The potential role of coconut in improving the sustainability of agriculture on tropical peatland: A case study of 32 years' practice in Pulau Burung District

Nurul I. Fawzi, Annisa N. Rahmasary, Ika Z. Qurani

Tay Juhana Foundation, Penjaringan, North Jakarta, Indonesia

SUMMARY

Catastrophic forest and land fires have turned a global spotlight on tropical peatlands in Indonesia. The consequent reformulation of Indonesian land-use policy has been complicated by the existence of two apparently opposing objectives, namely conservation and development. In many regions of the country, peatland agriculture is one of the pillars of development, but its sustainability is questioned. This article focuses on a coconut plantation managed by local stakeholders on peatland in Pulau Burung District (Riau Province) where excellent productivity has been achieved, promoting Indonesia as the world's largest supplier of coconut. Quantitative and qualitative approaches are employed to examine the sustainability of this agricultural system over a period of 32 years; in terms of water management, land management and socioeconomic development. The fundamental determinant of sustainability in this system is integrated water management which confined the annual range of water table fluctuations in 2018–2019 to 25–71 cm below ground surface. The resulting long-term rate of subsidence is 1.7 cm yr^{-1}, or up to 80 % lower than reported from peatland agriculture elsewhere. The combination of water management, land management and shared understanding in Pulau Burung means that the risk of peat fires is minimal. In 2013–2018, the plantation produced coconuts at an average rate of 6,500 ha^{-1} yr^{-1}. This converts to the standard international unit of copra productivity as 1.3 t ha^{-1} yr^{-1}, which is 55 % higher than the productivity achieved by Indonesia as a whole and 20 % higher than the corresponding global figure. A significant socioeconomic outcome has been the elevation of a village to a district encompassing 14 villages, with attendant benefits for local people in terms of living conditions and improved access to food, goods, services and education. We conclude that the integrated water management and interdependence of local stakeholders in Pulau Burung has managed to balance the peatland's role in developing human welfare with maintenance of the hosting environment over several decades.

KEY WORDS: BioPeat-Pine, NES transmigrants, socioeconomic development, Sumatra, water management

INTRODUCTION

Peatland has existed on Earth for millennia. Already known as a biodiversity hotspot, it is now most famous as the world's largest terrestrial carbon store (Warren *et al.* 2017). This arises because peat is an accumulation of partly decomposed organic matter, which is formed in the tropics by trees and a variety of other plants growing under wet conditions (Craft 2016). Peat formation occurs over long periods at a rate of about 1 mm yr^{-1} (Page *et al.* 2004), which means that a peat layer 1 m thick takes 1000 years to form.

In Indonesia, around 10 % of the land is peatland (Ritung *et al*. 2015), and some peat layers on the islands of Sumatra and Borneo (Kalimantan) are more than 10 m thick. This peatland has served a most important socioeconomic function in meeting the needs of local (especially indigenous) people. More recently, the shortage of high-grade agricultural land has made peatland (which is classed as suboptimal) an alternative target for agricultural development, offering a large area for food production (Mulyani *et al.* 2016). Peatland has also become fundamental to the production of many globally distributed commodities such as palm oil, pulpwood and timber (Uda *et al.* 2017).

Agricultural practice on peatland comes with many challenges because of the need to lower the naturally high water table of the peat soil (Goetz & Zilberman 1995) in order for most agricultural crops to grow. Conventionally, it involves drainage by excavating a ditch to discharge water to the nearest river, lake or sea. This causes 'irreversible drying' which means the peatland loses its capacity to absorb and store water, cannot be rewetted (Wardani *et al*. 2019), and becomes vulnerable to flooding and drought (Lupascu *et al.* 2020). Thus, the peat becomes more prone to fire during dry seasons.

In the mid-1990s Indonesia engineered a disaster in the form of the failed Mega Rice Project which destabilised the hydrological systems of some of the peatlands in Central Kalimantan, creating 1.4 million ha of degraded and abandoned land (Putra *et al.* 2008, Surahman *et al.* 2017). Activities such as logging, drainage, industrial plantation, and repeated fire events resulting from 'slash and burn' interventions have also become significant drivers of peatland degradation (Miettinen *et al.* 2012, Dohong *et al.* 2017, Uda *et al.* 2017) and, thus, of carbon emissions to the atmosphere (Page *et al.* 2002, Hafni *et al.* 2018, Ishikura *et al.* 2018). Degraded peatland has become the largest Indonesian source of carbon emissions, which increase during El Niño years owing to fires (Siegert *et al.* 2001, Atwood *et al.* 2016, Field *et al.* 2016, Yulianti *et al.* 2020). Peatland fires involve a combination of flaming and smouldering combustion, the latter penetrating deep into the organic peat layer if its soil moisture is depleted. This means that, even if a surface fire is extinguished, it can be reignited from below (Rein 2015). The carbon emission from burning tropical peatland is up to 114 Mg ha^{-1} for first fires and 13 Mg ha^{-1} for fourth and subsequent fires (Page & Hooijer 2016); and it has been estimated that 0.81 to 2.57 gigatons of carbon were emitted to the atmosphere from peat fires in 1997 (Page *et al.* 2009). The most recent extensive peatland fires occurred during the forest fires and haze crisis of 2015 (Atwood *et al.* 2016). Whilst Indonesia experienced the worst consequences in terms of both economic losses (estimated at US$15.8 billion) and the effects of poor air quality on human health (Uda *et al*. 2019), activities in neighbouring countries were also interrupted by the haze.

Carbon emissions also result from peatland drainage, which stimulates compaction and oxidation of the layer of organic material (peat) that overlies the mineral substratum. Subsidence (lowering of the soil surface) of up to 1 m yr^{-1} can be recorded in the first two years after installation of drains. On average, the initial subsidence rate is 45–75 cm yr^{-1} and subsequently decreases to 3.6–5 cm yr^{-1} (Price *et al.* 2003, Hooijer *et al.* 2012). Subsidence increases the risk of flooding and, in the long term, causes the peat layer to disappear. The loss of peat by decomposition/oxidation also releases CO_2 to the atmosphere.

Realising that such unsustainable use of peatland may accelerate its loss and increase carbon emissions (Rieley & Page 2008), the Indonesian government has increased its focus on balancing development and conservation. For example, Government Regulation of Indonesia No 57 of 2016 (PP No. 57/2016) regulates the management of existing peatland utilisation by setting a water table threshold to limit the depth of peat subjected to drying, and by encouraging community involvement in managing peatland. Water management in peatland is crucial because subsidence correlates strongly with water table depth (Hooijer *et al.* 2012, Carlson *et al.* 2015, Nusantara *et al.* 2018, Evans *et al.* 2019, Hoyt *et al.* 2020). Many studies have found a statistically significant relationship between peatland drainage (water table lowering) and increasing subsidence rate. Wösten & Ritzema (2001) found that every centimetre drop in water table level corresponded to 0.04 cm yr^{-1} of subsidence, while Nusantara *et al.* (2018) reported that subsidence became faster the more the water table was lowered. Evans *et al.* (2019) suggested that raising the water table to 40 cm depth on a drained peatland with *Acacia* plantation would reduce subsidence rates by 25–30 %.

During recent decades, the two opposing approaches to peatland use (development and conservation) have featured together in the formulation of policy for more sustainable land use in Indonesia. Sustainable practice in peatland management aims to benefit both the environment and the people (Nursyamsi *et al*. 2016). Even so, finding balance in the nexus of preservation and development is not straightforward and, most of the time, the balance is tipped towards either the environment or human (socioeconomic) interests. Despite the existence of a standard and framework with sustainability indicators, measurement of the sustainability of peatland management remains complex to implement (Thorburn & Kull 2015). The availability of various relevant sustainability frameworks (e.g. Reducing Emissions from Deforestation and Forest Degradation (REDD+), Roundtable on Sustainable Palm Oil (RSPO), Sustainable Peatland Management (SPM)) highlights the complexity of developing the right approach for sustainable peatland utilisation (Parish *et al*. 2012, Koh 2013, Nursyamsi *et al*. 2016). Moreover, differences in landscape and peatland condition between specific regions can pose challenges for framework implementation. Ultimately, improving peatland conservation and utilisation with a sustainable approach requires policy intervention (Harrison *et al.* 2020); which leads to the idea of formulating a set of approaches spanning science and policy, that forces agricultural practice to become more sustainable.

For the time being there will be continuing debate about the extent of sustainability in tropical peatland utilisation, which is dominated nationally by industrial agriculture for palm oil and pulp/paper production (Purwanto 2018). On the other hand, in the eastern coastal region of Riau Province (Sumatra) known as Indragiri Hilir, where peatland comprises 86 % of the total area, coconut (*Cocos nucifera*) has been an important commodity for local people since the late 1800s (Akmal *et al*. 2020). This species grows naturally in lowland and flatland regions with sufficient water supply and the practice of cultivating it on peatland is unusual, but it is found to thrive on peatland in Indragiri Hilir (Mubekti 2011). Here, coconut is close to people's hearts and is even given the name 'tree of life' (Foale 2003) owing to the usefulness of all parts of the tree for purposes ranging from healthy foods, beverages and handicrafts to furniture, house construction, and even bioenergy. In one of the coconut-producing districts, namely Pulau Burung, there is an application of integrated water management which regulates the water table level to accommodate agronomical productivity whilst also maintaining peatland functions, and has been in place for more than three decades. At a glance, this could be regarded as an exemplary case of sustainable peatland agriculture. However, a problem arises in relation to how the sustainability of this relatively unknown case of peatland agriculture can be substantiated because the available standard and framework require the examination of a long list of indicators, which is especially challenging in developing regions.

The concept of sustainability has been described in many ways depending on the context (McKenzie 2004). A potentially thin conceptualisation indicates that sustainability is achieved when an activity produces satisfactory results for an indefinite period of time (Hansen 1996); the term ‘satisfactory results’ meaning that the activity is not detrimental to the water, the land or the people. In the context of peatland, the ‘right and fitting approach’ in terms of water management, land management and socioeconomic development will optimise productivity whilst minimising negative effects on the peatland’s biophysical attributes and carbon emissions (Surahman *et al.* 2017).

Based on the reasoning above, this study aims to employ a more straightforward approach to examining sustainability, by using both quantitative and descriptive factors to represent the three aspects (water, land and people) in terms of water management, land management and socioeconomic development. Our primary focus is directed towards water management because of the ongoing discourse arising from the proposal of Wösten & Ritzema (2001) for a paradigm shift in peatland agriculture, from ‘drainage of excess water’ to ‘water conservation’. In other words, the water management practice can be regarded as sustainable if the peat deposit is preserved whilst maintaining agricultural productivity along with human security.

To this end we provide novel evidence relating to the sustainability of agriculture on peatland, for the case of the Pulau Burung coconut plantations. In the results, this large-scale practice of coconut agriculture is examined in terms of the three aspects of peatland sustainability identified above. After reflecting on the findings by delving more deeply into the dimensions of peatland sustainability, the article concludes with lessons learned from Pulau Burung and recommendations to support sustainable peatland agriculture in the future.

METHODS

Context and location

In global and national statistics, coconut productivity is measured in terms of copra (dried coconut kernels) and oil. Although the uses of coconut are more diverse and its value higher than these metrics convey (Foale 2003), there are few studies which calculate the total value of coconut production by including other products. The global average yield of copra increased from 0.85 ton ha^{-1} yr^{-1} in 2001 (FAO 2001) to 0.90–0.95 ton ha^{-1} yr^{-1} in 2016 (ICC 2016), and the largest areas under coconut production are to be found in Indonesia followed by the Philippines and India (Alouw & Wulandari 2020). The major coconut producing provinces of Indonesia include Riau, North Sulawesi and East Java (Alouw & Wulandari 2020), and one-tenth of the country’s coconut production area is in Indragiri Hilir Regency, Riau Province. Some of the plantations here are located on peatland, and the largest of these is in Pulau Burung District on the east coast of Sumatra (Figure 1).

Pulau Burung District has an area of 538.33 km^2, the average elevation is 12.5 m above sea level, the average slope is 8 %, and the annual rainfall is 1,641 mm yr^{-1}. It encompasses 14 administrative villages with a total population of 23,288 individuals residing in 5,762 households (2018 data; BPS 2019a). Locations on peatland are nowadays considered in the context of their Peatland Hydrological Unit (PHU), which occupies the area between two rivers or seas as defined in the Government Regulation of Indonesia No. 57 Year 2016. Pulau Burung lies within the Sungai Kampar - Sungai Gaung PHU whose extent is about 710,823 ha, with 45.9 % of its area categorised as protected zone with peat depth > 3 m (Ministerial Decree of Environment and Forestry No. 130 Year 2017). Over 80 % of land use in Pulau Burung is currently agricultural, dominated by coconut plantation (BPS 2019a).

Coconut agriculture was first introduced to Indragiri Hilir by the Banjarnese cleric Syech Abdurahman Siddiq when he moved into the region in the late 1800s (Akmal *et al*. 2020). Siddiq also initiated the excavation of an extensive network of

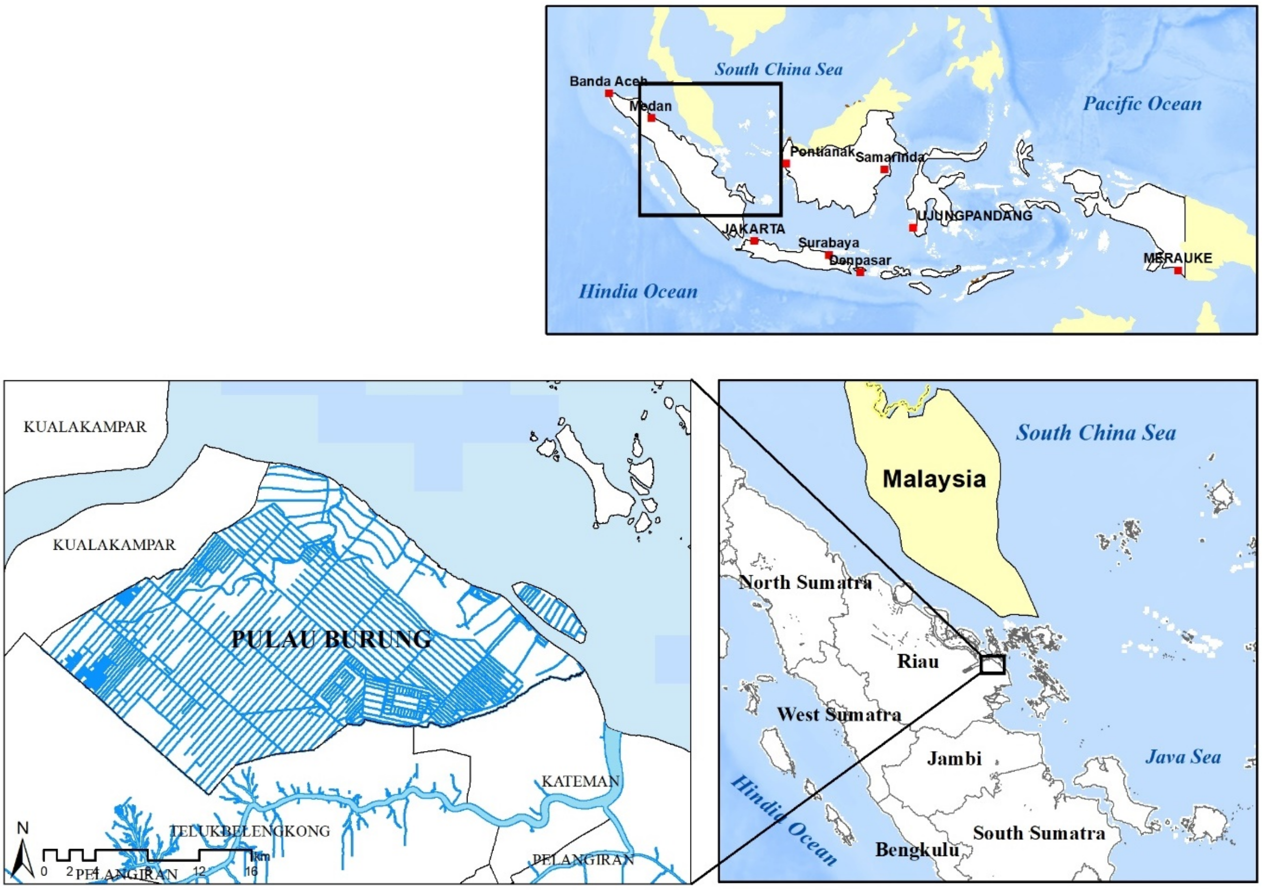

Figure 1. Map of the research location in Pulau Burung, Riau, Indonesia. The blue lines represent the canal network within the district.

canals for harvest transportation. A revival of coconut agroindustry began in the 1990s, when hundreds of Javanese people were relocated to this area (President of Indonesia Instruction No. 1 Year 1986) under the Nucleus Estate Smallholder (NES) transmigration scheme, known locally as the *Perkebunan Inti Rakyat-Transmigrasi* scheme. Also under this scheme, the local private coconut enterprise known as Sambu Group was appointed by the government to facilitate the practice of coconut cultivation on peatland and to support its supply chain.

Nowadays, Sambu Group owns 22,650 ha of coconut plantations and a compound of processing factories in the area. The population originating from the NES is increasing and its plantations generate more than 90 % of the coconuts supplied to the Sambu company's factory, which processes them into a wide variety of coconut products. Since the late 1990s, both the company and smallholder farmers in Pulau Burung have additionally produced pineapple from their land plots and a pineapple processing factory has been integrated into the company's compound. The majority of land plots are utilised for coconut monoculture, a lesser number are used for pineapple monoculture, and some lie within intercropping (coconut and pineapple) zones.

The distinctive feature of coconut agriculture on the Pulau Burung peatland is an integrated water resource management system known as the Water Management Trinity (WMT), or *trio tata air* in the local language. The three elements of the 'trinity' are canals, dikes, and dams with water gates (Figure 2). The WMT was first developed by Sambu Group in 1986 and later expanded along with the NES programme.

The design of the WMT was based on local wisdom gained by the residents of Indragiri Hilir in supporting their existence through agricultural activities on peat. The purpose of the canals is not to drain excess water; but rather to act as reservoirs, provide water regulation to support agronomy, and reduce the risk of fire. The canal network consists of primary (width 15–30 m, depth 5–7 m), secondary (width 4–6 m, depth 3–4 m) and tertiary (width 1 m, depth 1 m) channels. In the 22,650 ha of coconut plantations, the total length of the canals is around

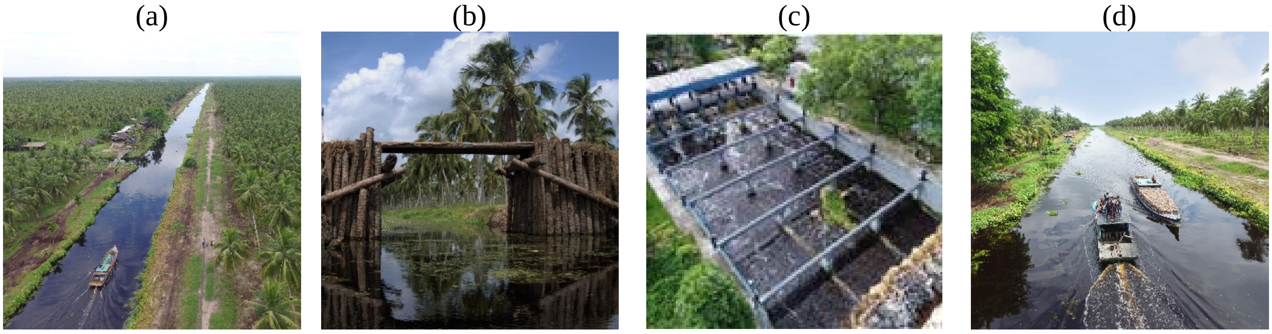

Figure 2. The three components of the water management system: (a) canal, (b) dike, (c) water gate, where (d) the canals are used as the main transportation system in the area.

2,494 km they can store 25 million m^3 of water (Sambu Group 2015).

The WMT is a closed system with (largely) manually operated water gates, that exploits the geographical setting of “a large rain-fed peatland catchment area”. Its main function is to maintain the water table at an optimal level to support the growth of coconut and keep the peatland wet. It prevents both flooding during rainy seasons and desiccation (that can lead to fire) during dry seasons, and is nowadays operated to comply with the 40 cm maximum water table depth (below ground surface) required by the Government Regulation of Indonesia No. 57 Year 2016. In addition to its water regulation function, the canal network serves as the main transportation system and there is limited road construction. Realising the importance and value of the WMT, all stakeholders in the area (i.e. the company, the farming community and local government) have maintained it collectively up to the present day.

Data collection and analysis

Even though the plantation has existed for more than 30 years, we are still barely scratching the surface in exploring the sustainability of coconut agriculture on the Pulau Burung peatland. The lack of local knowledge about sustainability indicators means it is likely that the availability of historical time series data for relevant biophysical factors will be limited. On the other hand, the human community that has flourished in the area for two generations can provide local perceptions of the changes that have occurred over time, especially in terms of socioeconomic conditions. Hence, during the data collection period in 2019, we employed a hybrid approach that combined both quantitative and qualitative study methods. All of the biophysical data used here were originally collected within the 22,650 ha of coconut plantation plots owned by Sambu Group (Figure 3), as part of the monitoring routine required of the company by government. The qualitative data were assembled from interviews and discussions involving a wider range of local stakeholders from five villages within the district of Pulau Burung. The types of data obtained and the corresponding analysis methods are described below.

Water management and subsidence

Water table level relative to ground surface was measured at 106 points located on the basis of elevation/topography, water management zonation, and consideration of the overflow from outlets; as required by Ministry of Environment and Forestry Regulation No. 15 Year 2017. The spatial density of measurement points was low because large parts of the study area lie at the same elevation. Every point was deliberately placed at the centre of a 50 ha land plot within the coconut plantation (Figure 3). At each measurement point a peat auger was used to drill a vertical hole into which a four-metre length of 2.5" (6.4 cm) PVC pipe with perforated walls (to allow entry of water) was sunk until only half a metre remained above the ground surface.

For this study we acquired water table depths that were measured manually in Week 2 and Week 4 of every month between 01 January 2018 and 31 December 2019. We also obtained daily rainfall data collected using a manual raingauge located at the central plantation office of Sambu Group (0° 21' 51.5" N, 103° 29' 27.0" E). Rainfall totals were calculated for the same time intervals as the water level measurements in order to access the relationship between water table depth and rainfall.

For subsidence analysis we acquired data collected by the company from four iron poles that were driven vertically through the peat layer into mineral soil in 1986 (first measurement in 1987), during development of the WMT and expansion of the coconut plantation. The locations of the poles are shown in Figure 3. The poles were installed for

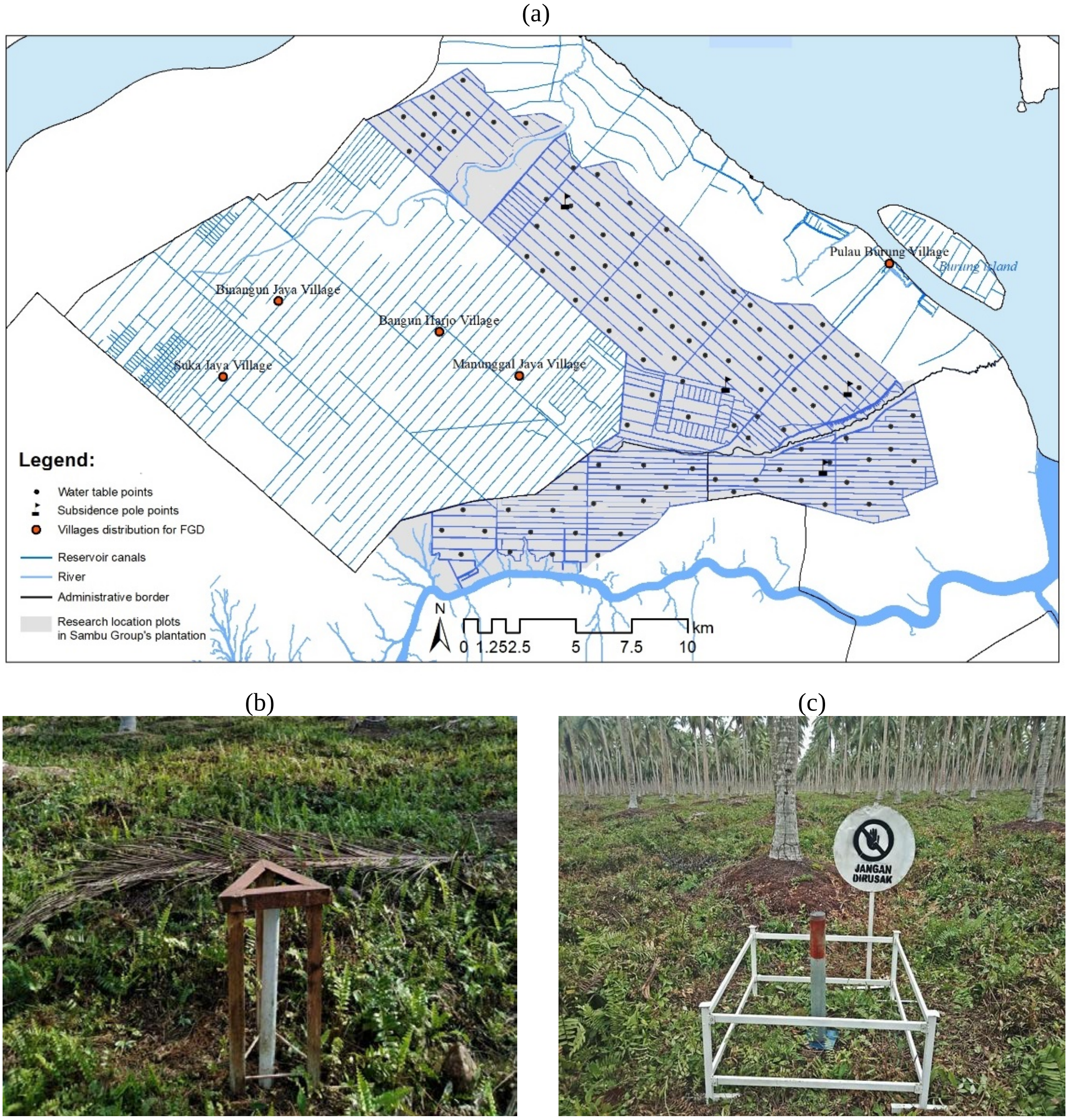

Figure 3. (a) Map showing the distribution of water table and subsidence measurement points in the Sambu Group plantation, and the locations of the five FGD villages. (b) PVC tube for measurement of water table level. (c) Iron pole for subsidence measurements.

baseline infrastructure work without any consideration of future research needs and their very low spatial density is problematic, but the series of subsidence measurements compiled covers a period of 32 years (1987 to 2019).

We were unable to acquire the corresponding historical data on peat depth and land use from company records because the resources available to this study were insufficient. The most recent survey of the plantation area (Sambu Group 2015) recorded the range of peat thickness as 0–6 m. The peat in this area is classified as sapric (mature) (Agus *et al*. 2011) with an average bulk density of 0.15 g cm^{-3}.

Land management

Primary data regarding coconut productivity and agricultural practice were obtained from the company. To determine productivity rate, we were permitted to use the annual coconut production data for the period 2013–2018. We also conducted desk research and thus identified an internal report for Sambu Group, about the situation of coconut agroindustry in Pulau Burung and the neighbouring district of Kateman, which provided complementary information about production. To investigate land management practice, we conducted unstructured interviews with the relevant officer of the company and accessed documentation on their Standard Operating Procedure (SOP). Descriptive information from the company's Research and Advisory division supported us in gaining insights about these aspects. The information obtained from the company about the practice they implement (e.g. fertiliser application, pest control techniques, weeding) was cross-checked with local field workers (employed by the company) and local farmers (who work their own land plots). This cross-referencing was conducted through unstructured interviews with coconut farmers during the period of field observations in May and July 2019, as well as through a series of focus group discussions (FGDs) in five of the Pulau Burung villages in July 2019 (further explanation below).

Socioeconomic development

The interdependence between stakeholders in Pulau Burung is noteworthy. Until the 1980s, most of the local population were traditional fishermen and farmers. Over the following 30 years, landscape change was driven by the opening (in the 1980s) and development of Sambu Group's coconut agroindustry, and was followed by significant demographic change with arrival of the NES transmigrants in the mid to late 1990s. Presently, the majority of occupations are related to the coconut agroindustry. While this history underpins the value of our study, it also makes the acquisition of information challenging because numerical recording of the NES process was not reliably completed.

Four indicators were chosen to describe the socioeconomic situation in Pulau Burung, namely: population growth, household welfare, access to education, and access to food. These four indicators were selected because they reflect the development of the region, and relevant data are available and accessible. The last three were also chosen because they were aspects of life that local people could readily relate to and report on across generations of their own families. We adopted the 'before-after' approach, which assesses the progress of local development by comparing present circumstances with those that prevailed in the past (European Commission 2008). We utilised three primary sources of socioeconomic data, namely: official documents, FGDs and questionnaire interviews. Demographic data were obtained from official statistical records (BPS 2010, 2019a, 2019b; Rahmasary *et al*. 2020). The other three indicators were derived from information collected during FGDs which were conducted in July 2019 as part of our independent study of sustainable agriculture dimensions in the area; which also encompassed fire management, infrastructure development, water and land management, and waste treatment.

The FGDs were conducted in five villages within Pulau Burung District which were selected to differentiate the 'before-and-after' of coconut agroindustry revival. We chose one indigenous village and four villages developed under the NES programme, the latter being chosen primarily on the basis of distance from the district centre and initiatives of village officials. The villages selected were Pulau Burung, Binangun Jaya, Manunggal Jaya, Suka Jaya and Bangun Harjo (see Figure 3).

In the FGDs we conducted open-ended questionnaire interviews, with questions relating to the indicators. It was planned that each of the five villages should have six respondents representing six different backgrounds, i.e., farmer, landless farmer, woman farmer, trader, youth, and community leader; which were the majority groups identified from initial stakeholder analysis and village demographic information. By including these different groups we aimed to maximise the diversity and objectivity of opinions canvassed. To gauge socioeconomic development that could be associated with the coconut plantation, we compared circumstances in the late 1990s (initial years of transmigrant settlement) with the situation in the late 2010s (current years of the study). Questionnaires were actually completed by 29 respondents.

RESULTS

Water management and subsidence

Figure 4 shows that the requirement for water table depth ≤ 40 cm set by PP 57/2016 was met at the times of 13 (27 %) of the 48 readings acquired for 2018–2019, and that the envelope of (spatial) average water table depth for that period was 25 to 71 cm below ground level. The variability is due to the alternation of rainy and dry seasons in conjunction with management aiming to achieve the target maximum water table depth of 40 cm required by the relevant government regulation. The graph indicates that the water table fluctuations followed the variations in precipitation rate. The water table reached its minimum level of -71 cm in late August 2019, when the lowest monthly rainfall was also recorded. At this time, the weak El Niño caused precipitation to be lower than usual. When appreciable rainfall occurred in September, the water table started returning

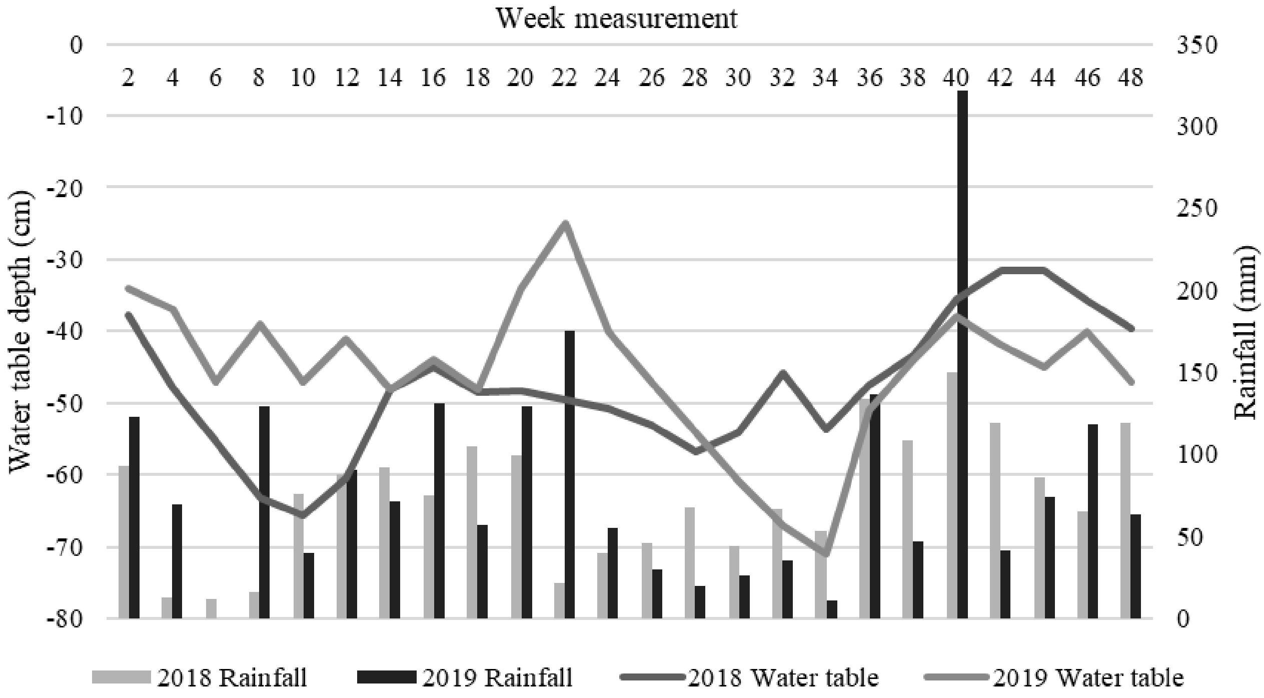

Figure 4. The average water table depth from measurement data collected at 106 points, alongside rainfall data in the study area.

towards the target level of -40 cm (attained six weeks later). Nonetheless, the relationship between rainfall and water table level was weak (R^2 = 0.2901).

The WMT functions as a reservoir that is frequently topped up to its regulated overflow level by rainfall during the wet season. Thus, the water table in the peatland is prevented from rising above or falling below the optimal depth range for growth of coconut whilst keeping the remainder of the peat deposit wet. During the dry season the water gates are closed to retain stored water and thus minimise water loss which can then occur only by evapotranspiration. Under these conditions the degree of water table drawdown depends on the duration of the dry season. Figure 4 shows that both the timing and the degree of maximum drawdown may vary from year to year.

Figure 5 shows the average (n = 4) annual subsidence for every year since establishment of the Pulau Buru plantations and WMT. Total subsidence during those 32 years was 54.1 cm, giving an average subsidence rate of 1.7 cm yr^{-1}. Average subsidence in the first year was 3.3 cm and cumulative subsidence in the first five years was 14.3 cm. In newly drained peatland, the highest subsidence rate is recorded in the early years of plantation development. Wösten & Ritzema (2001) estimated the subsidence after two years of establishment as up to one metre, with a yearly average of 47 cm yr^{-1}. This result is similar to the subsidence rate calculated by Hooijer *et al.* (2012) from observations in an *Acacia* plantation on peatland elsewhere in Riau Province; where the subsidence rate was 75 cm in the first year after development, 19 cm in each of the second and third years, and 142 cm in the first five years. After that, the subsidence rate stabilised at around 5 cm yr^{-1}. These data are shown for comparison in Figure 5. Over the 32-year period (1986–2019), subsidence was about 80 % less in Pulau Burung than in the *Acacia* plantations studied by Hooijer *et al*. (2012). The most striking contrast between the two subsidence curves in Figure 5 is the 127.7 cm difference in totals for the first five years after plantation development commenced. Indeed, a phase of rapid primary consolidation (Parish *et al*. 2019, Roadex 2021) was hardly observed at Pulau Burung. It is possible that this area had been previously affected by the excavation of channels for transporting coconut, which became widespread in Indragiri Hilir from the time of Siddiq (see 'context and location' in Methods, also Akmal *et al*. 2020). However, available satellite imagery and mapping show the area covered by apparently natural forest prior to establishment of the Sambu Group plantation around 100 years later. The subsidence curve for coconut agriculture in Pulau Burung is also generally flatter than the curve for *Acacia* cultivation. The difference in subsidence rates from Year 5 onwards indicates that reduction of the peat layer is ongoing at both sites but the progress of subsidence processes has been slower under the coconut than under the *Acacia*.

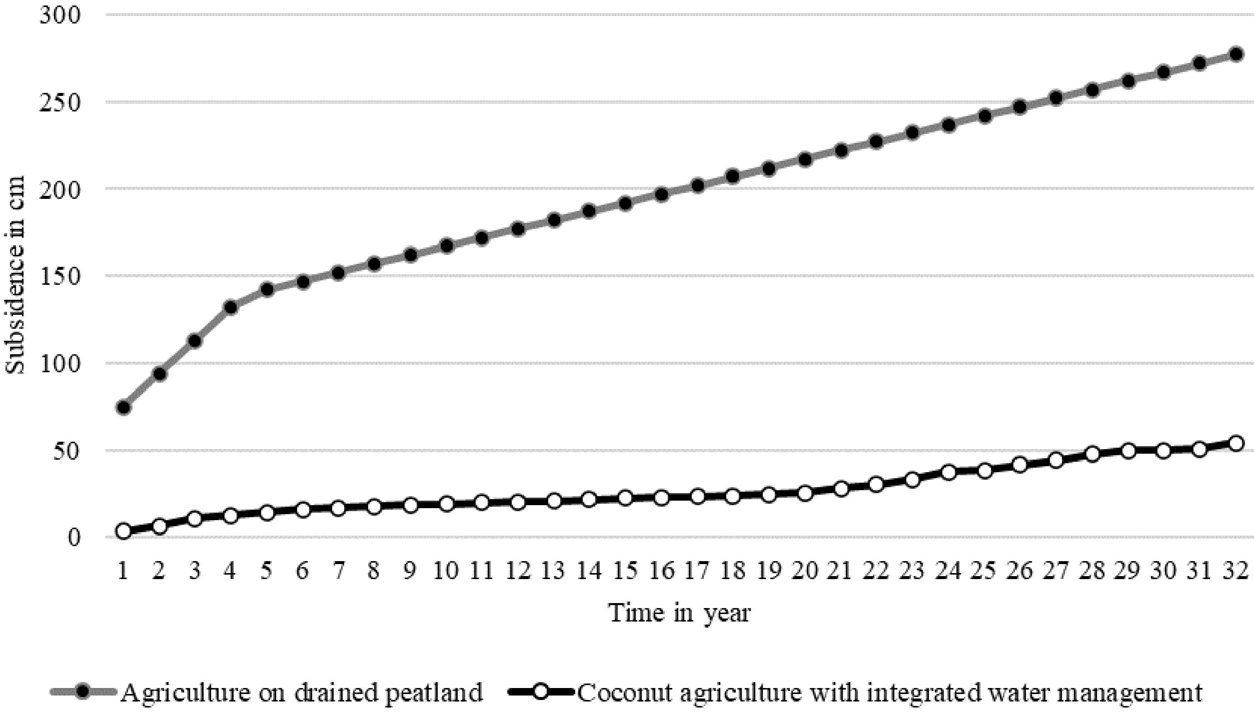

Figure 5. Comparison of accumulated subsidence between drained peatland under agriculture from Hooijer *et al.* (2012), and the Pulau Burung coconut plantation area.

Land management

The company's annual coconut production in Pulau Burung is presented in Figure 6. Between 2013 and 2016, coconut fruit production increased from 7,385 ha^{-1} yr^{-1} to 8,154 ha^{-1} yr^{-1} but in 2017 and 2018 it decreased to around 4,500 ha^{-1} yr^{-1}. The decline was due to monsoon irregularities and mirrored a global trend. Over the six years 2013–2018 inclusive, the average coconut fruit production was 6,500 ha^{-1} yr^{-1}. Converting to the international standard unit (5,000 nuts yield one metric ton of copra; World Bank 1986), this equates to an average copra production of 1.3 t ha^{-1} yr^{-1} (range 0.90–1.6 t ha^{-1} yr^{-1}). For comparison, copra production is 1.08–1.12 t ha^{-1} yr^{-1} globally (ICC 2016) and 0.84 t ha^{-1} yr^{-1} in Indonesia (Alouw & Wulandari 2020). Thus, the average productivity at Pulau Burung exceeded the global average by 20 % and the national average by 55 %.

Similar levels of productivity were achieved in the Pulau Burung NES plantations. The average coconut production of smallholder farmers was 5,345 ha^{-1} yr^{-1} in 2015 (Pasaribu *et al*. 2016), decreasing to around 4,569 ha^{-1} yr^{-1} in 2018 (Sambu Group & IPB 2019). The same report indicated that coconut production in the neighbouring Kateman District was only 2,855 ha^{-1} yr^{-1}, or around half the production rate achieved at Pulau Burung.

The coconut farmers in Pulau Burung mentioned old coconut trees, pest attack and water problems as contributors to decreasing productivity. The study from Adevia *et al.* (2017) also outlined the issues of pests, disease and replanting in the context of farmers' financial constraints. Similar situations occur in other coconut districts in Indragiri Hilir Regency (Aumora *et al*. 2016, Hadi 2017). While the lifespan of coconut trees ranges from 50 to 100 years depending on variety, productivity peaks at 50 % of lifespan (Foale 2003). Also, productivity is often disturbed by pest attacks (e.g., rhino beetle, hispid beetle, *Sexava* spp.), and disease (e.g., bud rot disease, nut fall disease) (Suriya 2016, Alouw & Wulandari 2020); and is also influenced by climate and seasonal variability of weather (Peiris *et al.* 2008). The fluctuating prices of pesticides and herbicides have led the farmers of Pulau Burung to favour mechanical methods of pest control over chemical ones (Aumora *et al.* 2016).

Our findings also highlight the challenge for agronomic practice. Although the peat soil in the study area has high cation exchange capacity (CEC) ranging from 271.2 to 1,170.4 me kg^{-1}, it has low base saturation and is thus low in plant nutrients. The cheapest way to improve the conditions for agriculture is to prepare peatland plots by burning the vegetation and soil. Burning controls weeds and produces ash which reduces soil acidity. The uncontrolled burning of this 'slash and burn' practice tends to cause peat fires (Goldstein *et al*. 2020) and

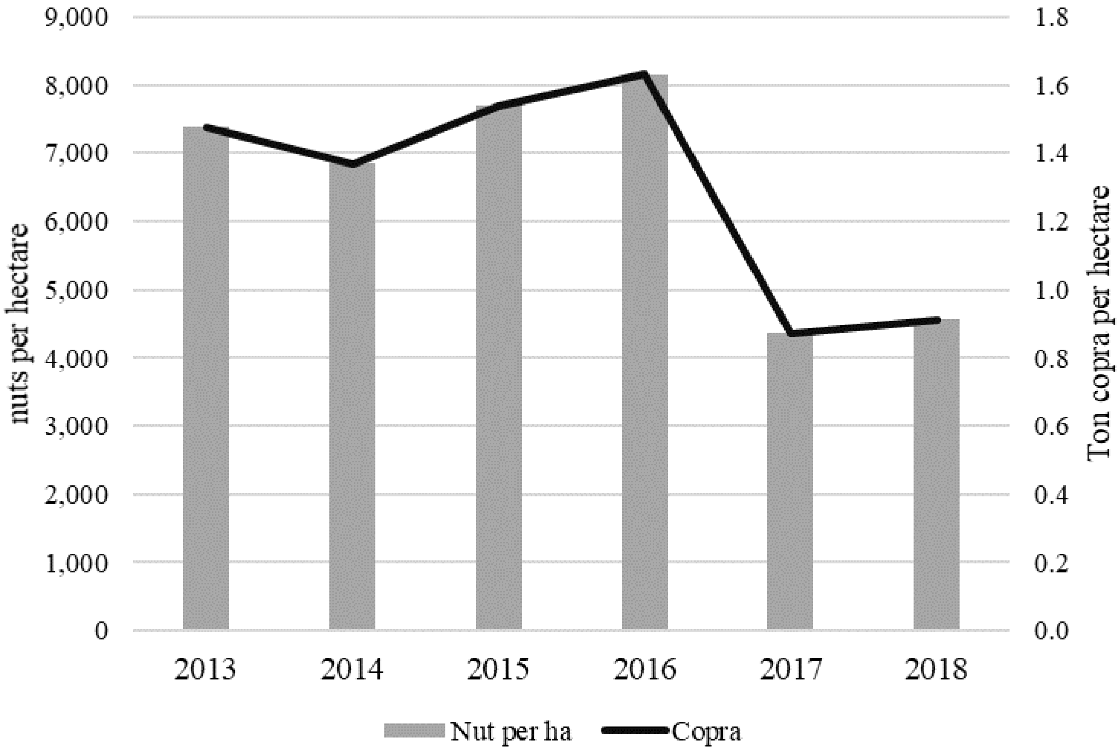

Figure 6. Coconut productivity in the Pulau Burung coconut plantation over six years.

is nowadays discouraged by the strong enforcement of fire prevention measures by local government in collaboration with the police department. Moreover, in this case study the smallholder coconut farmers and the company managed to avert any need for burning by utilising BioPeat to increase soil pH.

BioPeat is an organic ameliorant made from farming waste. In Pulau Burung, a joint initiative of the Agency for the Assessment and Application of Technology Indonesia (BPPT) and Sambu Group produced BioPeat-Pine which is manufactured locally by processing pineapple waste with fungi belonging to the genus *Trichoderma*. Pineapple is a secondary agricultural product in Pulau Burung, cultivated mostly as an intercrop plant utilising empty space between coconut trees but also in monoculture. The production of pineapple continuously supplies waste to form the ingredient of BioPeat-Pine, which can be used not only for land preparation but also as fertiliser.

Socioeconomic development

Table 1 summarises the socioeconomic changes in Pulau Burung that can be associated with the development of coconut agriculture, in terms of the four selected indicators.

The most obvious socioeconomic change is the elevation of villages to the status of administrative districts. Before 2001, Pulau Burung was a village within Kateman District. The initial driver of development was the arrival of the first wave of NES transmigrants, who generally settled in the area. The development of coconut agroindustry supported by a large company attracted more people seeking jobs (Akmal *et al*. 2020) and resulted in the success of further waves of incoming NES transmigrants between 1995 and 1998. As the population increased, more infrastructure was made available in this previously remote area. According to farmers, the development of infrastructure in many NES villages and plantations was largely self-funded with support from local government and the company. Akmal *et al*. (2020) found that such scenarios were common in Indragiri Hilir Regency. Pulau Burung became a District on 26 May 2001 under Regional Regulation of Indragiri Hilir No. 39/2000. Indeed, both Pulau Burung and the adjacent Teluk Belengkong District are proliferation territories of Kateman District.

Our findings showed that welfare, access to education and access to food are governed by financial income. In Pulau Burung, the stability of household incomes correlates with sustainability of the peatland coconut agriculture. Before the WMT was made to regulate the water, the traditional coconut plantations were adversely affected by seawater intrusion. This led to productivity decline, reducing farmers’ incomes (Hadi 2017) and leading to weakening of the supply chain.

Table 1. Comparison of socioeconomic indicators in Pulau Burung before and after the arrival of coconut agroindustry. Population data were obtained from statistical records (BPS 2010, 2019a, 2019b; Rahmasary *et al*. 2020), and the remaining three indicators summarise information provided directly by local people.

Socio-economic indicator	**Before (late 1990s)**	**After (late 2010s)**
Population growth	Pulau Burung was a village under the jurisdiction of Kateman District. The total population of the district was around 42,800 people.	Pulau Burung and Teluk Belengkong Districts had been separated from Kateman. The total population of Kateman, Pulau Burung and Teluk Belengkong was around 69,000 in 2000 and had increased to around 89,000 by 2019.
Household welfare	The houses were semi-permanent wooden constructions and there were no motorcycles in the area.	The houses had been renovated with concrete and there were many motorcycles in all villages for primary transportation.
Access to education	The local people (1st generation) only finished junior and high school, due to limited access to schools in the region.	Schools had been built meaning that children of the local people (2nd generation) could finish senior high school, and even gain university places.
Access to food	Subsistence farming, limited access to markets due to lack of infrastructure, and rationing (for transmigrants).	Diverse subsistence farming, improved infrastructure, increased access to more diverse food (in particular poultry and livestock produce).

Our FGD results recorded that the farmers spent most of their daily incomes on food and education (including transport to schools). Significant amounts were also invested (in buying new land plots) and donated (sent to families outside the area). This consumption pattern was also reported by Pasaribu *et al*. (2016) and Damanik (2015), who ascertained that farmers received better and more stable incomes from the coconut sector after a proper supply chain system (plantation and processing industry) had been established.

Consequently, the price of coconut became the main concern of farmers. Like any other commodity, the price of coconut fluctuates with supply and demand. In recent years, coconut prices have fluctuated between 960 and 1,780 Indonesian rupiah (IDR) per mature coconut fruit (Plantation Office of Riau Province 2020). When the FGD was conducted, the coconut price was around IDR 1,700 per fruit, meaning the coconut farmers in Pulau Burung were able to sell their produce for around IDR 6.92–7.76 million (€ 391–440) ha^{-1} yr^{-1}. On average, a smallholder farmer who supplies coconut to the processing factory owns 3 ha of land and, thus, receives an annual income from coconut of IDR 20.7–23 million (€ 1,170–1,300) (Pasaribu *et al*. 2016, Sambu Group & IPB 2019). Although this is below the average annual salary for both Indonesia and Indragiri Hilir, farmers are able to undertake additional work (e.g. as employees of Sambu Group) during the intervals between the three-monthly coconut harvests, and most households have multiple sources of livelihood.

The success of coconut agriculture has encouraged supply chain enhancements to drive regional development. As shown in Table 1, stable incomes have also enabled the farmers to improve their welfare. The people now have more permanent living quarters, transportation systems that enable a flow of goods and services, and increased opportunities to pursue higher education. This situation is consistent with the reasoning of Spangenberg (2005), who argued that the sustainability of the community can be gauged from the degree to which it can maintain stable income and carry out sustainable management of resources.

DISCUSSION

Dimensions of sustainable peatland use

The even balance between environmental, social and economic factors that is widely advocated as a foundation for sustainability is an unsuitable basis for the sustainable use of peatland. The foundation of sustainability in peatland agriculture should be preservation of the peat material whilst utilising the land. Peatland is classified as marginally suitable for all agricultural activities except those involving minimal human interference, such as forestry (including non-timber forest products) and traditional fisheries (Wildayana 2017), mainly because peat soil is characterised by its acidity and low productivity. However, the effort to meet human needs has driven the utilisation of peatland for other purposes including agriculture.

The unique attributes of peatlands dictate a need for greater emphasis on the environmental dimension of sustainability. In Pulau Burung, sustainability relies on water management via the WMT maintaining the water table at a desirable level for agriculture whilst also preserving some hydrological functions and preventing irreversible drying of the bulk of the peat deposit. A similar principle of water management is embodied in the ‘eco-hydro’ approach, in which comb-like relocation channels (Ritzema *et al.* 2014) act as a series of buffer zones to redistribute water that would otherwise be lost via drainage. In Semenanjung Kampar, Riau, this technique reduced the subsidence rate by around 20 % (Hooijer *et al*. 2015). The importance of water management in peatland also makes it the basis of peatland restoration. Options for restoring the hydrological system in peatland include blocking ditches to prevent water flowing into the river, constructing bunds or dikes, and reconfiguring the surface by planting trees (Ritzema *et al.* 2014, Budiman *et al*. 2020, Harrison *et al.* 2020).

With peatland use for coconut plantations founded on the WMT, the feature that supports the sustainability dimensions of Pulau Burung is the interdependence between the coconut farmers, the company and the government. The stakeholders in the area, especially the farmers, understand the importance for coconut productivity of managing water, hence they regularly work together to maintain the WMT infrastructure. A similar attitude to fire management is adopted, and this is strengthened by strict policing. As a result, the condition of land in this area is better than in neighbouring districts located outside the WMT system, such as Kuala Enok, where the houses, infrastructure and plantations of local coconut and oil palm farmers are damaged every year due to severe subsidence. On average, the damage costs US$ 79 yr^{-1} and the farmers account it as income loss (Saputra 2019, Saputra *et al*. 2019).

From a socioeconomic perspective, sustainability means increasing quality of life within communities (McKenzie 2004). Due to the limited resources available, this research focuses on four indicators only. Very limited official documentation that can support research into the human aspect of coconut farming in the area is available. Therefore, further study with a longer involvement period of respondents is needed to gain inherent knowledge. As pointed out by Akmal *et al.* (2020), even the statistical record of Indragiri Hilir for 1998–2000 is unavailable.

Understanding socioeconomic aspects is, nonetheless, important in relation to the impact of Indonesian peatland management. There are communities who have lived on peatland for generations that rely on this ecosystem for their livelihoods. For the community in Pulau Burung, our study finds that maintaining stable income, which is a main factor in improving quality of life, depends on water management. This lesson can be adapted to improve the sustainability of regions with peatland agriculture, by securing appropriate water resource management to maintain both soil humidity and the water requirement for crops. Water management is the basic foundation for preserving the environment in peatlands, which also results in the improvement of people’s welfare.

The future sustainability of peatland agriculture

In today's world, the use of peat for agriculture is a relatively common practice and is likely to continue, particularly in countries where demand for food is high and peatland is plentiful. To ensure this utilisation can be sustained for as long as possible, it is imperative that agricultural practice should strike an optimal balance between minimising environmental degradation and improving the wellbeing of local communities. While the example of Pulau Burung District shows promising results, implementation of the approach in other peatland areas must take into account (and be modified in accordance with) site-specific and local considerations.

While our findings indicate that the foundation of sustainable peatland agriculture lies in water management, there are other factors that also play crucial roles. The determination of techniques for increasing productivity also depends on the location and on the crop itself. It will always be desirable to assess land suitability in terms of physical factors such as climate, soil, topography, and hydrology (Wildayana 2017). In Pulau Burung, coconut is currently the main cash crop, but the FGD found that local farmers were interested in focusing more on growing other plants such as pineapple, areca nut and cocoa. Furthermore, as shown in Table 1, the people could grow a greater variety of food plants in their domestic gardens, not only for subsistence but also for sale in local markets.

Coconut is highly adaptable with the ability to thrive in lowland and highland locations (Lal *et al.* 2003, Osak *et al.* 2018). However, coconut also has inherent problems, just like any other crop. As pointed out in our findings on land management, the older trees produce lower yields. Unfortunately, replanting is not straightforward because, in addition to the high cost, there are gaps in policy and incoming regulations about peatland utilisation (Ministry of Agriculture Regulation No. 11 Year 2015, RSPO 2019). Due to these issues, some farmers said during the FGD that they might choose other crops when the time for replanting arrives.

Some approaches for addressing the aforementioned issues can be highlighted. First, we deal with finding alternative or complementary ways to increase the overall productivity of coconut agriculture, such as intercropping and integrated farming. Intercrops in coconut plantations increase food security for local people, improve the farmer's income, diversify plant genetic resources and the soil microflora, generate additional biomass and promote its recycling (Alouw & Wulandari 2020). An integrated farming system allows crops and livestock to coexist, with crops benefiting from a steady supply of manure as organic fertiliser. However, there are challenges in processing livestock manure owing to its bulkiness and relatively low nutrient content, the increased labour requirement, pungent odours, and indirect effects on plants (Osak *et al.* 2018). In Pulau Burung, farmers generally favour the idea of growing pineapple as an intercrop with coconut and uptake is increasing. Limited integrated farming has been initiated in Sambu Group plantations but the results are not yet observable. Secondly, there is a need for focus on resources and regulations pertinent to peatland management and land use allocation. The allocation of land for agriculture and industrial forestry is restricted to thin and medium-depth sapric and hemic peat soils (Ministry of Agriculture Regulation No. 11 Year 2015), but enforcement is currently confounded by the absence of an accurate and integrated peat depth map. Therefore, different government ministries have created their own sectoral maps (Uda *et al.* 2017), which are not always compatible. The newer regulations constraining peatland allocation according to peat depth has exacerbated the situation because peatland in Indonesia has been utilised for decades; so conflicts arise in places where land allocated for development turns out to lie within a conservation zone, and sustainable land management is often hampered by socioeconomic considerations (Buschmann *et al.* 2020).

The term ‘sustainability’ has a definition, but discourse on the topic always sparks arguments. Some people believe that agriculture on peatland is impossible due to the 'destructive' nature of agriculture itself (Wijedasa *et al*. 2017). However, with learning from best practices, most agriculture on peatland could be conducted more sustainably than at present whilst still supporting food production, the incomes of farmers and the reduction of carbon emissions (Surahman *et al.* 2017). In practice, an ideal condition of “true sustainability” is difficult to achieve (Shastri *et al*. 2008). This article argues that sustainability can be maximised by minimising negative effects and optimising for desirable benefits. The WMT suppresses the rate of degradation while supporting productivity; thus maintaining a workable balance between peatland conservation, social improvement and economic development. Furthermore, the interdependence between stakeholders strengthens social self-responsibility for maintaining the ecosystem that supports the flourishing coconut agroindustry and its supply chain. We conclude that these two dimensions define the sustainability of peatland use in Pulau Burung.

The lesson learned from Pulau Burung that can be applied to enhance the future sustainability of peatland agriculture elsewhere is that it is beneficial to improve the ability and the capacity of local stakeholders, especially farmers, to adopt integrated water management as a component of their routine practice. The provision of adequate support and enforcement has instilled in local practitioners an understanding of their responsibility for maintaining environmental sustainability that leads to betterment of everyone's well-being. The minimal incidence of peat fires in the area is a product of this shared understanding amongst all local stakeholders. A tangible action plan to address the pressing need to improve sustainability in peatland utilisation could extend the implementation of integrated water management and stakeholder interdependence into other peatland regions.

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AUTHOR CONTRIBUTIONS

ANR and IZQ helped to acquire data. NIF curated the data and developed the methodology for their analysis. NIF and ANR prepared the original draft of the manuscript.

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Author for correspondence: Nurul Ihsan Fawzi, Department of Research and Knowledge Management, Tay Juhana Foundation, Jln. Rawa Bebek Utara No. 26, Penjaringan, North Jakarta, Indonesia 14440.
Tel. +6221-6603926; Email: ihsan@tayjuhanafoundation.org