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Expansion of traditional land-use and deforestation: a case study of an adat forest in the Kandilo Subwatershed, East Kalimantan, Indonesia

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Abstract Deforestation issues are more problematic when indigenous (adat) communities, living within a forest, have lived there for many generations. These adat communities, who employ traditional land-use, are frequently accused of encroaching on the forest. To understand existing and future trends in the spatial patterns of the expansion of traditional land-use and deforestation, we conducted a case study in the Kandilo Subwatershed using mixed methods with image interpretation, spatial modelling and sociocultural surveys to examine the interrelationships between physical conditions, community characteristics and traditional land-use expansion. We investigated community characteristics through household interviews, communication with key informants, and discussions with focus groups. By using an area production model, we were able to analyze the effect of improved farming systems, policy intervention and law enforcement on traditional land-use expansion and deforestation. Based on our examination of a 20-year period of traditional land-use activities in adat forests, the evidence indicated that the steeper the slope of the land and the farther the distance from the village, the lower the rate of deforestation. Our study found that customary law, regulating traditional land-use, played an important role in controlling deforestation and land degradation. We conclude that the integration of land allocation, improved farming practices and enforcement of customary law are effective measures to improve traditional land productivity while avoiding deforestation and land degradation.

Keywords Adat people · Agriculture expansion · Area production model (APM) · Customary law · Deforestation · Traditional land-use

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Introduction

Deforestation is defined as the conversion process of forested land to nonforested land (Blaser 2010; Boucher et al. 2011; Kementerian Kehutanan 2011). The most common causes of deforestation include resource privatization, fiscal incentives for land conversion, tenure policies, urbanization, resettlement development, and in tropical areas, the demand for agricultural land is the main driver (Adams et al. 2013; Akinyemi 2013; Barbier 2004; Boafo 2013; Chi et al. 2013; Foley et al. 2005; Palm et al. 2010; Shearman et al. 2009). According to the FAO (2011), during the period 2000–2010, the annual world rate of forest conversion to agricultural land was approximately 13

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million hectares. For the period 1990–2005, Indonesia was responsible for approximately 23% (1.9 million ha/year) of deforestation worldwide (the highest deforestation rate in the world), and slowed to 0.68 million ha/year between 2005 and 2010 (FAO 2011).

Recent evidence shows that in areas with a high rate of deforestation, commercial farmers are the main agents of deforestation (Adams et al. 2013; Lininger 2011; Mertz 2009; Rudel et al. 2009; Seidenberg et al. 2003). In areas with low deforestation rates, however, small farmers and subsistence shifting cultivation are seen as the major contributors (Damnyag et al. 2013; Geist and Lambin 2002; Lininger 2011; Rudel et al. 2010; Shearman et al. 2009). The potential pressure of small farms on forests is high due to the millions of people who rely on agriculture for their livelihoods, dwelling in or near forest areas. In Indonesia, approximately 25,800 villages (36.7% of all villages in Indonesia) are inside or adjacent to forest areas. Of these, 98% rely on agriculture for their livelihoods (Badan Planologi Kehutanan 2007; Direktorat Jenderal Planologi Kehutanan 2009).

These issues are more problematic when indigenous people have lived inside the forest for many generations. In Indonesia, adat or customary land rights and customary systems of tenure have become a critical element of contention (Heryani and Grant 2004; Yasmi et al. 2010). Following the introduction of Forestry Law No. 41/1999, concerning the change in status from adat forest to state forest, adat communities living in these forests, who have done so for generations, have been accused of encroaching (Hartanto et al. 2008). In many parts of Indonesia, adat communities have been blamed for deforestation and forest destruction (Cahyadi 2014; IWGIA 2011; Wijaya 2014).

Traditionally, adat land-use is a system of shifting cultivation that incorporates long fallow periods based on indigenous knowledge and bound by customary laws. Based on their research, scientists believe that indigenous knowledge is a valuable source for maintaining a balance between natural resource conservation and farming activities (Chun 2014; Mulyoutami et al. 2009; Wangpakapattanawong et al. 2010). In this paper, we will test the hypothesis that managed forest based on customary law and indigenous wisdom will report lower rate of deforestation.

Previous studies from many countries show how improved productivity and policy interventions concerning land rights security have positive impacts on food security and deterring deforestation (Angelsen and Kaimowitz, 2001; Araujo et al. 2010; Branca et al. 2011; Chi et al. 2013; Epule et al. 2014; Fearnside 2001; Tachibana et al. 2001; Tomich et al. 2001). However, there are still knowledge gaps, especially in the relationships between and among the biophysical, economic development,

sociocultural aspects, and effective policy responses (Carr 2008; Chomitz et al. 2007; Damnyag et al. 2013; Mattsson et al. 2012; Pasgaard 2013; Pouliot et al. 2012). Moreover, most studies of deforestation drivers have been based on macrolevel regional or national data, thus presenting difficulties in addressing the complexity of local situations (Bottazzi and Dao 2013).

The aim of this study was to generate an understanding of spatial patterns of existing and future trends in traditional land-use expansion and deforestation. We used image interpretation, spatial modelling and sociocultural surveys to examine interrelationships between and among the physical conditions, community characteristics and traditional land-use expansion. In this paper, traditional land-use refers to shifting agricultural systems with very low or no external inputs and low outputs (Gonzales Bernaldez 1991; Ochoa-Gaona 2001; Plieninger et al. 2006; Susana and Ochoa-Gaona 2011). Using an area production model (APM), we simulated the effect of improved traditional farming systems, policy intervention and law enforcement on traditional land-use expansion and deforestation.

Materials and methods

Research area

Kandilo Subwatershed (Fig. 1) is located in the Paser District in southeastern East Kalimantan Province, Indonesia, on the island of Borneo. The area covers 206,460 ha distributed over 17 villages of two subdistricts (Muara Komam and Batu Sopang). Its main river, the Kandilo (181 km), flows from the Mount Lumut Protection Forest (1210 m a.s.l.) to the downstream flood plain in Tanah Grogot, the capital city of Paser District. The Kandilo River is the main water source for the lowland areas of Paser District. Approximately 96 million m^3/year of irrigation and domestic water, valued at US $ 7.8 million per year, is provided by Mount Lumut Protection Forest (Tropenbos International Indonesia 2006).

Based on the analysis of the Designation of Provincial Forest Area and Inland Water, Coastal and Marine Ecosystems Map (Ministry of Forestry Decree No. 79/Kpts-II/2001), 22% of the Kandilo Subwatershed (46,250 ha) is a nonforest area (Area Penggunaan Lain–APL) and 78% (160,210 ha) is forest zone: protection forest (Hutan Lindung–HL), production forest (Hutan Produksi–HP) and limited production forest (Hutan Produksi terbatas–HPT). Based on our analysis of land cover for 2012, forested land covered 160,914 ha. Agricultural land covered 30,090 ha, consisting of subsistence food crops (27,147 ha), oil palm (1444 ha), and rubber
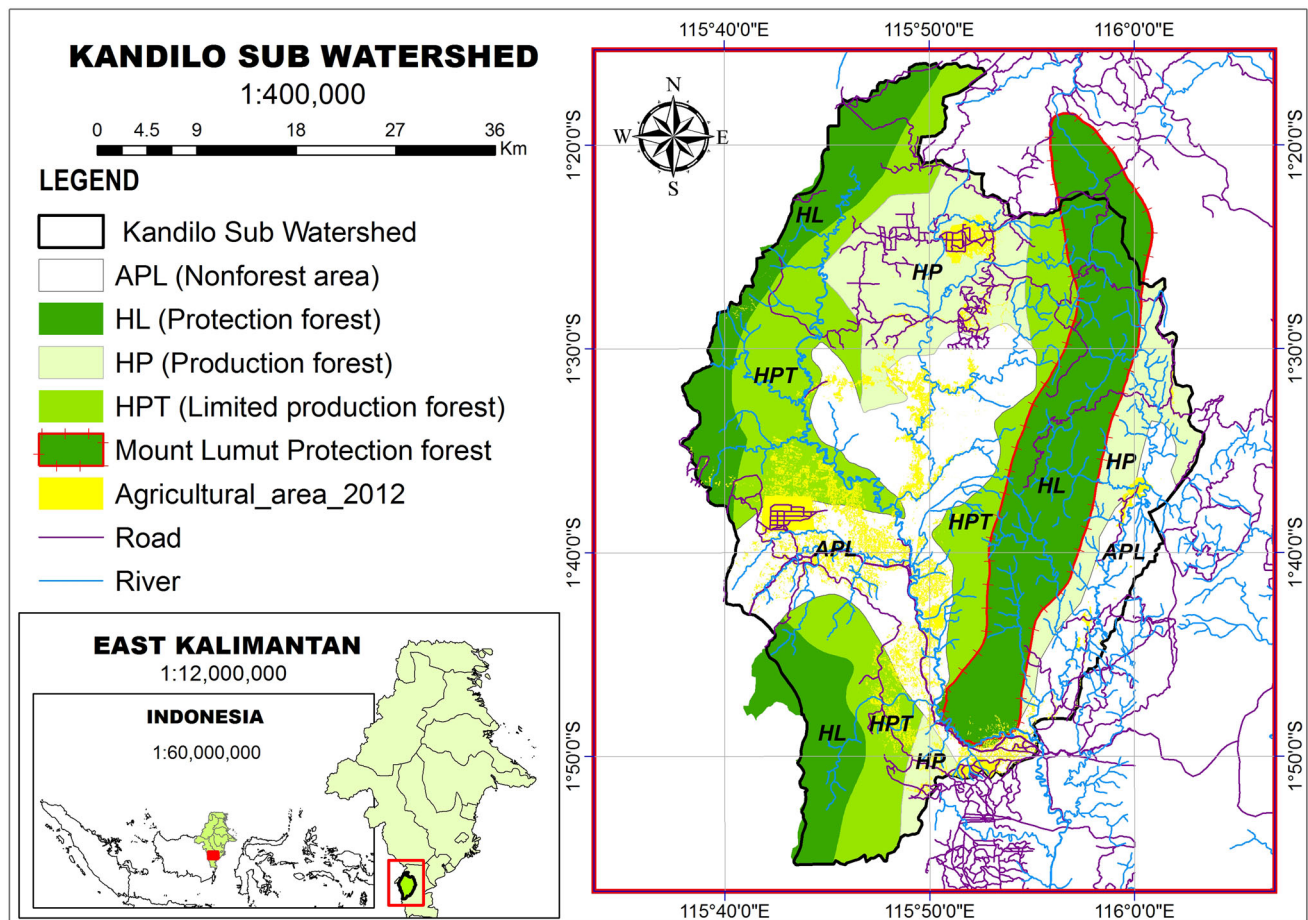
Fig. 1 Map of Kandilo Subwatershed

plantations (1449 ha); 34% of the subsistence food crops, 17% of the oil palm, and 10% of the rubber plantation areas were situated in forest zones.

The people in the Kandilo Subwatershed represent three sociocultural backgrounds: (1) Paser indigenous people (Dayak Paser), (2) Banjar people, immigrants from South Kalimantan, and (3) migrants from outside Kalimantan, primarily from Java and Sulawesi through the central government Transmigration Program.

Subsistence farming with minimum inputs and outputs is the most common agricultural system in the study area. The immigrants originally practiced permanent farming systems of planting food crops (e.g., upland rice, soybeans, maize) and rubber. The adat communities cultivated primarily upland rice in shifting cultivation systems applying very low amounts of fertilizer, herbicides and other agrochemical inputs.

Traditionally, land parcels were 1–3 ha per parcel, constant from year to year. Upland rice was planted for two to three seasons (2–3 years) followed by an average of 10 years fallow. After 3 years, when soil fertility diminished, farmers moved to regenerated secondary forest, their

previous fallowed sites, and cleared them using slash and burn methods.

The upland rice, oil palm, and rubber adat communities planted an annual average production of 0.6, 3.6 and 0.48 tons/ha respectively. This is low when compared to the annual district productivity levels of 2.9, 14, and 1.4 tons/ha in the same period (2010–2011) (BPS Kabupaten Pasir 2011). Based on a standard conversion from unhusked rice to husked rice (milling yield) in Indonesia, which is 62.7% (Suhari 2015), an average number of household members of five people and an average extent of cultivated land about 1 ha per household, rice production in the study area was estimated equal to 107 kg per capita per year. Minimum standard of living for rural people in Indonesia is equivalent to 132 kg of rice per capita per year (Ratnasari 2013), and the optimum standard of living (including sugar, fish, meat, clothes, housing, education) is equivalent to 1 ton of rice per capita per year (KLH 2009).

However, in the last decade, villagers in general in many parts of the world have started to change their farming methods from shifting to permanent cultivation (Hariyadi and Ticktin 2012; Heinimann et al. 2013; Mertz 2009). In

response to better access to urban areas and changing prices, many farmers have started to cultivate permanent rubber or oil palm crops mixed with upland rice. After 3 years, when the rubber/oil palm canopies block the sun and upland rice cannot grow, they start to clear new land for another plantation of mixed crops. However, due to the presence of the rubber and oil palm, the farmers no longer return to a parcel of land after 15 years. After 3 years, they look for new land to cultivate. Without appropriate measures from both external and/or internal institutions, this uncontrolled system will lead to excessive deforestation.

Data preparation

We collected both spatial and nonspatial data. Our spatial data consisted of maps of land-use, designated forest, slope, rivers, roads, settlements, and adat forest. Satellite images with less than 10% cloud cover from 6 years (1992, 1996, 2000, 2006, 2009 and 2012) were analyzed using image processing software Ermapper 7.1 (Earth Resource Mapping, USA) and ArcGIS 10.1 (Esri, Redlands, CA, USA) to produce land-use and land cover maps based on the APM land-use classification.

Spatial APM differentiates land-use into three land categories: agricultural, forest, and other (Forest Science Division 2001). Each category is then divided into subcategories (agricultural land: subsistence food, local market and industrial crops; forest land: farm, industrial and environmental forests; other land: potential agricultural, potential forest and unproductive land).

For an accurate classification, several ground checks were conducted from 2009 to 2013. In this study, shifting agricultural systems with very low or no inputs were categorized as subsistence crops. Oil palm and rubber plantations were classified as market crops. Settlements, rivers, and lakes were classified as unproductive land.

Nonspatial data consisted of district and village level data. District level data covered population growth, gross domestic product/capita, agricultural and commodity productivity derived from a series of statistical data of Paser Regency from 2000 to 2012. Data at the village level was collected using surveys through informal dialogues with individuals, household interviews using questionnaires, interviews with key informants, focus group discussions, farmland/field visits and analysis of secondary data from annual unpublished village reports that provide basic data and information on the village from 2000 to 2012. For a better understanding of how sociocultural variables influence land-use change and deforestation, we observed three communities living in forest areas representing different cultures: (1) Muluy (adat community), (2) Rantau Layung and Rantau Buta (mixed adat and migrant community), and (3) Swan Slutung (migrant community). The three communities were visited periodically from 2009 to 2013 to observing daily activities, norms and beliefs through deep interviews, focus group discussions (FGDs) and informal meetings. Our hypothesis was that different cultures will have different opinions and preferences and will behave differently, which will affect deforestation differently.

To acquire more detailed information on specific issues, we conducted personal interviews with key respondents such as adat heads and elders.

Achieving accurate sociocultural data based on direct interviews was challenging since some respondents refrained from openly discussing their "considered-illegal" forest-based activities. To minimize misinformation and to anticipate some inconsistent responses, especially with regard to farming systems, forest-based income generation, implementation of customary law, and the extent and location of traditional land-use, we conducted a series of periodic field visits from 2009 to 2013.

Analysis of existing traditional land-use expansion

By overlaying a series of land-use and land cover maps, we were able to calculate and locate traditional land-use expansion and forest conversion. In this study, upland rice, rubber and oil palm plantations cultivated by adat communities were classified as traditional land-use. The main output of this analysis process was a map of existing (observed) traditional land-use expansion from 1992 to 2012. By overlaying this map with maps of slope class, roads, rivers and villages, we were able to calculate the extent and density of traditional land-use expansion based on slope class, and distance from road, river and/or village. Further, the observed land-use change was used to validate the APM by comparing the observed to the predicted expansion (APM output) in the same period pixel by pixel.

Modelling traditional land-use expansion and forest conversion

Modelling is a simplification of reality to enhance understanding of the systems scientifically and to project future outcomes (Jakeman et al. 2009; Wätzold et al. 2006). In this study, we used APM, a simulation model of land-use changes (Hussin et al. 1995; Sandewall and Nilsson 2001; Xiao et al. 2001), to project traditional land-use expansion in the future as a response to exogenous variable changes: human population pressure, economic development, improved agricultural productivity and policy intervention. The APM was developed in 1982 by the FAO to numerically simulate land-use changes. In 1991, APM was connected to the Integrated Land and Water Information System (ILWIS), a raster-based geographic information

system (GIS) by de Gier and Hussin to improve the spatial capacity of the model in predicting which areas would be the new land-use (Forest Science Division 2001; Hussin et al. 1995). On the basis of several uses at different sites, APM is considered an appropriate tool to model deforestation and forest degradation (Ato 1996; Hamzah 2012; Hussin et al. 1995; Sandewall and Nilsson 2001; Sawathvong 2004; Yanuariadi 1999).

The area production model runs on three assumptions: (1) the demand for subsistence crops depends only on population growth, (2) the demand for market crops and industrial/export crops is influenced by economic factors (GDP), and (3) production depends on productivity and the extent of the cultivated area (Forest Science Division 2001). These assumptions are in line with findings mentioned by several scholars. The correlation between agricultural land demand and deforestation is significantly affected by population pressure (Akinyemi 2013; Chi et al. 2013; Entwisle et al. 2008; Mertens et al. 2000; Pfeffer et al. 2005), accessibility (Entwisle et al. 2008; Lininger 2011; May-Tobin 2011; Purnamasari 2010), growth of income per capita, rising costs, price of agricultural products, and other macroeconomic factors (Barbier, 2004; Gaveau et al. 2009; Mertens et al. 2000).

There are two steps to predict future deforestation. The first step is to calculate agricultural demand using numerical APM, and the second step is to predict spatial deforestation using spatial APM.

The demand for new land for agriculture was calculated using the following formula (Forest Science Division 2001):

$$N_{\mathbf{Ag}} = [C_{\mathbf{S}}(iPop/iAg_{\mathbf{S}})^n] + [C_{\mathbf{M}}(iGDP/iAg_{\mathbf{M}})^n] + [C_{\mathbf{I}}(iGDP/iAg_{\mathbf{In}})^n],$$

where $N_{\mathbf{Ag}}$ is the projected area of agricultural land, n is the number of simulation years, N is the new area needed, C is the current area, iPop is the growth factor of population, Pop is the population, iAg_s is the growth factor of subsistence crop productivity, $iAg_{\mathbf{M}}$ is the growth factor of market crop productivity, $iAg_{\mathbf{In}}$ is the growth factor of industrial crop productivity, $iGDP$ is the growth factor of gross domestic product.

The total demand for agricultural lands resulting from the numerical APM will be written in the ILWIS script as an input for a spatial APM to predict spatial/locational distribution of new agricultural land. When demand is positive, there will be land-use conversion from nonagricultural land (forest and shrub). Spatial APM assumes that land-use conversion starts from the periphery of existing agricultural land and converted to forestland or other land according to a friction value and the distance to an agricultural area. In general, when demand for agricultural land increases, land transfer from another class is generated in a

certain priority order (Hussin et al. 1995; Sawathvong 2004; Yanuariadi 1999). The general framework of the spatial APM is presented in Fig. 2.

The growth factors for this simulation are presented in Table 1. Growth of population, GDP and agricultural productivity in the Paser District were analyzed from statistical data for the Paser District. Productivity growth at the village level was derived from our village surveys.

Analysis of the factor map

We found four factors that influenced deforestation susceptibility: distance to village, distance to roads, distance to rivers, and slope. The APM assumes a positive relationship between the distance from villages to forests and land conversion; moreover, the steeper the slope, the slower the land conversion. Each factor was analyzed separately to identify its significance in affecting land-use conversion. Then each factor was crossed with the observed land-use conversion in order to calculate the density value for each factor. Density values were calculated as a percentage of the converted area for each factor.

Model validation

Validation was conducted by overlaying predicted land-use conversion maps with observed land-use conversion maps for the same periods. Due to data availability (population, GDP, and agriculture production), the APM validation was run for the period 2000–2012. For spatial validation, we compared the predicted and observed maps pixel by pixel. The number of overlapping pixels of the two maps represents the accuracy of APM in projecting locations of land-use conversion.

Scenario development and model simulation

Scenario development refers to the creative process to define the pathways of exogenous variables for particular systems to deal with future complexities and uncertainties (Verburg et al. 2006; Wollenberg et al. 2000).

We conducted model simulations to project the impacts of exogenous variables (population pressure, economic development, improved farming practices and policy intervention) on the future state of traditional land use and deforestation.

The simulation period was 25 years (2012–2037) applying the following sets of assumptions: (1) Population growth was projected to simulate population pressure. (2) GDP growth was projected to simulate economic development. (3) Increased agriculture productivity was projected to simulate improved farming practices. (4) The order of priority of land-use transfer was changed to simulate policy interventions and law enforcement.

Fig. 2 Framework of Spatial APM
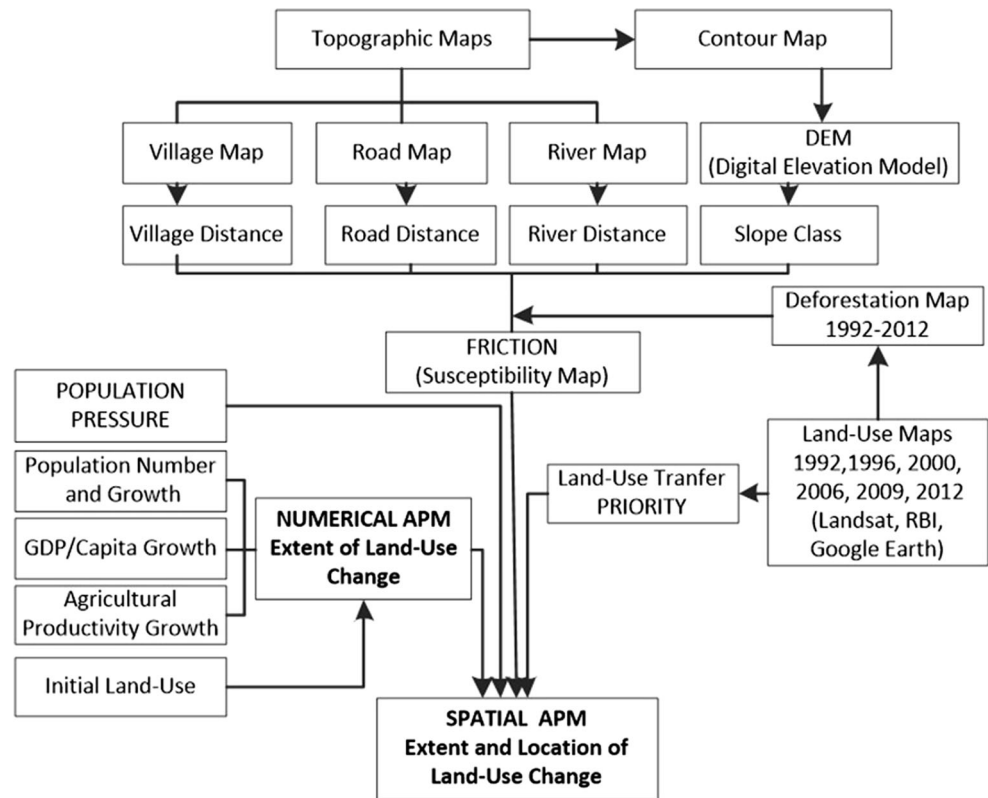
Table 1 Growth factors for the period 2000–2012

Year	Population growth		GDP growth	Growth of crop productivity/increase in crop productivity					
				Subsistence crops (upland rice)		Market crops (oil palm)		Market crops (rubber)	
	District	Villages	District	District	Villages	District	Villages	District	Villages
2000–2006	1.027[a]	1.020	1.079	1.039	0.78[b]	1.072	1.001	1.003	0.985
2006–2012	1.053	1.029	1.092	1.014	0.76	1.024	1.018	1.001	0.985

[a] 1.027 means 2.7% growth

[b] 0.78 means 22% decline

The challenge in developing scenarios, however, was to produce realistic values for input variables. In this study, input variables at the village level were projected based on our survey findings. Concurrently, regional level variables (population and GDP growth) were synchronized with projections by the National and Regional Planning Agency (BAPPEDA Kalimantan Timur 2008; BAPPENAS 2005).

Based on actual data and information generated from our village surveys, we developed three scenarios: an unexpected, an expected, and a visionary outcome. The first considers unexpected situations to reflect the negative that the existing situation could deteriorate. The second scenario estimates the most likely outcomes driven by existing trends of exogenous factors, a business-as-usual scenario. The third scenario reflects our vision about future

livelihood security, land tenure certainty, and synergizing adat law (*hukum adat*) and formal law.

Scenario 1: unexpected outcomes

Under the unexpected outcome scenario, the population will increase constantly at the previous growth rate until the second period and then ascend. In the existing situation, there is illegal immigration of people looking for land as a result of new road developments passing through the forest area. Conversely, the young people from forest villages move to peri-urban and urban areas in search of off-farm employment and will leave their land unmanaged. We assume that this phenomenon will persist until the second period. In this scenario, productivity of food crops is

constant as a result of limited labor, good quality seed and fertilizer. Meanwhile, industrial crop productivity (oil palm and rubber plantations) will start to increase slowly in the fourth period. In terms of economic development, the GDP per capita will increase following the trend in agricultural sectors at the provincial level, but will slow down in the third period. We assume that there is no significant new policy concerning forest management throughout the duration of the scenarios. In the existing situation, the regional forestry office conducts insufficient forest monitoring and law enforcement due to limited authority and budget. Local institutions, wisdom, norms and values of the adat communities are slowly being eroded by consumerism and short-term economic considerations. For the APM in this situation, we have given the same priority to all land-use types in terms of land-use conversion. At the same time, agricultural land will expand taking over all other types of land. Slope and accessibility are the only factors determining which area will be converted first. The growth factors for Scenario 1 are presented in Table 2.

Scenario 2: expected outcomes, business as usual

Under the scenario of business as usual, the population growth is constant in forest villages and increase in villages outside forests after the second period following the growth trend at the provincial level (BAPPENAS 2005). Better prospects of on-farm income trigger people from other area to migrate into slightly sloped areas in the forest periphery. Productivity of food and market crops in forest villages is constant until 2025 but will then increase. Meanwhile, in the villages outside forests, we assume that the Ministry of Agriculture Regional Office will introduce new technologies and deliver better production inputs to farmers. In terms of economic development, the GDP per capita will increase following the trend in agricultural sectors at the provincial level (BAPPEDA Kalimantan Timur 2008). In this scenario, we assume that the Ministry of Forestry Regional Offices will start to enforce the law. But due to limited authority and resources, these efforts will only focus on protection forests close to roads and villages. In our spatial APM, the scenario of such policy interventions will be executed by setting a certain priority order of land-

use conversion. The conversion of protection forest will not start until all land in the higher priority classes has been converted. The growth factors for Scenario 2 are presented in Table 3.

Scenario 3: visionary outcome

Under this scenario, population growth in all villages will increase after the second period following population growth rates at the district level. The GDP per capita will increase following the trend in the agricultural sector, especially for oil palm and rubber. We assume that the central government will enact new regulations concerning forest boundaries. Disturbed production forests in areas with slopes under 40% will be excluded from state forests and handed over to indigenous communities (Fig. 3). In this policy scheme, adat communities will have legal tenure to manage their land.

Under Scenario 3, according to the proposed regulations, several villages will be situated in nonforest areas. As a result, villagers who formerly utilized forestland using subsistence farming methods, will improve their farming systems due to tenure security by applying better technology and production inputs to increase productivity. The regional offices (Ministry of Agriculture) will introduce better farming techniques and deliver better production inputs (fertilizer, seedlings) to farmers living outside forest areas.

Under Scenario 3, formal laws will be enforced consistently in line with adat law implementation. Protection forest will only be utilized by indigenous people in limited areas, under strict monitoring and with no disturbance to the environment. This includes restrictions on the use of the riparian buffer zone 100 m to the left and right of the riverbank and forestland with slopes above 40%.
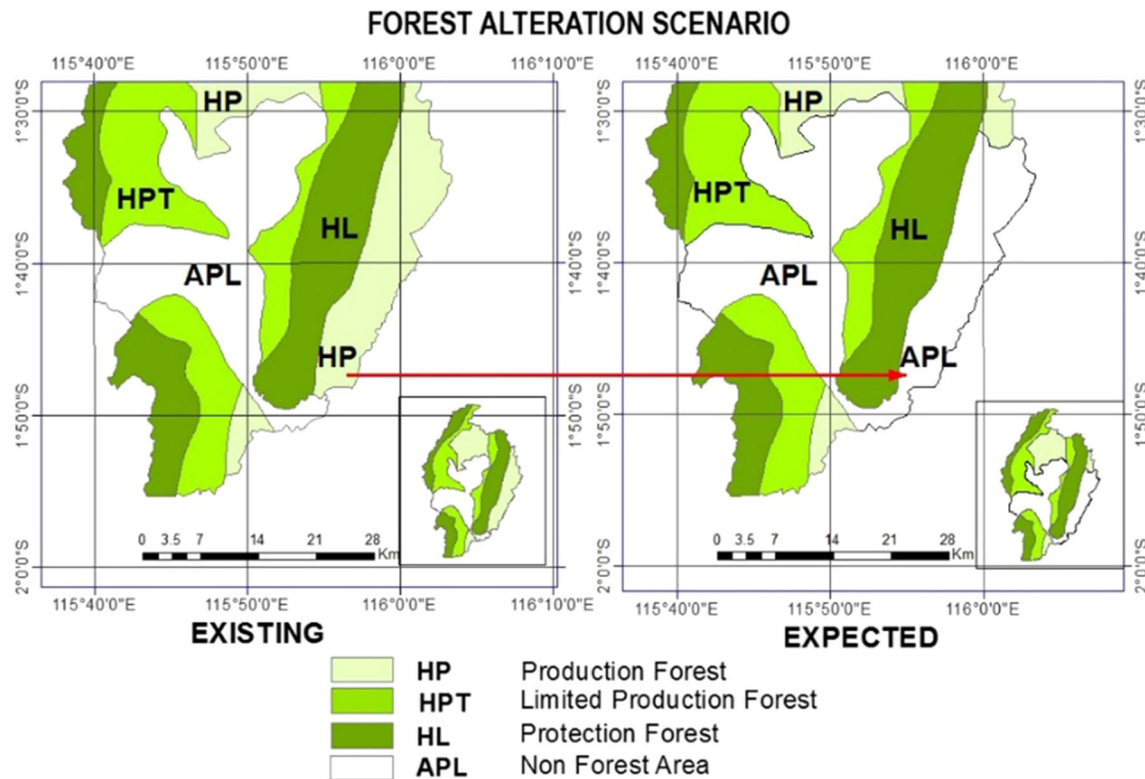
In this scenario, we assume that customary rights and adat institutions will consistently regulate the daily activities of the adat people. In restricted areas, based on customary law, farming activities will not be allowed. In the APM, implementation of policy intervention and revitalization of adat rule are simulated by reclassifying land-use codes and resetting the order of priority from low to high: nonforest areas, production forest, limited production forest

Period	Year	Population growth	GDP growth	Crops productivity growth		
				Upland rice	Oil palm	rubber
1	2012–2017	1.0300	1.092	1.0000	1.0010	1.0010
2	2018–2022	1.0300	1.092	1.0000	1.0010	1.0010
3	2023–2027	1.0600	1.092	1.0000	1.0100	1.0100
4	2028–2032	1.0800	1.092	1.0000	1.0100	1.0100
5	2033–2037	1.0800	1.092	1.0000	1.0160	1.0160

Table 2 Growth factors in Scenario 1

Table 3 Growth factors in Scenario 2

Period	Year	Population growth	GDP growth	Crops productivity growth		
				Upland rice	Oil palm	Rubber
1	2012–2017	1.0200	1.0920	1.0000	1.0010	1.0010
2	2018–2022	1.0200	1.0920	1.0000	1.0100	1.0100
3	2023–2027	1.0500	1.0920	1.0000	1.0200	1.0200
4	2028–2032	1.0600	1.0920	1.0000	1.0400	1.0400
5	2033–2037	1.0600	1.0920	1.0000	1.0600	1.0400

FOREST ALTERATION SCENARIO

	HP	Production Forest
	HPT	Limited Production Forest
	HL	Protection Forest
	APL	Non Forest Area

Fig. 3 Forest zone alteration in Scenario 3

and protection forest. In this order, deforestation in protection forests will not start before production forests are deforested/converted to another use. The riparian buffer zone and sloping areas above 40% were classified as unproductive land and were given a value of 0 (zero) in the priority order. By having 0 value, the areas will not be converted to agriculture land. The growth factors for Scenario 3 are presented in Table 4.

Results

Traditional land-use expansion for the period 1992–2012

The land-use and cover changes from 1992 to 2012 are illustrated in Figs. 4 and 5. Figure 4 shows the spatial distribution of traditional land-use expansion, and Fig. 5 shows trends in each land-use change. From 1992 to 2012, forest cover decreased from 185,957 to 175,515 ha at a rate of 0.29% per year. Shrub increased from 12,605 to 14,664 ha at a rate of 0.74% per year and traditional farming increased from 6412 to 30,090 ha at a rate of 8.1% per year.

In contrast to the trend in agriculture, which consistently increases, the trend in both forest and shrub cover shows an alternating increase and decrease every fourth and sixth year (Fig. 5). This finding reflects a sequence process of forest recovery from abandoned agricultural land returning to shrub and from shrub to secondary forest as a characteristic of a traditional shifting agricultural system. In the ninth and tenth years after being abandoned and covered by secondary forest, the land is again reopened. These results are consistent with the results of our social surveys and

Table 4 Growth factors in Scenario 3

Period	Year	Population growth	GDP growth	Crops productivity growth		
				Upland rice	Oil palm	Rubber
1	2012–2017	1.030	1.100	1.020	1.020	1.000
2	2018–2022	1.025	1.110	1.020	1.040	1.040
3	2023–2027	1.020	1.130	1.050	1.040	1.040
4	2028–2032	1.060	1.140	1.050	1.060	1.080
5	2033–2037	1.060	1.150	1.050	1.060	1.080

interviews with farmers in which the average fallow period is 10 years.

The resulting factor map analysis shows that traditional land-use expansion occurs mainly on slightly sloped areas. In the period 2000–2012, the majority (80%) of land-use conversion was located on slopes under 10%, 17% on slopes of 10–25% and only 3% on slopes above 25%.

Traditional land-use expansion generally starts from villages and the periphery of agricultural areas. The agricultural lands were located 0–8 km from the villages. Fifty-five percent were concentrated between 1 and 3 km, and 25% were located between 3 and 5 km (Fig. 6). However, few locations were situated far from the village and the agricultural periphery.

With respect to distance to the main road, 87% of new traditional land-use was located less than 1 km, and 12% occurred between 1 and 2 km. There was no agricultural activity farther than 4 km from the river; 67% was located within a radius of less than 1 km.

In terms of correlation between deforestation rate and cultural background, Table 5 shows the location and distribution of deforestation and deforestation per capita per year in three sampled communities with different cultural backgrounds.

In Table 5, deforestation per capita in Muluy is lower than in the other two villages. The Muluy people (indigenous Dayak Paser) are more reluctant to adopt new farming systems, which require more labor, time, and production inputs than traditional systems do. In general, Muluy people grow annual upland rice on a single parcel for 3 years and then abandon the land for 10–15 years. Deforestation is lower in Muluy than in Rantau Layung and Rantau Buta, due to the strict adat regulations governing their farming activities and gathering of forest products. Meanwhile, people from Java and Sulawesi living in Swan Slutung have more experience in intensified farming than do the indigenous and local migrants from Kalimantan. On the other hand, Rantau Buta and Rantau Layung, consisting of the Banjar people and indigenous Dayak Paser, have started planting permanent crops such as rubber and oil palm. The Banjar people have more financial capital, knowledge and experience. These results support our hypothesis that different cultures will have different strategies and behaviors. Yet, the migrant and indigenous communities do exchange knowledge about farming systems.
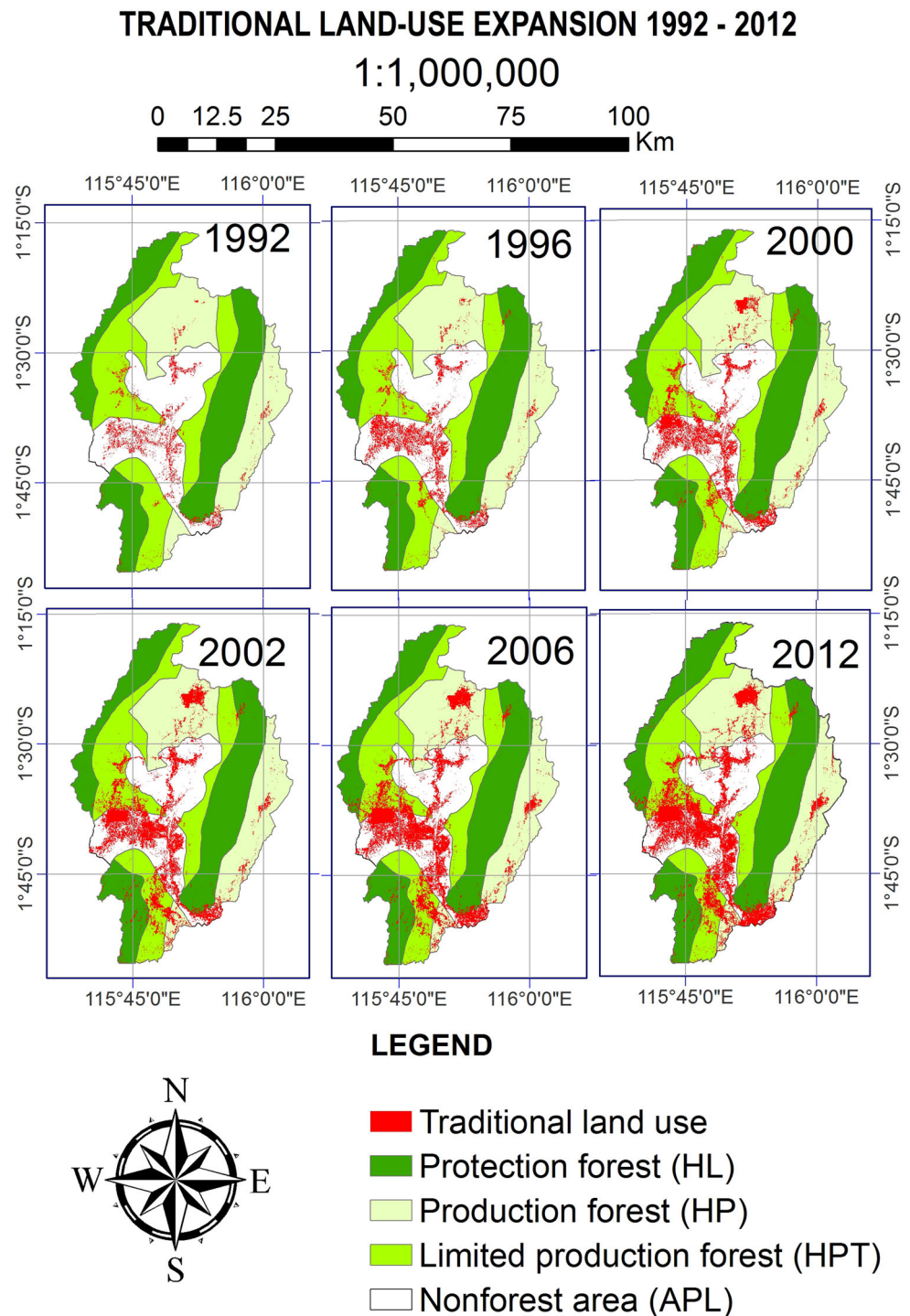
Figure 7 shows a map of forest designation and traditional-land use areas of the adat forests of Muluy and Rantau Layung. The adat communities divide adat forests into several functions using their own language: Strat (area designated for houses and other facilities), Alas adat and Alas Tuo (restricted forest areas forbidden for swidden activities), Alas Nareng and Alas Burok (reserved forest areas for agricultural activities), Awa Pengeramu (communal forest for fruit trees and wood), Awa Ngumo and Awa Penyekulo (areas designated for agricultural activities to produce staple foods). In Fig. 7, we can see that in general, adat systems designate land in line with the Ministry of Forestry.

From interpretations of the adat map (Fig. 7) supported by series of field visits, we conclude that in general, adat people have a sustainable system for utilizing their forests. In Rantau Layung Forest, awa ngumo, awa penyekulo, and awa pengeramu forests are situated in gentle-sloped production forests. Alas adat and alas nareng are situated in protection forests and steep-sloped production forests. Cultivated areas from 1992 to 2012 were consistently located in Awa Ngumo and Awa Penyekulo, areas designated for agriculture (Fig. 7). Likewise, in Muluy Forest in the middle of the Mount Lumut Protection Forest, people have been conducting subsistence shifting cultivation for years, but only in limited areas close to roads and rivers. However, since 2010, with the boom in oil palm cultivation in the Paser District, a few people have started to expand their agriculture land by opening alas adat/alas tuo forest close to the new main road.

Projected traditional land-use expansion and deforestation

To determine the level of confidence in our APM for representing measured experimental data, we validated our numerical and spatial APM. Numerical APM accuracy was determined by comparing the extent of the predicted with the observed traditional land-use expansion for the period 2000 to 2012.

Fig. 4 Spatial distribution of traditional land-use expansion from 1992 to 2012

TRADITIONAL LAND-USE EXPANSION 1992 - 2012
1:1,000,000

LEGEND

- ■ Traditional land use
- ■ Protection forest (HL)
- ■ Production forest (HP)
- ■ Limited production forest (HPT)
- □ Nonforest area (APL)

Using numerical APM, the agricultural area in 2012 covered 29,169 ha, 4% of which was under the observed agricultural area; 96% accuracy indicates that the growth of the population, GDP and crop productivity are reliable variables for predicting the trend in agricultural development. Figure 8 depicts the spatial distribution of the predictive validity of land-use conversion from non-agricultural area into agricultural area for the period 2000–2012. Using the spatial APM and pixel-by-pixel analysis, we found that 67% of the observed expansion of traditional land-use into non-agricultural area was accurately predicted. The other 33% could not be predicted (unpredicted). The result of the validation assessment of the APM is presented in Table 6.
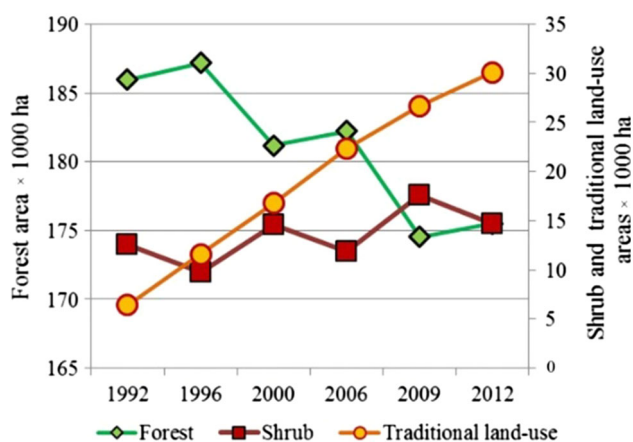
Fig. 5 Trends in land cover and land-use change from 1992 to 2012

Traditional land-use projection

We identified critical elements in the development of our scenarios. Villagers in general were trapped in subsistence farming systems, with low inputs and outputs. They were unable to afford the cost of better farming inputs. Considered as encroachers, there was no farming input subsidy from the regional government such as seed, fertilizer and technology for people living inside the forest. Relying only on the natural fertility of the land, production of upland rice decreased by almost half for the second consecutive year. As a consequence, when productivity decreased in the second and

third year, farmers sought new areas to cultivate. In general, their main concerns in deciding which particular locations to cultivate were distance from village, slope and accessibility. Relating regional government absenteeism to low productivity underlies the assumption of crop productivity in scenarios 1 and 2. Based on interviews, planting upland rice has been part of the local culture. Farmers will always plant upland rice using shifting cultivation although they have enough money to buy rice from the local market as found in previous studies in other areas (Hariyadi and Ticktin 2012). Shifting cultivation is not only an activity for producing food, but also part of the culture for maintaining a relationship among and between the community and nature.

The results of our 25-year projection are presented in Tables 7, 8 and 9 and Fig. 9. For the BAU scenario, traditional land-use will expand by 201% in 25 years at a rate of 1.4% per year. Thirty six percent of the new land will be situated in forest areas, mainly in permanent production and limited production forest.

In the sustainable scenario, due to improved farming systems, forestry law enforcement synergized with the revitalization of adat law and enactment of the forest alteration policy, the model predicts that traditional land-use in 2037 will have expanded by 53%, with 10% of that new land in forest areas. In this scenario, the 2012 productivity of upland rice, rubber and oil palm will triple.

To map spatial distribution of land-use conversion and to calculate deforestation, we overlaid the spatial output of APM onto the Designation of Provincial Forest Area and Inland
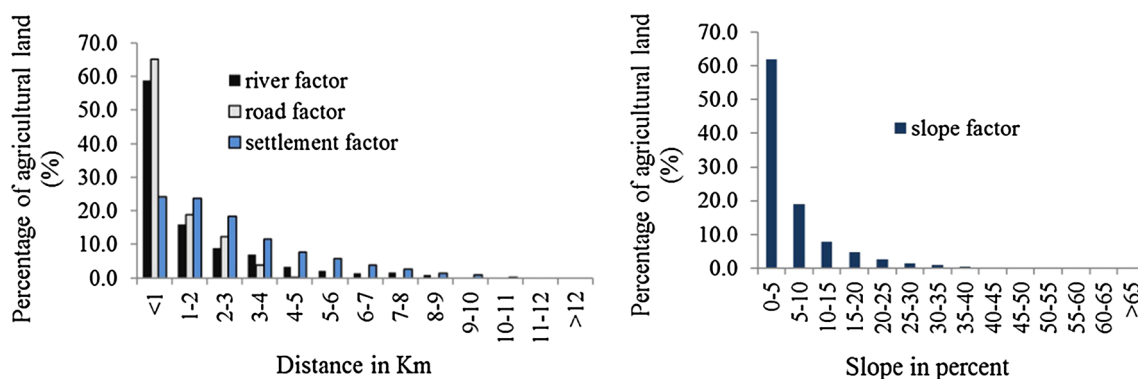

Fig. 6 Distribution of traditional expansion based on slope of land and distance to the river, the road, and the settlement

Table 5 Deforestation per capita/year in three communities with different cultural backgrounds

Communities	20 years deforestation (ha)	Population	Deforestation (ha) per capita/year	Forest designation
Rantau Buta–Rantau Layung	940	343	0.14	Production forest
Swan Slutung	1556	651	0.12	Production forest
Muluy	128	128	0.05	Protection forest
Total	2624	1122	0.12	

Fig. 7 Map of Adat forest of Muluy and Rantau Layung
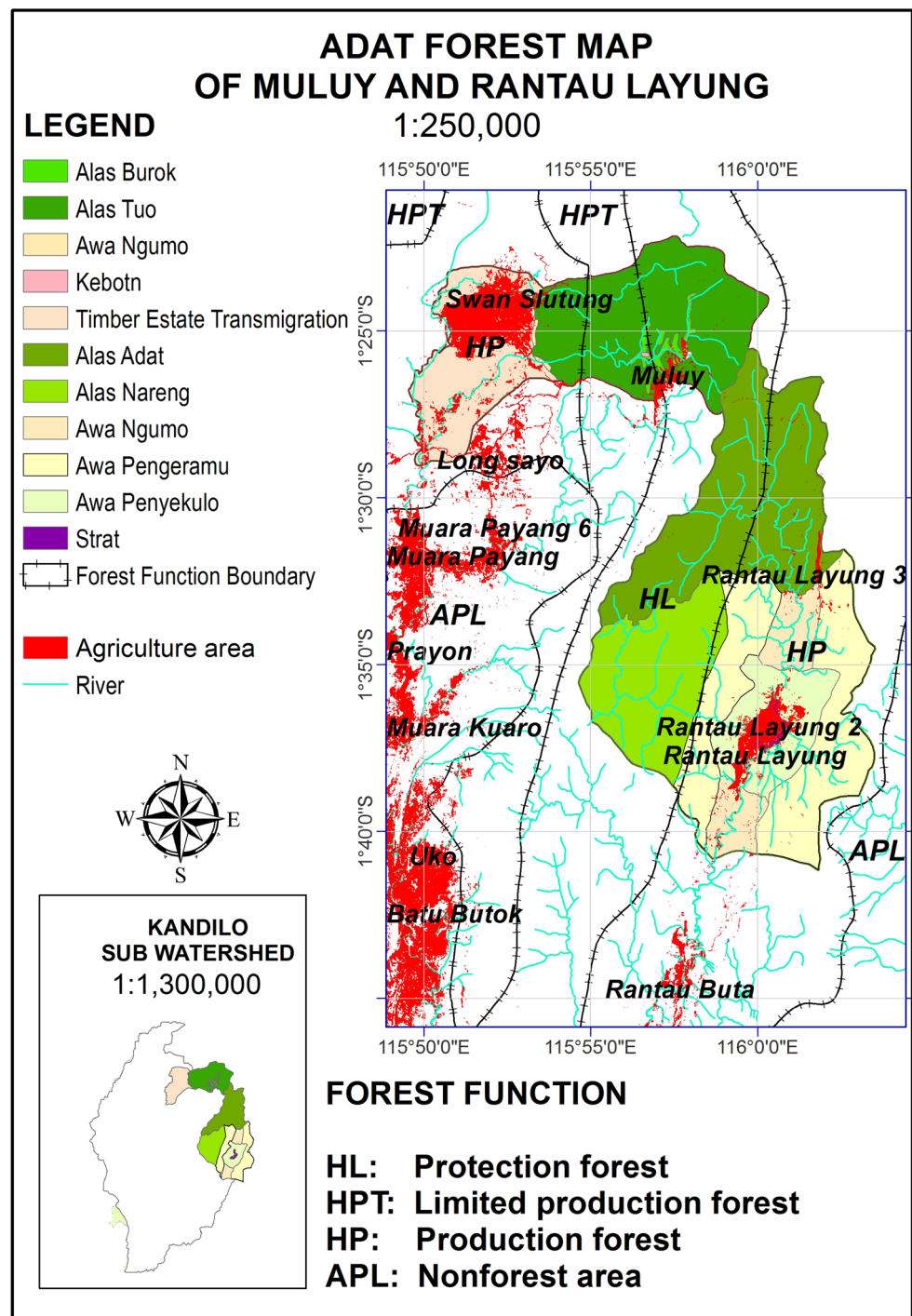
Water, Coastal and Marine Ecosystem of East Kalimantan Province Map. This map divides East Kalimantan Land into 4 designated areas: HPT, HP, HL, and APL. The spatial distribution of future agricultural expansion is presented in Fig. 9.

In Fig. 9, we can see that in scenario 1 (unexpected) and scenario 2 (expected/BAU), traditional land-use expanded to all land-use in almost similar proportion. In contrast, scenario 3 (visionary) directed the majority of the traditional land-use expansion to the nonforest area. The

distribution of traditional land-use based on forest designation of the three scenarios is presented in Table 9.

Discussion

The engagement of adat communities in the sustainable forest management of Indonesia has proven to be reliable. Three scenarios were used to further test the reliability of

Fig. 8 Spatial distribution of the predictions for land-use conversion

VALIDATION MAP
1:300,000
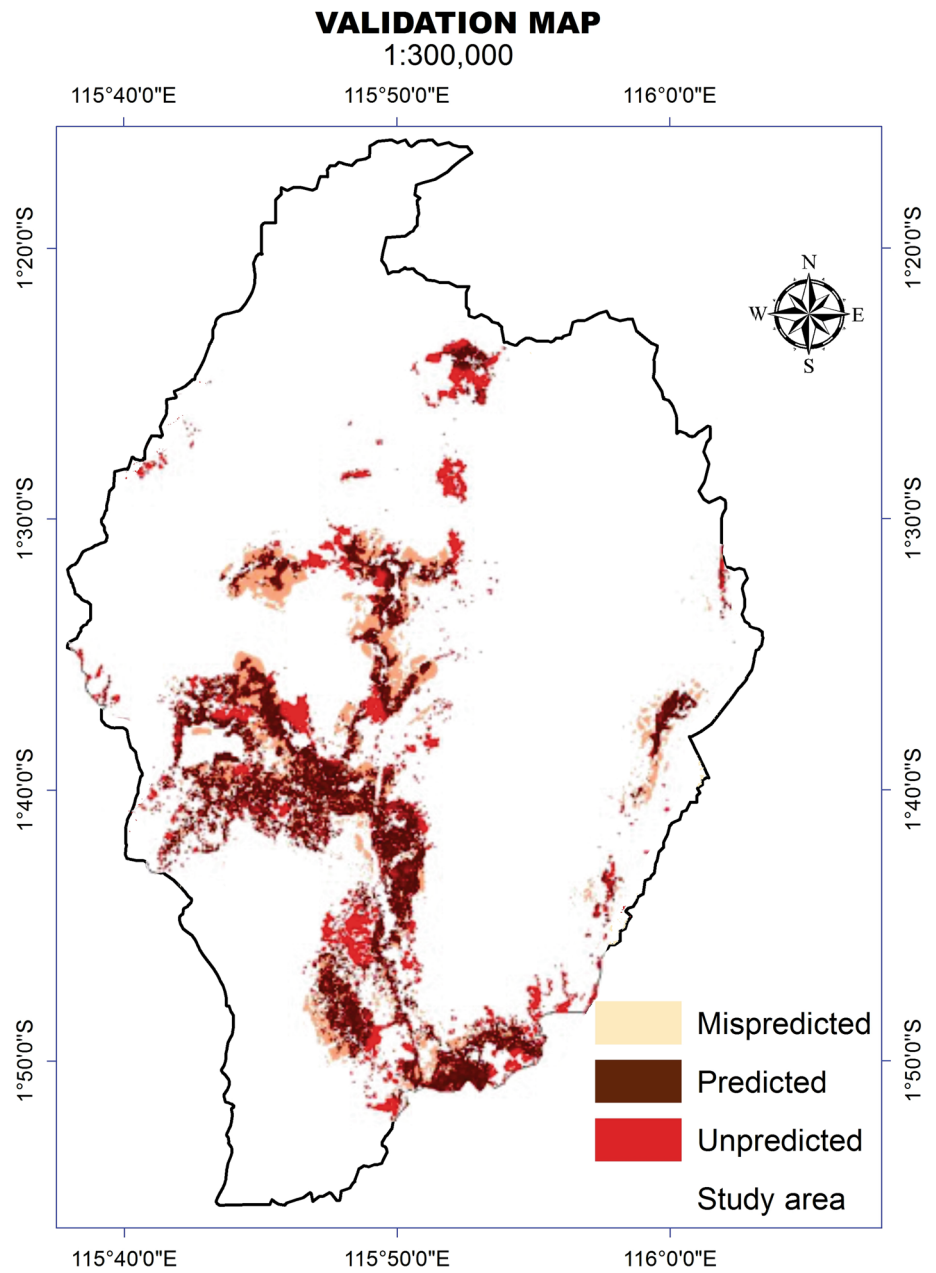
Table 6 Validation assessment of APM

Category	Area (ha)	Validity (%)
Observed agriculture area for 2012 based on map analysis	30,090	
Predicted agriculture area for 2012 using numerical APM	29,169	96
Observed land-use conversion based on map analysis	9170	
Predicted land-use conversion using spatial APM	10,555	
Location accurately predicted	6192	67
Unpredicted	2979	33

Table 7 Agricultural productivity in 2037

Scenarios	Food crops		Oil palm		Rubber	
	Productivity (tons/ha)	Increase (%)	Productivity (tons/ha)	Increase (%)	Productivity (tons/ha)	Increase (%)
Existing	0.6		3.6		0.48	
(1) Unexpected	0.6	0	4.35	21	0.58	21
(2) Expected/BAU	0.6	0	6.84	90	0.85	77
(3) Visionary	1.52	153	10.54	193	1.53	219

Table 8 Agricultural area in 2037

Scenarios	Food crops		Oil palm		Rubber		Total	
	Area (ha)	Increase (%)	Area (ha)	Increase (%)	Area (ha)	Increase (%)	Area (ha)	Increase (%)
Existing	27,147		1444		1449		30,090	
(1) Unexpected	106,241	291	9892	585	10,829	647	126,962	322
(2) Expected/BAU	76,631	182	6349	340	7577	423	90,557	201
(3) Visionary	28,343	4	8950	520	8780	506	46,073	53

Table 9 Projected traditional land-use expansion and deforestation

Forest designation[a]	Existing forest (ha)	Traditional land-use (ha)							
		Baseline		Scenario 1		Scenario 2		Scenario 3	
		2012	Def. (%)	2037	Def. (%)	2037	Def. (%)	2037	Def. (%)
HPT	50,657	6175	−12.2	26,889	−53.1	19,249	−38.0	8306	−16.4
HP	49,549	5764	−11.6	42,963	−86.7	32,605	−65.8	6868	−13.9
HL	60,708	1563	−2.6	20,598	−33.9	7422	−12.2	2059	−3.4
APL	45,546	16,588	−36.4	36,512	−80.2	31,281	−68.7	28,840	−63.3
Forest	160,914	13,502	−8.4	90,450	−56.2	59,276	−36.8	17,233	−10.7
Total	206,460	30,090	−14.6	126,962	−61.5	90,557	−43.9	46,073	−22.3

[a] HPT: limited production forest; HP: production forest, HL: protection forest; APL: nonforest area; Def: deforestation

such engagement. These scenarios (unexpected, expected, and visionary outcomes) emphasize our expectations of future livelihood security, land tenure certainty, and synergizing adat law and formal law.

The spatial analysis shows that traditional land-use expansion increases as slope and distance to villages, roads, and rivers decreases (Fig. 6). This same pattern is common; farmers first clear flat areas, close to water sources or roads and then move to steeper slopes farther from roads (Avoided Deforestation Partners 2009; Kinnaird et al. 2003; Lambin and Meyfroidt 2010; Ochoa-Gaona 2001; Ochoa-Gaona and González-Espinosa 2000).

However, our data from the factor map analysis support statements that land-use change and forest transition patterns are dynamic (Lambin and Meyfroidt 2010); people's actual behaviors are not always associated with "intentions" and "attitudes" (Holdershaw and Gendall 2008; Lu 1999). Only 2–5% of the traditional land-use was situated on steep slopes, far from villages, agricultural peripheries, roads and rivers.

This potential for unpredictable behaviour is reflected in the results of our APM validation (Fig. 8; Table 6); 33% of observed land-use conversion could not be predicted due to their limited relevance of slope and distance factors. However, in terms of accuracy of location, the use of spatial APM in this study was better than the study in Phrao, which reached 53% (Ato 1996) and in Kutai Barat, which reached 65% (Hamzah 2012).
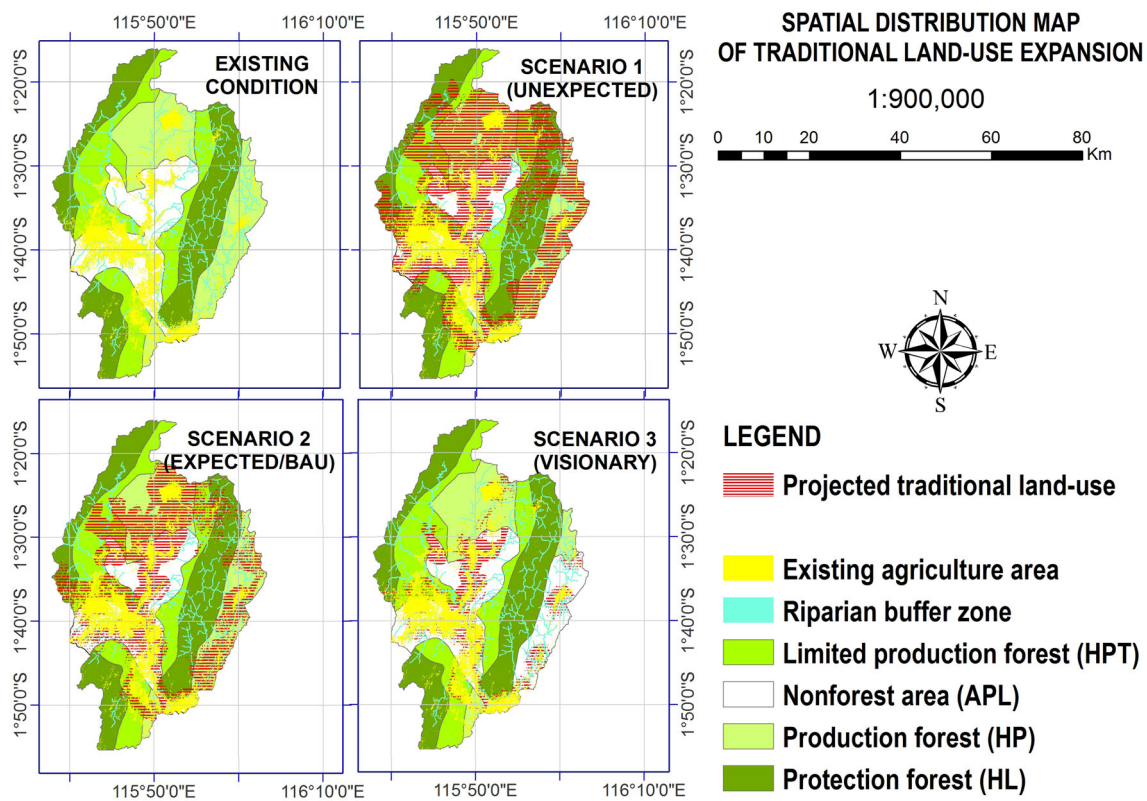
Fig. 9 Spatial distribution of agricultural expansion for three different scenarios

Our spatial analysis of three villages showed that sociocultural characteristics, experiences, and farming systems (Table 5) can affect deforestation per capita. The lowest deforestation per capita occurred in Muluy communities, in line with the study of (Chi et al. 2013) who mentioned that cultural characteristics of communities are one of the most important factors affecting land-use conversion. Norms, beliefs and traditions are tightly linked to the ways indigenous people manage their forest resources (Mulyoutami et al. 2009; Sasaoka and Laumonier 2012). In the village dominated by adat people, adat regulations and beliefs concerning the best time to start land clearing, plugging and planting, which areas and trees are forbidden to cut, and how large an area can be utilized per household per planting season are still followed. The adat law has governed adat forest management for many generations by regulating people's rights of access to forest products, the designation of forestland cleared for agriculture, and the planting or protection of trees in the forest (Butt 2014).

Traditionally, the period of cultivation ends when the soil fertility is exhausted and productivity decreases. Instead of intensifying inputs to raise production, farmers expand their land into forest areas. In forest areas, agriculture cannot be intensified and thus ensure food security and income generation (Brown and Schreckenberg 1998; Grogan et al. 2013).

For decision-makers, the essential task, however, is how to develop new policies enabling traditional communities to meet their basic needs for an adequate standard of living (such as for sugar, fish, meat, clothes, housing, education), which is equivalent to 1 ton/capita/year of rice without damaging the environment. For villagers whose livelihoods depend on agriculture, the minimum for farm production per household is equivalent to 7.9 tons of upland rice per year.

In the visionary scenario, farming systems are improved in line with consistent law enforcement, synergizing formal law regulating general prohibition and adat law regulating daily based norms and activities. Based on our observations of the cultivation areas of the adat communities from 1992 to 2012 (Fig. 7), we came to understand that adat people have managed their forest in line with adat law.

In the visionary scenario, certain forest areas with slopes under 40% are given to indigenous communities together with the revitalization of customary rights and adat institutions. As a result, in the final year, productivity of food and market crops will increase by 180 and 200%, respectively, compared with the initial year (Table 7). Even though rice production is still lower than the district level, it will be sufficient to provide a minimum standard of living. After forest conversion, there is a possibility that villagers could legally have 3–4 ha of land. One hectare for

upland rice and 2–3 ha for rubber would be sufficient to provide enough rice for household needs and other food for the whole year. By having more land with secure tenure, local people would be able to improve their farming systems. Two village areas would be excluded from the forest zone starting with the third period. Since both villages will no longer be situated in the forest zone, the regional government will be able to officially support them to improve farming production inputs and technology. However, in Indonesia, communal rights to land are among the most intriguing of concepts (Bakker 2008). In some cases, communal ownership can be subject to forest degradation when local institutions are managed inappropriately (Perez-Verdin et al. 2009). In such a scenario, deforestation can occur, but to a lesser extent compared with the initial deforestation rate, which would be 10.7% over a 25-year period (Table 9) at a rate of 0.4% per year.

Conclusions

This paper discusses spatial patterns of traditional land-use expansion and deforestation and how physical aspects as well as socioculture and policy affect their dynamics. The evidence indicates that slope and accessibility are important factors affecting traditional land-use expansion. The steeper the slope and the farther the distance, the lower the rate of deforestation. However, due to the dynamics of human behavior, some areas of traditional land-use are randomly located, inconsistent with these factors.

The results of the village surveys support our hypotheses concerning the sociocultural aspects of deforestation. Our spatial analysis of three villages shows differences between sociocultural characteristics, experience, and farming practices. The lowest rate of deforestation per capita occurred where customary laws strictly regulate people's activities. Meanwhile, in the more modern communities, deforestation was higher as a consequence of higher financial capital as well as knowledge and experience. Analyzing adat forest designation maps and 20 years of traditional farming practices of the adat people, we reached the conclusion that adat people manage their forest sustainably. In general, there were similarities between land designated under adat law and that under the Ministry of Forestry. The adherence of adat law is a key reason that deforestation was controlled.

Since shifting cultivation has been part of adat culture for many generations, the solution is not to force them to convert to permanent agricultural systems. Rather, ensuring the security of land rights and assisting in the improvement of their shifting cultivation while moving toward more productive systems, with longer fallows, and providing better farming inputs and technology to maintain

soil fertility. In fact, traditional land-use systems are feasible systems when physical constraints make modernization of agriculture impossible (Plieninger et al. 2006).

The essential measures, however, are empowerment of customary law and adaptation of indigenous knowledge in forest management to meet current needs and conditions. Long-term security and short-term consumption of agricultural commodities should be optimized through the combination of land management and local institutional enforcement. Land-use management that enhances farming income while avoiding deforestation and degradation must be promoted, supported by land allocation and implementation of formal laws that respect adat law and revitalize adat institutions.

Based on our projections, at least three factors decrease deforestation and increase community welfare: (1) improvement of farming practices, (2) land allocation to ensure livelihood security, and (3) law enforcement synergizing formal law and adat law to ensure implementation of sustainable land-use management. A combination of the three approaches will result in an increase in crop productivity, sufficient for households to have a minimum standard of living with less deforestation. However, to determine the reliability of our conclusions, further studies and more replication in other locations are needed.

Finally, instead of developing approaches to stop deforestation, this study explored spatial analytical approaches to provide a better understanding of deforestation in correlation with agricultural expansion. The accuracy of all projections may be subject to question. Different resolutions of spatial data as well as nonspatial data may produce different results. However, by combining spatial models with GIS and field surveys to develop scenarios that are as realistic as possible, we can provide better evidence to help decision-makers and other stakeholders design what strategies to prevent the projected outcomes.

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