbang Nusa village, mounding technology is quite expensive because they have to buy mineral soil from outside the village and fertilizer to fill the inside of the mound. They tend to consider that the effort required was greater than the benefits they received, especially the older respondents. One of the farmers in Tumbang Nusa village noted that he had switched from cropping to duck farming because the ducks are easier to maintain and do not require the same level of labour input.

Polybags are one solution for farmers with limited mineral land, degraded land or land with low productivity, and/or for land that is often flooded, as in Tumbang Nusa village, for agricultural cultivation activities. The use of polybags has advantages and limitations. Interestingly, the community of Tumbang Nusa uses household plastic waste to reduce costs, they note that the use of fertilizer is more efficient because fertilizer can be measured as needed per polybag and is not washed away by flooding; weeding is easier to do than cultivation on degraded land; the composition of the planting media can be adjusted to an optimum fertility [55]; and importantly, it can be cultivated regardless of the season as it can be moved to a place that is safe from flooding.

The limitation of cultivation in polybags includes that they are only suitable for fast growing annual crops such as vegetables, chilli, tomatoes, ginger, and others, but it cannot be used to plant tree species. The material used for polybags has limited durability, it is not suitable for large-scale businesses because in the end it will encourage the use of plastic in large quantities, which will result in accumulation of plastic waste [56,57]. In Tumbang Nusa, the community also diversified into making environmentally friendly pots from woven purun plants. Purun pots can be planted directly into the ground with the plants, but the price is still more expensive than plastic and is not economical for nursery businesses.

4.3. Practices Taken Up by Others Which Are Yet to Be Adopted by the Respondents

The planting technique with the raised bed system can utilise a form of local wisdom whereby one section of the component is elevated (elevated bunds/beds) and the other section is excavated (sunken beds) [58]. Plants that are not resistant to flooding are planted on the raised section, and plants that are flood tolerant are planted in the lower section. The alternating bed system can reduce Fe levels from the first month to the fifth month, while sulfate increases in the first and second months and decreases after the third month. However, respondents generally only planted the raised part and not the excavated bottom part, so the advantages of this system (increasing the intensity of land use, increasing diversity of cultivated varieties, reducing the risk of crop failure, and increasing income, [58]), have not been fully obtained.

5. Conclusions

Sustainable cultivation of the fragile peatland ecosystem requires that farmers take extra care and consider how their practices impact on both the long-term sustainability of their peatlands, and on the broader public good. Due to past mismanagement of peatlands in Tumbang Nusa, they are now prone to fires in the dry season, susceptible to flooding in the rainy season, and the peat has acidified. These conditions make most villagers reluctant to cultivate the peatland. However, some Tumbang Nusa farmers consider their peatlands as an asset and are interested in managing it as productive land either for a source of income or for fulfilling family needs. They understand there are a lot of challenges to overcome in utilizing peatlands.

The peat land in the yard is used to meet daily, monthly, and yearly needs, as well as for investment purposes. For investment, people tend to plant species that are native to peat soils. However, to fulfill daily, monthly, and yearly needs, people are more familiar with and tend to plant species that are native to mineral soil. The incompatibility of the types of plants cultivated on degraded peatlands makes the cost of farming expensive with a high risk of failure. Various technologies are applied to overcome various challenges in managing the yard, such as the use of polybags, development of raised beds, making peat mound, and amelioration with dolomite lime and fertilizer. From these various technologies, the use of polybags to cultivate agricultural crops, to meet the daily needs of farming families, provides the effective home yard management and the simultaneous preservation of the peatlands for the study areas. This technology is the easiest and cheapest/to overcome problems related to standing water. This technology can be carried out by all family members and has the potential for wider scale adoption. To optimize the use of home gardens, planting of species that are native to peat soil by utilizing the space below the stand will simultaneously restore degraded peatland and provide long-term investment.

Managing the risk of flooding through adopting these technologies also means that peatland restoration through canal blocking can occur without substantially impacting on farmer livelihoods. Farmers have options to directly plant endemic species that will return an income (and act as a long-term savings), as well as obtain cash flow from shorter term production of agricultural species using these techniques. There should also be some consideration given to providing explicit and financial recognition of the social benefits provided to broader society from the restoration efforts of the farmers, notably prevention of greenhouse gas emissions and reduction in smoke haze from fires, particularly if the peat is allowed to be rewet.

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