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Proximate and underlying causes of forest cover change in Peninsular Malaysia

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ABSTRACT

This study examined the process and causes of forest cover change in Peninsular Malaysia from 1970 to 2010. Time series data on forest cover, land use, timber production, and socio-economic variables of Peninsular Malaysia were analyzed by regression modeling using Akaike Information Criterion (AIC). Peninsular Malaysia experienced extensive deforestation during the 1970s and early 1980s, but since then deforestation has slowed down substantially. Regression results highlighted that poverty alleviation was the principal underlying factor leading to change in forest area. Neither population growth nor economic growth was a major factor affecting forest cover. Oil palm expansion was identified as the main proximate cause of deforestation. Regression results also indicate that oil palm expansion greatly contributed to poverty reduction. Our empirical evidence suggests that in Peninsular Malaysia, agricultural development to reduce poverty, in particular oil palm development, initially led to deforestation. However, substantial decrease in poverty caused decrease in deforestation over the long term. Based on the results of this study, we propose poverty alleviation as a strategy to reduce deforestation. Our findings demonstrate the need to analyze factors that reduce deforestation and to develop effective REDD programs.

1. Introduction

Reducing deforestation has become an issue of global importance, not only for environmental conservation, but also for climate change mitigation. The United Nations' program on Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD) is being intensively discussed as a key framework in international conventions on climate change. Stern (2006) suggested that if the right policies and institutional structures were in place, preventing further deforestation would be cheaper than other types of mitigation strategies for greenhouse gas emissions. However, the issues surrounding deforestation in developing countries are not easily resolved. The major proximate causes of deforestation, such as commercial agriculture, are difficult to halt because they are important economic activities. It is also difficult to implement the right policies and institutional structures to slow down deforestation in developing countries. To solve the problem of deforestation effectively and sustainably, factors that drive deforestation, as well as those that reduce deforestation, need to be clarified.

Deforestation is caused by various factors, including economic, demographic, political, and institutional drivers (Geist and Lambin, 2002). Deforestation is a complex process that is driven by a combination of proximate and underlying causes, which can vary from region to region (Geist and Lambin, 2001; Lambin et al., 2003; Rudel et al., 2005). Numerous studies identify agricultural expansion as the major proximate cause of tropical deforestation, particularly the production of commercial commodities such as rubber, palm oil, cattle, soybean, coffee, and cocoa (DeFries et al., 2010; Fearnside, 2001; McMorrow and Talip, 2001; Miyamoto, 2006; Motel et al., 2009; Zak et al., 2008). Empirical studies show that the prices of agricultural commodities and deforestation are positively correlated, which could be interpreted as evidence for a causal relationship between these quantities (see Angelsen and Kaimowitz, 1999). In developing countries, commercial export agriculture has expanded to meet the growing global market demand (Lambin et al., 2001; Thongmanivong et al., 2005). The increasing demand for agricultural products on the global market has driven tropical deforestation (Gibbs et al., 2010; Rudel et al., 2009). In addition to agriculture, road construction, unsustainable commercial logging, and fuel-wood collection are proximate causes of deforestation (Cropper et al., 2001; Etter et al., 2006; Geist and Lambin, 2002; Miyamoto, 2007).

The underlying causes of deforestation are not fully understood, and the influence of various factors has been extensively debated. These include population growth (Jha and Bawa, 2006; Mahapatra and Kant, 2005; Zak et al., 2008), poverty (Angelsen and Wunder, 2003; Sunderlin et al., 2008; Wunder, 2001), economic development (Bhattarai and Hammig, 2001; Michinaka and Miyamoto, 2013; Rudel et al., 2005;

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Stern, 2006), insecure land tenure (Börner et al., 2010; Robinson et al., in press), and weak law enforcement (Gaveau et al., 2009), among others. Land-use change is driven by a combination of synergetic factors: pressures on resources, opportunities created by markets, policy intervention, vulnerability, and social organization (Lambin et al., 2003). Lambin et al. (2003) suggested this view as a framework for understanding the complexity of deforestation and other land-use changes.

Recent studies have explored the causes of reduced deforestation and the reversal of net deforestation to net reforestation (so-called forest transition). Thailand has reduced its deforestation rates since the 1980s through logging bans, increased income, and a decline in the use of land for agriculture (Meyfroidt and Lambin, 2011; Wannitikul, 2005). Vietnam experienced forest transition in the 1990s. Reforestation was driven by forest scarcity, economic growth, land privatization, land-use zoning, agricultural intensification, and market liberalization (Meyfroidt and Lambin, 2008a, 2008b). In India, an increase in the demand for forest products associated with economic growth resulted in increased forest cover, while agricultural intensification associated with the green revolution and rising rural wages did not affect forest cover (Foster and Rosenzweig, 2003). Rudel et al. (2005) proposed two pathways of forest transition: (a) "forest scarcity," which prompts governments and landowners to plant trees, leading to afforestation (Asian countries) and (b) "economic development," which creates enough off-farm jobs to draw farmers away from rural and into urban areas (European countries). Lambin and Meyfroidt (2010) suggested globalization, state forest policy, and smallholder tree-based land-use intensification as three additional pathways of forest transition.

Peninsular Malaysia has experienced deforestation, mainly due to the expansion of rubber (in the early to mid-20th century) and oil palm (from 1960s onwards) (Abdullah and Nakagoshi, 2008; Henson, 2005). Between 1972 and 1982, the annual deforestation rate of Peninsular Malaysia was estimated by GIS to be 1.7% (Brown et al., 1994). However, the rate of deforestation has declined in recent decades. Henson (2005) showed that the decline of forest area in Peninsular Malaysia was more gradual between 1980 and 2000 than it had been earlier. Abdullah and Nakagoshi (2008) also reported that in the state of Selangor in Peninsular Malaysia, oil palm expansion caused forest loss from 1966 to 1981, but that the rate of loss slowed down between 1981 and 1995.

The present study examined the process and causes of change in forest cover and land use from 1970 to 2010 in Peninsular Malaysia. This analysis was based on time series data on forest cover, land use (for oil palm and rubber), forestry (exports and imports of timber products, log production, sawn timber production, and plywood production), and socio-economic variables [population, gross domestic product (GDP) variables, employment variables, household income, and poverty rate]. To investigate the causes of change in forest cover, we analyzed the factors affecting forest area and poverty rate (identified as the most important variable for describing forest area) by regression modeling using the Akaike Information Criterion (AIC).

2. Methods

2.1. Study site

Malaysia is an upper-middle income country in Southeast Asia, which had a GDP per capita of $15,182 in 2010 (The World Bank, 2013). The annual deforestation rate in Malaysia is relatively low (0.42% for the period 2005–2010) compared with other Southeast Asian countries, such as Cambodia (1.22%), Myanmar (0.95%), and Indonesia (0.71%) (FAO, 2010).

Peninsular Malaysia is the part of Malaysia that lies on the Malay Peninsula. Its area is 131,822 km^2 (Forestry Department Peninsular Malaysia, 2010) and its climate is characterized by abundant rainfall, high humidity, and high temperatures. Forest cover, land use, forestry, and socio-economic data on Peninsular Malaysia for 1970–2010 are shown in Table 1. The forest area in 2010 was 5.8 million ha, representing approximately 44% of land area. The other main land uses are oil palm plantations (2.5 million ha, representing 19% of land area in 2010) and rubber plantations (0.7 million ha, representing 6% of land area). Together, forest, oil palm, and rubber cover 70% of the total land area. Other agricultural land uses from 1970 to 2010 were paddy (2–3%), coconut (1–2%), and orchard (up to 1%) (Department of Agriculture Peninsular Malaysia, unpublished data).

The human population in Peninsular Malaysia was 22,146,000 in 2009, translating into a population density of 168 people per km^2. The population has more than doubled since 1970. The main ethnic groups in Peninsular Malaysia are Malays, Chinese, Indians, and indigenous people. The total GDP grew significantly from 40 billion RM in 1971 to 477 billion RM in 2010. (GDP is adjusted by a deflator at constant 2000 prices.) In 2010, services accounted for 60% of the total GDP, while manufacturing accounted for 29%. The service, manufacturing, and agriculture industries employed 61% (5.2 million), 19% (1.6 million), and 9% (0.7 million) of the total labor force, respectively.

2.2. Data

Statistical analyses were based on forest cover, land use (oil palm and rubber), forestry (exports and imports of timber products, log production, sawn timber production, and plywood production), and socio-economic data (population, GDP variables, employment variables, household income, and poverty rate) of Peninsular Malaysia from 1970 to 2010 (Table 1). The whole of Peninsular Malaysia was used as the unit of analysis. Data were available for some variables for every year from 1970 to 2010, but data were missing for other variables in certain years. As a result, we only used data from the years for which all variables were represented (1976, 1979, 1984, 1987, 1989, 1992, 1995, 1997, 1999, 2002, 2004, 2007, and 2009) in our regression analysis.

Forest cover data were obtained from the Forestry Department Peninsular Malaysia (1979, 1994, 1996, 2001, 2006, 2010, 2011). The forest cover data exclude the area covered by agricultural plantations, such as rubber and oil palm. Forest cover data from 1983 were excluded from the analyses because the data showed extreme change, with a 9% increase in forest area from 1982 to 1983 and a 7% decrease in forest area from 1983 to 1984.

Data on the area of oil palm plantations were obtained from the Malaysian Palm Oil Board (unpublished data). Data on the area devoted to rubber were obtained from the Ministry of Plantation Industries and Commodities (unpublished data).

Data on forest cover and land uses were validated using independent data obtained from the Department of Agriculture Malaysia (unpublished data), which are based on land-use maps obtained from satellite images and other sources for the years 1966, 1984, 1990, 1997, 2000, 2002, 2004, 2006, and 2008. Changes in forest cover and land-use data were analyzed, and the time that the changes occurred was recorded. For example, the land-use map data from Department of Agriculture Malaysia showed a huge reduction in forest area per year for 1966–1984. However, from 1984 to 2008, the reduction in forest area progressed at a much slower pace (Miyamoto et al., 2013). This trend is consistent with the statistical data obtained from the Forestry Department Peninsular Malaysia. The two sets of data are considered independent because the Forestry Department Peninsular Malaysia and other agencies generate statistical data aggregated from local administrative divisions, whereas the Department of Agriculture Malaysia calculates its data from land-use maps from satellite images and other sources. Statistical data from relevant agencies were considered to be reliable to use in the analysis of factors driving forest cover change because they showed similar periodic trends with the land-use map data from the Department of Agriculture Malaysia (Miyamoto et al., 2013).

Forestry-related data, such as exports and imports of timber products and logs, sawn timber, and plywood production, were obtained from the Forestry Department Peninsular Malaysia (1979, 1994, 1996, 2001, 2006, 2010, 2011). Data on population and employment by sectors were obtained from the Ministry of Plantation Industries and Commodities

Table 1
Variables used in regression analyses and their trends from 1970 to 2010.

Variable[a]	Description	Unit[b]	1970 (or 1971–72)	1990 (or 1989)	2010 (or 2009)
Forest and land uses					
Forest area	Forested area	1000 ha	8012	6269	5864
Oil palm area	Planted area under oil palm	1000 ha	55	1698	2524
Rubber area	Planted area under rubber	1000 ha	1723	1536	775
Forestry					
Exports of timber products	Exports of major timber products	RM 1000	9920	2742	3586
Imports of timber products	Imports of major timber products	RM 1000	9765	121	1104
Log production	Production of logs	1000 m^3	6542	12,819	4162
Sawn timber production	Production of sawn timber	1000 m^3	2326	6183	2659
Plywood production	Production of plywood	1000 m^3	179	955	382
Socio-economic					
Population	Population	1000	9147	14,627	22,146
Total GDP	Gross domestic product (GDP) at purchasers' prices, adjusted GDP by deflator at constant 2000 prices	RM million	40,441	146,355	477,183
Agricultural GDP	GDP by sector: agriculture, livestock, forestry and fishing, adjusted	RM million	11,245	21,532	25,750
Mining GDP	GDP by sector: mining and quarrying, adjusted	RM million	2489	7230	24,715
Manufacturing GDP	GDP by sector: manufacturing, adjusted	RM million	6346	39,250	138,684
Construction GDP	GDP by sector: construction, adjusted	RM million	1641	5179	16,576
Service GDP	GDP by sector: service, adjusted	RM million	17,627	74,214	287,988
Mean household income	Mean household income	RM	245	1195	3930
Poverty rate	Incidence of poverty	%	53	16	3
Employment in agriculture	Employment by sector: agriculture, forestry, livestock & fishing	1000	1776	1889	777
Employment in mining	Employment by sector: mining & quarrying	1000	87	29	39
Employment in manufacturing	Employment by sector: manufacturing	1000	301	1333	1655
Employment in construction	Employment by sector: construction	1000	91	424	813
Employment in services	Employment by sector: services	1000	1085	3154	5220

[a] All data presented were obtained from the whole Peninsular Malaysia (unit of analysis).
[b] RM is Malaysian Ringgit.

(2002, 2004, 2008, 2011). Total GDP and GDP by sectors were obtained from the Department of Statistics Malaysia (unpublished data). GDP data were adjusted by a deflator to yield constant 2000 prices for analysis. Mean household income was obtained from the Economic Planning Unit (2012a). Incidence of poverty was also obtained from Economic Planning Unit (2012b).

Poverty in Malaysia "is measured on the basis of a minimum expenditure level or the Poverty Line Income (PLI) to separate the poor from the non-poor," according to the Fifth Malaysia Plan 1986–1990 (Economic Planning Unit, 1986). The official poverty line in Malaysia has been defined in subsistence terms as indicated in the Third Malaysia Plan 1976–1980 (Economic Planning Unit, 1976). Poverty is defined as "deficiency in absolute standards of living in terms of caloric intake and nutrition levels, clothing, sanitation, health, education, and other socio-economic variables." Furthermore, "poverty in the country has been measured by comparing absolute levels of household income with income required for minimum subsistence or what may be termed a poverty line income. This income takes account of minimum nutritional and other non-food requirements of each household to sustain a decent standard of living" (Economic Planning Unit, 1976).

2.3. Regression analysis

Linear regression analysis was used to investigate factors affecting forest cover. We analyzed data from 1976, 1979, 1984, 1987, 1989, 1992, 1995, 1997, 1999, 2002, 2004, 2007, and 2009 for the 22 variables shown in Table 1. The number of observations for each variable was 13.

The dependent variable was forest area, while the explanatory variables included two land-use variables (i.e., areas of plantations of oil palms and rubber), and five forestry variables (i.e., exports of timber products, imports of timber products, log production, sawn timber production, and plywood production). Explanatory variables included 14 socio-economic variables (i.e., population, total GDP, agricultural GDP, mining GDP, manufacturing GDP, construction GDP, service GDP, household income, poverty rate, employment in agriculture, employment in mining, employment in manufacturing, employment in construction, and employment in services).

Model selection was conducted using the AIC. Model selection procedures, such as AIC, are employed to help choose an appropriate model to explain a dependent variable. In the AIC, the commonly adopted criterion used to compare models for goodness of fit, a lower AIC value indicates a better model (Burham and Anderson, 2002).

As the number of variables in our study was large, evaluation of all possible models was not practically feasible. Therefore, we performed a variation of forward selection method using AIC. Starting with a model that has no variables, we added variables to the model as follows. For a one-variable model (i), we tested the addition of each variable using AIC and chose the top one-variable models with the lowest AIC values. There were several chosen models (in contrast with the ordinary forward selection, which chooses only one). We basically chose three models. However, if more than three models had AICs that differed by less than 1 from the lowest AIC, we chose all such models. For a two-variable model (ii), for each of the chosen one-variable models, we tested the addition of variables that were not already included in the model. We then chose the top two-variable models. A search for three-variable models was undertaken in the same way. The procedure ended when there were no further variable additions that could lower the AIC. However, we repeated the procedure until we found the top five models, even when further additions of variables did not decrease the AIC.

The top five models had the lowest AICs of all the evaluated models. During the process of selection, models that had variance inflation factors (VIF) greater than 10 and/or standardized partial regression coefficients greater than 1.0 were excluded to avoid multicollinearity (Chatterjee and Hadi, 2006). We then tested the top five models for the presence of serial correlation within the time series data, using the Durbin–Watson test. A Durbin–Watson statistic close to a value of 2 indicates that there is no serial correlation. However, the test depends on the numbers of observations and variables (Chatterjee and Hadi, 2006; Savin and White, 1977). The Durbin–Watson test has three possible outcomes: (1) there is significant serial correlation, (2) there is no serial correlation, or (3) the test is inconclusive, meaning that there may be serial correlation but it is not significant. The final decision about the best model was based on goodness of fit, multicollinearity, and serial correlation.

The same model-selection procedure was used to examine factors affecting poverty rate, which was identified as the primary factor influencing forest cover. The explanatory variables included all the variables in Table 1 except forest area and poverty rate. All statistical analyses conducted in this study were implemented using IBM SPSS Statistics version 21.

3. Results

3.1. Change in forest cover and land use

The change in forest cover in Peninsular Malaysia shows that extensive deforestation occurred from 1970 to 1982. However, from 1982 onward, deforestation slowed down (Fig. 1). Forest area accounted for 8.01 million ha in 1970 (representing 60.8% of land area) and decreased to 6.18 million ha (representing 46.7% of land area) by 1982. By 2010, the forest area had gradually declined to 5.86 million ha (covering 44.3% of land area). From 1970 to 1979, the annual deforestation rate was high (2.4%), but it sharply decreased to 0.4% between 1980 and 1989, rose slightly to 0.6% between 1990 and 1999, and then dropped to 0.1% by 2010. This finding indicates that Peninsular Malaysia has reduced deforestation substantially without reducing forest cover to very low levels.

The major land uses in Peninsular Malaysia have been oil palm (19% of land area in 2010) and rubber (6% in 2010), while other land uses (paddy, coconut, and orchard) accounted for no more than 3% each. Oil palm plantation has expanded dramatically from 0.4% of land area (55 thousand ha) in 1970 to 19% (2.52 million ha) in 2010, while rubber plantation accounted for 13% (1.72 million ha) in 1970 but declined to 6% (0.77 million ha) by 2010 (Fig. 1). From 1970 to 2010, oil palm area increased by 2.47 million ha, which is more than the area that was deforested (2.15 million ha) during this period. The main proximate cause of deforestation was conversion of forest to oil palm plantation. However, although the area under oil palm continued to expand, the rate of deforestation continued to slow down from the mid-1980s, indicating that oil palm expansion was no longer the cause of deforestation.

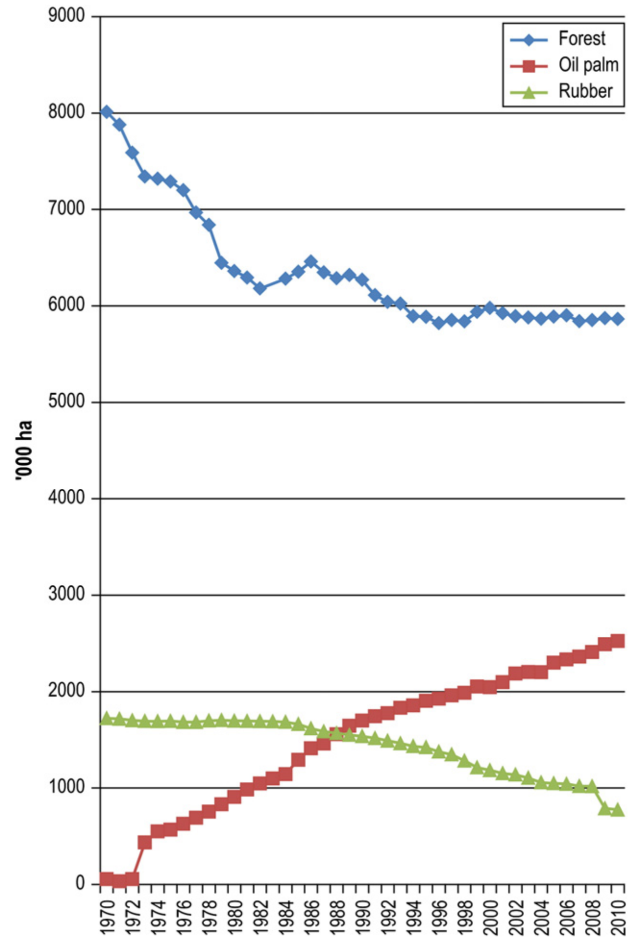

Fig. 1. Area covered by forest, oil palm, and rubber in Peninsular Malaysia (1970–2010).

3.2. Factors affecting forest cover

The results of regression analysis showed that the poverty rate is the principal explanatory variable for forest cover. Table 2 presents the results of model selection using AIC for forest area from 1976 to 2009. None of the top five models has significant serial correlation, according to the Durbin–Watson tests (the Durbin–Watson statistics range from 2.11 to 2.61). Remarkably, the single-regression model that attempts to explain variation in forest area by correlating it with poverty rate is superior (i.e., it has the lowest AIC) to all the other models. Moreover, the Durbin–Watson test showed that this model has no serial correlation (Durbin–Watson statistic = 2.11). Thus, we identified this model (ranked first in Table 2) as the best-fit model to explain variation in forest area. The model shows that poverty rate has a significant positive impact on forest area and that 90% of the variation in forest area can be explained by poverty rate. The results indicate that a reduction in poverty rate is most strongly associated with a decline in forest area (Table 2).

All the good-fit models shown in Table 2 included poverty rate and highlighted the significance of poverty rate as an explanatory variable for forest area. When other variables, such as employment (manufacturing and construction), construction GDP, rubber, and sawn timber production were included in models together with the poverty rate, there were no additional significant effects on forest area. Oil palm area, identified as the proximate cause of deforestation on the basis of land-use data, had a significant negative relationship with forest area in a single-regression model. This model had no serial correlation, according to the Durbin–Watson test (Durbin–Watson statistic = 1.51), but it had a much higher AIC (316.9) than the best poverty rate model (AIC: 307.0). This result indicates that oil palm area does not explain the variation in forest area as well as poverty rate explains it.

The results in Table 2 also show that the degree of decrease in poverty rate is strongly related to the degree of decrease in forest area. This finding is supported by historical data on poverty rate and forest cover (Fig. 2). The poverty rate fell sharply from 53% in 1970 to 20% in 1984 (decreasing by 2.4% each year on average), while at the same time extensive deforestation occurred. Since then, the poverty rate has fallen less sharply, from 20% in 1984 to 2.6% in 2009 (decreasing by 0.7% each year on average), while the rate of deforestation also declined. Initially, poverty alleviation and deforestation rates progressed rapidly and then decelerated. Fig. 2 shows that the turning point occurred when the poverty rate dropped to 20% (at which point poverty was substantially reduced).

In contrast, GDP and forest cover did not show similar trends over time (Fig. 2). GDP grew rapidly from the 1990s onwards, after the deforestation rate slowed down in the mid-1980s. The results in Fig. 2 indicate that GDP growth did not have much effect on forest cover.

3.3. Factors affecting poverty rate

The model that was selected as the best-fit model to explain variation in poverty rate indicated that an increase in oil palm plantations and an increase in forestry activities, such as export of timber products and plywood production, are strongly associated with poverty reduction in Peninsular Malaysia. Table 3 shows the results of regression modeling using the AIC to explain variation in poverty rate for 1976–2009. The good-fit models for explaining variation in poverty rate included more

Table 2
Results of model selection using the Akaike Information Criterion (AIC) for forest area (n = 13).

Rank	Model[a]	Standardized coefficient	AIC	adjusted R^2
	Dependent variable: forest area			
	Explanatory variable			
1	Poverty rate	Pov[1] 0.95**	307.00	0.90
2	Pov + construction GDP + rubber	Pov 0.94**; CG[2] −0.29; Rb[3] −0.30	308.20	0.90
3	Pov + employment in manufacture	Pov 0.87**; Em[4] −0.09	308.52	0.89
4	Pov + sawn timber production	Pov 0.98**; St[5] −0.05	308.75	0.89
5	Pov + employment in construct	Pov 0.88**; Ec[6] −0.08	308.86	0.89

All the models were significant ($p < 0.001$).
[1]Pov = poverty rate; [2]CG = construction GDP; [3]Rb = rubber area; [4]Em = employment in manufacture; [5]St = sawn timber production; [6]Ec = employment in construct.
** $p < 0.01$.
[a] These five models had the lowest AIC values when all variables in Table 1 were used in the regression analysis. Only time series data for years of 1976, 1979, 1984, 1987, 1989, 1992, 1995, 1997, 1999, 2002, 2004, 2007, and 2009 were used. Models with variance inflation factor (VIF) greater than 10 and/or standardized coefficients greater than 1.0 were excluded to avoid multicollinearity.

independent variables than did models fitted to forest area. None of the top five models has significant serial correlation, according to the Durbin–Watson tests (the Durbin–Watson statistics range from 1.77 to 1.98). However, the Durbin–Watson tests of the models that were ranked first and second (Table 3) are inconclusive, showing that there may be serial correlation but it is not significant. The test of the model that was ranked third (Table 3) showed no serial correlation (Durbin–Watson statistic = 1.92). Considering both AIC values and Durbin–Watson test results, we identified this model (i.e., the model ranked third in Table 3) as the best-fit model to explain poverty rate. The explanatory variables of this model include oil palm area, exports of timber products, plywood production, and employment in construction. Oil palm area, exports of timber products, and plywood production have significant effects on poverty rate in the best model. The impact of oil palm area was the greatest because its standardized coefficient is much higher than that of the other variables. Employment in construction was included in the best model but did not have a significant effect.

The good-fit models in Table 3 always included oil palm area, exports of timber products, and plywood production. The models show that the effects of oil palm area and exports of timber products on poverty rate are always significant, while the effect of plywood varied. When employment variables (agriculture and construction), construction GDP, sawn timber production, and imports of timber products were included in the models, their effects were not significant.

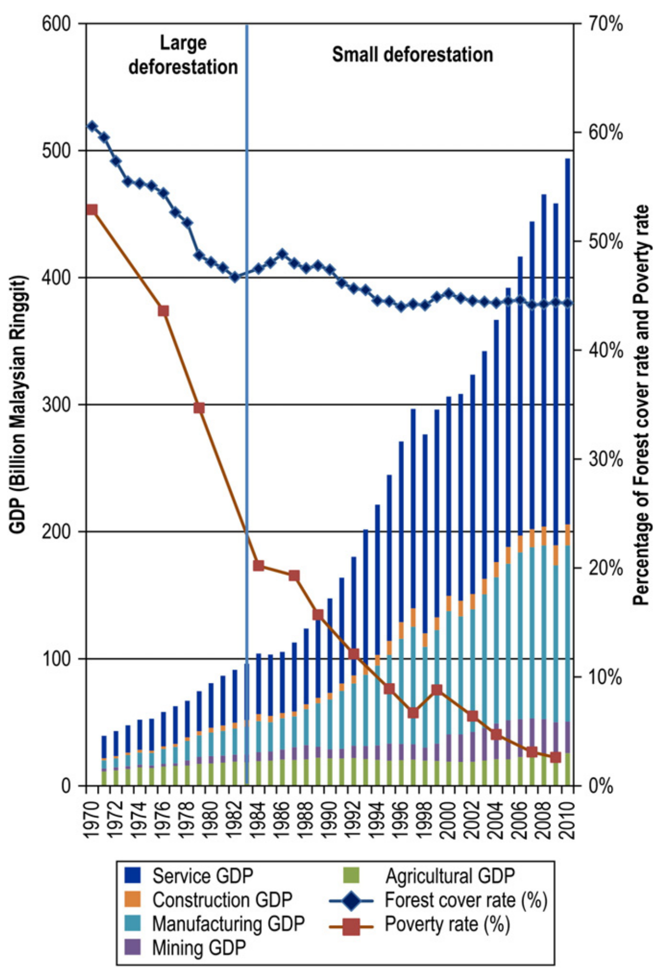

Fig. 2. Forest cover rate, poverty rate, and GDP of Peninsular Malaysia (1970–2010).

4. Discussion and conclusion

We showed that Peninsular Malaysia experienced extensive deforestation in the 1970s and early 1980s, as forest cover dropped from 61% in 1970 to 47% in 1982 (Figs. 1 and 2). However, since the mid-1980s, deforestation has slowed down, and the forest cover remained 44% in 2010. Our results are consistent with those of Brown et al. (1994), who used 1972–1982 data from Peninsular Malaysia, and with Henson (2005) who analyzed data from 1980 to 2000 from Peninsular Malaysia. In tropical Asia, India and Vietnam have experienced forest transitions, while Thailand and Peninsular Malaysia have reduced their rates of deforestation (Henson, 2005; Mather, 2007; Wannitikul, 2005). Forest areas in India, Vietnam, and Thailand have declined to a very small proportion of total land area. India's forest area was estimated at 19% of land area in 1987 (Mather, 2007), Vietnam's at 25–31% between 1991 and 1993 (Meyfroidt and Lambin, 2008b), and Thailand's at 25% in 1998 (Wannitikul, 2005). Peninsular Malaysia has maintained a relatively large forest cover rate compared with India, Vietnam, and Thailand.

Oil palm expansion was anticipated to be the main proximate cause of deforestation, on the basis of land-use data. Indeed, it was inferred from regression analysis that this variable was significantly related to forest area. However, the area devoted to oil palm did not explain the variation in forest area as well as the poverty rate did, according to the AIC values. The results in Figs. 1 and 2 show that when the poverty rate dropped below 20%, oil palm development ceased to be a significant explanatory variable for deforestation. Oil palm area continued to expand from 1973 to 2010, but deforestation began to slow down from the mid-1980s. This slowing occurred because the sites for oil palm planting shifted from newly cleared forest land to land that had been previously used for rubber, coconut, cocoa, and other agricultural commodities that had become less profitable than oil palm (Henson, 2005). In other developing countries and regions, agricultural expansion leads to deforestation (Geist and Lambin, 2002; Miyamoto, 2006; Motel et al., 2009). The reason why the expansion of oil palm is no longer decreasing forest area in Peninsular Malaysia could be related to decreased poverty and the resulting shift of the labor force from the agricultural to more lucrative sectors. The decrease in the agricultural population in turn decreases the demand for newly cleared land.

Table 3
Results of model selection using the Akaike Information Criterion (AIC) for poverty rate (n = 13).

Rank	Model[a]	Standardized coefficient	AIC	Adjusted R^2
	Dependent variable: poverty rate Explanatory variables			
1	Oil palm + exports of timber products + plywood + construction GDP + employment in agriculture	Pal[1] −0.87**; Ex[2] −0.19**; Pl[3] −0.15*; CG[4] −0.24; Ea[5] −0.22	18.76	0.98
2	Pal + Ex + Pl + employment in construction + sawn timber production	Pal−0.73**; Ex −0.21**; Pl −0.12; Ec[6] −0.24; Sa[7] −0.11	19.67	0.98
3	Pal + Ex + Pl + Ec	Pal −0.71**; Ex −0.22**; Pl −0.19**; Ec −0.19	20.09	0.98
4	Pal + Ex + Pl + Ea + CG + Sa	Pal −0.88**; Ex −0.19*; Pl −0.13; Ea −0.21; CG −0.25; Sa −0.05	20.11	0.98
5	Pal + Ex + Pl + Ec + Sa + imports of timber products	Pal −0.71**; Ex −0.20*; Pl −0.10; Ec −0.24; Sa −0.12; Im[8] 0.04	21.13	0.98

All the models were significant ($p < 0.001$).
[1]Pal = oil palm area; [2]Ex = exports of timber products; [3]Pl = plywood production; [4]CG = construction GDP; [5]Ea = employment in agriculture; [6]Ec = employment in construct; [7]Sa = sawn timber production; [8]Im = imports of timber products.
**$p < 0.01$, *$p < 0.05$.
[a] These five models had the lowest AIC values when all variables in Table 1 except forest area were used in the regression analysis. Only time series data for years of 1976, 1979, 1984, 1987, 1989, 1992, 1995, 1997, 1999, 2002, 2004, 2007, and 2009 were used. Models with variance inflation factor (VIF) greater than 10 and/or standardized coefficients greater than 1.0 were excluded to avoid multicollinearity.

However, this understanding is beyond the scope of this study and further research is necessary in order to examine it.

Regression results in Table 3 suggest that increases in oil palm development (i.e., plantations) and forestry activities (i.e., export of timber products and plywood production) reduced poverty in Peninsular Malaysia. However, forestry activities did not affect the forest area. GDP and other socio-economic variables were included in the regression models but did not show significant effects on poverty rate. Oil palm development was one of the main poverty reduction strategies initiated by the government in Peninsular Malaysia. The Federal Land and Development Authority (established in 1956) developed oil palm plantations, along with rubber, and provided them to the landless poor (to a total 112,000 households) until 1992 when the development of new areas was stopped. Such agricultural schemes increased crop yields and increased the incomes of poor people (Hussin and Abdullah, 2012; Mohd Parid et al., 2013; Simeh et al., 2001).

Regression results in Table 2 indicate that poverty rate best explains the variation in forest cover change for 1976–2009 in Peninsular Malaysia, compared with other investigated variables. Poverty rate was most strongly and positively associated with forest area. The results in Tables 2 and 3 suggest that poverty alleviation associated with agricultural development (oil palm in particular) was the principal underlying factor leading to change in forest area. Earlier studies (Choumert et al., 2013; Culas, 2007; Rudel et al., 2009) have discussed possible underlying factors; in the present study, we found that population and economic growth were not significant underlying factors influencing forest cover change in Peninsular Malaysia. Population was not included in the good-fit models for forest area. The population increased at the same rate despite changes in deforestation rate during the study period (Table 1). Some GDP and employment variables were included in the good-fit models but showed no significant impact on forest area. In addition, GDP grew dramatically starting in the 1990s, after the rate of deforestation began to decelerate in the mid-1980s (Fig. 2). Thus, the empirical evidence presented in this study shows that the principal underlying factor leading to forest cover change in Peninsular Malaysia was poverty reduction. Neither population nor economic growth was a major underlying factor leading to forest cover change.

Our results presented in Tables 2 and 3 suggest that agricultural development to reduce poverty, in particular oil palm development, led to deforestation in Peninsular Malaysia. However, the rate of deforestation has decelerated since the mid-1980s. The historical data in Fig. 2 show that initially both poverty alleviation and deforestation progressed rapidly, and both began to decelerate in the mid-1980s. Furthermore, the finding that decreasing poverty rate led to decreasing forest area implies that the reduction of poverty alleviation efforts led to a reduction in deforestation. Thus, the key question is why agricultural development to alleviate poverty slowed down.

The results in Fig. 2 show that the turning point occurred when the poverty rate dropped to 20%. Hence, these findings suggest that the achievement of a substantial decrease in poverty (the poverty rate declined from 53% in 1970 to 20% in 1984) is likely to have slowed down poverty reduction (associated with oil palm expansion) since the mid-1980s, which has led to a slow-down of the rate of deforestation. The time lag between implementation of poverty alleviation strategies and any observable effect on the reduction of deforestation is the time that it took for the poverty rate to fall from more than 50% to 20%.

The evidence from Peninsular Malaysia suggests that agricultural development to alleviate poverty led to deforestation, and that when poverty had sufficiently decreased, a reduction in deforestation resulted. These findings are relevant to the hypothesis of the environmental Kuznets curve (EKC), which assumes that economic development increases forest loss but that forest area increases at a higher economic level. EKC theory is supported only by weak empirical evidence, even though many studies examined EKC using GDP, gross national income (GNI), and average household income as an indicator of economic level (Bhattarai and Hammig, 2001; Stern, 2004; Van and Azomahou, 2007). Our results suggest that instead of economic growth, a decrease in the poverty rate could be used as a socio-economic factor to explain the shift from accelerating deforestation to reduced deforestation.

Recent studies have identified several factors that reduce deforestation and/or lead to forest transition. These include forest scarcity, economic development, agricultural intensification, and globalization (Angelsen, 2009; Lambin and Meyfroidt, 2011; Meyfroidt and Lambin, 2008a; Rudel et al., 2005). In Peninsular Malaysia, forest scarcity appears not to be an important factor in the reduction of deforestation because forest cover did not drop to very low levels (Fig. 1) and log production increased from 1970 to 1992 (Table 1). The effects of economic development on forest cover are ambiguous. As pointed out earlier, when GDP and employment variables were included as explanatory variables in regression models, they did not show significant impacts on forest cover (Table 2). In addition, high GDP growth was seen after deforestation began to decelerate (Fig. 2). On the other hand, agricultural intensification and globalization could be relevant to the reduction of deforestation in Peninsular Malaysia, because the development of oil palm plantations represents an intensification process that is meant to take advantage of the global market and thereby greatly reduce poverty.

In conclusion, this study showed that poverty alleviation was the principal underlying factor leading to forest cover change in Peninsular Malaysia. Our findings suggest that poverty reduction through oil palm expansion caused extensive deforestation initially, but that a substantial decrease in poverty led to a sustainable slow-down of deforestation. The evidence from Peninsular Malaysia is important because the relationship between poverty and deforestation has not been clarified at a macro level, and even at the micro level, the impacts of poverty on forests have been ambiguous, suggesting, for example, that poverty alleviation can either accelerate or decelerate forest loss (Angelsen and Wunder, 2003; Duraiappah, 1998; Wunder, 2001). The influence of poverty alleviation on deforestation is difficult to grasp as a whole. To explore the relationship, it is necessary to conduct macroscopic long-term studies that accumulate empirical evidence.

The implication of this study is that poverty alleviation strategies, even if they initially lead to deforestation to some extent, can contribute to a reduction in deforestation over the long term. On the basis of our findings from the sub-national data of Peninsular Malaysia, we propose poverty alleviation as a strategy for reducing deforestation. The rate of deforestation in Peninsular Malaysia declined without the forest cover falling to very low levels. Our findings highlight the need to explore factors that reduce deforestation and to develop effective REDD programs and other strategies to combat deforestation.

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