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Forest Ecology and Management 191 (2004) 283–299

Forest Ecology and Management

www.elsevier.com/locate/foreco

# Appropriate measures for conservation of terrestrial carbon stocks—Analysis of trends of forest management in Southeast Asia☆

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Received 25 February 2003; received in revised form 15 August 2003; accepted 19 December 2003

**Abstract**

The 21st century has brought new challenges for forest management at a time when global climate change is becoming increasingly apparent. Additional to various goods and services being provided to human beings, forest ecosystems are a large store of terrestrial carbon and account for a major part of the carbon exchange between the atmosphere and the land surface. Depending on the management regime, forests can thus be either a sink, or a source of atmospheric carbon. Southeast Asia or ASEAN comprises 10 countries of different cultures and political background. Rapid economic development and fast-growing population in the region have raised much concern over the use of natural resources, especially forest resources. This study aims at finding the appropriate measures for sustainable use and management of tropical forests on a long-term basis. Between 1990 and 2000, about 2.3 million ha of forest were cleared every year and lost to other forms of land use. In terms of carbon emissions, a net amount of approximately 465 million t per year were released to the atmosphere over the same period, which amounts to 29% of the global net carbon release from deforestation worldwide.

This study provides an approach to analyzing the implications of alternative forest and land management options on forest carbon stocks. This is done in three steps: First, observed trends in land use are expressed in terms of a model in order to create a scenario for the period 1980–2050. Second, forest management practices and timber production rates are analyzed and three management scenarios are created: (1) continuing the current rate of exploitation, (2) management for long-term economic gains, and (3) climate-beneficial management. Third, the impact of the three scenarios on regional carbon storage is estimated on the basis of a carbon balance model. Comparing the additional rate of carbon sequestration of scenario (3) over scenario (2), and taking into account differing management costs, we also discuss a framework for industrialized countries to invest in carbon credits in the region in order to fulfil their commitments under present and future climate protection agreements.


*Keywords:* Southeast Asia; Carbon stock; Tropical forest management; Land-use change

☆ This paper was presented at the International Conference on Interactions of Forest Carbon Management and Maintenance of Biodiversity, 4–7 September 2002, Gustavelund, Tuusula, Finland, and the International Workshop on Sustainable Technologies for the 21st Century, 12–13 December 2002, Delemenhorst, Germany.

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doi:10.1016/j.foreco.2003.12.019

## 1. Introduction

Global climate change and rising global temperatures are likely to occur as a result of anthropogenic greenhouse gas emissions (IPCC, 2001). Fossil fuel burning and changes in land cover are the major causes of anthropogenic greenhouse gas emissions. Carbon dioxide ($CO_2$) emissions from land use and land use change, predominately from forested areas, have accounted for 33% of global $CO_2$ emissions during the period 1850–1998 (Bolin and Sukumar, 2000). Because forests and the forest sector are very sensitive to climate change (Lindner et al., 2002), the issue of using forests to absorb atmospheric carbon should be well understood. Since forest ecosystems exchange large amounts of $CO_2$ with the atmosphere through photosynthesis and respiration, they are able to sequester large amounts of carbon in regrowth stages (Schimel et al., 2001). Thus, additional to various goods and services being provided to human beings, forests act as a natural storage for carbon at the global scale, contributing approximately 80% of terrestrial aboveground, and 40% of terrestrial belowground carbon storage (Kirschbaum, 1996). Sustainable management of plantations and natural forests requires the delivery of an ongoing supply of required goods and services. Some managed forests in Europe (Valentini et al., 2000) and in North America (Greco and Baldocchi, 1996; Goulden et al., 1996a,b; Baldocchi et al., 1997) are able to take up as much as 2.5–6.6 Mg C $ha^{-1}$ per year. However, forests may also become a source of atmospheric carbon depending on the management regime designated to meet one or more objectives within a certain period of time.

Decision-making in the face of climate change requires a long-term view and appropriate models and scenarios. Because policy decisions have effects on all kinds of developments and environmental protection, demand on accurate models is high. For instance, models describing the terrestrial biosphere's response to climate are required for a complete assessment of the impacts of climate change on the global carbon cycle (Knorr, 2000). Until recently, not many studies had been done on development of models for land-use change, growing stock and carbon balance to assess forest management and potential carbon stock under different management options both in ASEAN (Association of Southeast Asian Nations) and elsewhere. The present study attempts to analyze the trends of forest management, develop scenarios based on models, and, based on these, propose appropriate measures to preserve terrestrial carbon stocks as well as to achieve sustainable forestry in this region and worldwide.

Forest management in the developing world has received more attention since the United Nations Conference on Environment and Development (UNCED) in Rio in 1992. Management of carbon stocks in forests in developing countries has received more attention since the signing of the Kyoto protocol. The protocol provides the involvement of developing countries in a global climate protection regime under its clean development mechanism (CDM). Under CDM, carbon credits through carbon trading would be gained from activities in developing countries related to reforestation and afforestation during the first commitment period (2008–2012). As forest management is already included in the Kyoto protocol as an activity for gaining carbon credits (for industrialized, so-called Annex I countries), it is likely that this will become a valid activity for tropical countries during future commitment periods. Those carbon credits could provide an effective financial incentive for sound forest management in ASEAN. If a first analysis, such as this one, shows that carbon credit incentives turn out to be a feasible option for sound sustainable forest management in this region, more studies on management practices that lead to sustainable forest management and improvement of sinks will be required. This study aims at finding the appropriate measures for sustainable use and management of tropical forests on a long-term basis.

## 2. Forests in ASEAN

ASEAN comprises 10 countries of different political backgrounds and cultures. The ten countries include Brunei, Cambodia, Indonesia, Laos, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Vietnam. Rapid economic development (4–7% per year, World Bank, 2002) and fast growing population (2.3% per year, World Bank, 2002) in ASEAN have posed much concern over the overexploitation of

Table 1
Change in forest cover in ASEAN (1990–2000)

| ASEAN | Forest cover (×1000 ha) | | Annual change rate | | Annual carbon release (Tg C) |
|---|---|---|---|---|---|
| | 1990 | 2000 | ×1000 ha | % | |
| Vietnam | 9303.0 | 9819.0 | 51.6 | 0.6 | −10.3 |
| Singapore | 2.0 | 2.0 | 0.0 | 0.0 | 0.0 |
| Brunei | 452.0 | 442.0 | −1.0 | −0.2 | 0.2 |
| Laos | 13088.0 | 12561.0 | −52.7 | −0.4 | 10.5 |
| Cambodia | 9896.0 | 9335.0 | −56.1 | −0.6 | 11.2 |
| Thailand | 15886.0 | 14762.0 | −112.4 | −0.7 | 22.5 |
| Malaysia | 21661.0 | 19292.0 | −236.9 | −1.1 | 47.4 |
| Indonesia | 118110.0 | 104986.0 | −1312.4 | −1.1 | 262.5 |
| Myanmar | 39588.0 | 34419.0 | −516.9 | −1.3 | 103.4 |
| Philippines | 6676.0 | 5789.0 | −88.7 | −1.3 | 17.7 |
| Total | 234662.0 | 211407.0 | −2325.5 | −1.0 | 465.1 |
| Percentage of net tropical deforestation (%) | | | 48.0 | | 26.0 |
| Percentage of net worldwide deforestation (%) | | | 24.7 | | 29.1[a] |

*Note*: carbon emission was estimated by area_of_forest_loss times 200 Mg C $ha^{-1}$. A 200 Mg C $ha^{-1}$ was taken as an average of gross carbon in live vegetation (i.e. before deducting the regrowth of the landscape that replaces vegetation when cleared) in Asian undisturbed tropical moist and seasonal forests (Houghton, 1999). *Source*: FAO (2001a,b).

[a] Compared with 1980s figure presented by Houghton and Hackler, (1995).

natural resources, including forest resources, to meet the various growing demands for urbanization, resettlements, agricultural land, food, timber and non-timber consumption, and other environmental services. Forest clearing, overexploitation of forest products and negligent forest management practices have caused rapid deforestation and forest degradation (Environmental Investigation Agency (EIA, 2001); FAO, 2001a; KimPhat et al., 1999). Even though data on degraded areas are difficult to obtain, deforestation has been well documented (FAO, 2001a,b; ITTO, 2000). According to FAO (2001a,b,c), ASEAN forest area declined from 234.7 million ha in 1990 to 211.4 in 2000 at an average loss rate of 1.0%. The Philippines and Myanmar have the highest rates, about 1.4% each, followed by Malaysia and Indonesia, about 1.2% each (Table 1). Although forest area in ASEAN still remains considerable large, its growing stock has declined due to many reasons, e.g. bombardment during the Vietnam War (in the case for Cambodia, Vietnam and Laos) (DFW, 1988; World Bank et al., 1996; Van, 1998), overexploitation, and illegal logging (EIA, 2001; FAO, 2001a; DFW, 1988; Global Witness, 2002; Van, 1998). The loss of forests in Cambodia has been relatively low (annual decrease of 0.6%), but growing stock has declined by about 284 million $m^3$ within 20 years during 1969–1986 (1.3% per year) (DFW, 1988), continuing until recently due mainly to over-exploitation and illegal logging (Global Witness, 2002). In addition to anthropogenic emissions as a consequence of deforestation, deforestation has caused floods and droughts in the region in recent decades. With regard to biodiversity degradation, Kou Prey (jungle cow, *Nouvibos savelis*), and some already rare luxury tree species of Beng (*Afzelia xylocarpa*) and Niengnuon (*Dalbergia beriensis*), which were found in Cambodia before 1970, have gradually disappeared. This represents an immediate need to bring the remaining forests under sustainable use and management. Based on an average carbon stock in live vegetation in Asian tropical moist and seasonal forests of 200 Mg C $ha^{-1}$ (Houghton and Hackler, 1995), it is estimated that about 465 Tg C were released every year between 1990 and 2000 from ASEAN additional to other carbon emissions from degraded forests due to overexploitation. Compared to the net carbon balance of tropical forests, this amounts to approximately 26% of net carbon release. At the global scale, where more regrowth occurs and the net source is smaller, the figure rises to about 29% (Table 1).

Figures of harvested wood in ASEAN also suggest serious overexploitation. For 1977, about 97 million $m^3$ were officially recorded[2] but the actual harvested wood was estimated at about 140 million $m^3$ (this estimate was derived by total harvested wood times illegal logging rate in each country); sources of the rates of illegal logging were quoted from EIA (2001), Djuhari (2001), Larsen (2002), World Bank et al., (1996). Rapid economic development and fast growing population have increased the demands for wood and other products, and ASEAN's actual harvested wood rose to 152 million $m^3$ in 1991. More recently, however, rapid deforestation and forest degradation in ASEAN have started to cause decline in the amount of wood available for harvest. In 2000, official rates of harvested wood were about 96 million $m^3$, but the actual harvested amount was 150 million $m^3$ (cf. Section 4.2). In Indonesia (Larsen, 2002; FWI/GFW, 2002) and Cambodia (DAI, 1998),[3] the amount of harvested wood is more than three times higher than the governments' estimation of sustainable yield.

## 3. Models and methods

### 3.1. Forest land use model

The purpose of the land use model is to provide an area-based framework for the modeling of changes in carbon stocks associated with different forest management scenarios. It is based on current observed trends in the region, and assumptions about the continuation of a political and economical framework. It considers natural forests and forest plantations, as well as a category for other uses. Natural forest (NF) in this region is classified into natural production forest (NPF), protected forest (PrF), and potential conversion forest (PoCF). Forest plantations are considered as commercial (CFPl), i.e. for wood production, and non-commercial (nCFPl), i.e. for fuelwood consumption, watershed protection, recreational and other purposes (FAO, 2001a). NPF is a forest where commercial logging is allowed. This forest is usually granted to logging companies for management under a forest concession agreement between the government as a resource owner and companies as forest management practitioners. Due to the fact that such forest is controlled and managed by concession holders or concessionaires, and access to such forest is very limited, it is likely that deforestation, except for degradation of growing stocks, will not take place in this forest (see next for its assumption). Protected forest, where logging is prohibited, includes national parks, wildlife sanctuaries, areas of scenery and landscape protection and other lands under protection. Potential conversion forest is forest subject to conversion to resettlements for peasant farmers, agricultural lands, urban areas, forest plantation and others under the governments' development plan. It will be converted to forest plantation (FPl) and other land uses as mentioned above. The change of PoCF and FPl can be estimated by equations as shown below. We assume a constant share of established forest plantations to be for commercial purposes, the rest being established as non-commercial forest plantation. The time horizon for this model is 1980–2050. The basic equations are as follows:

$$\frac{\mathrm{dPoCF}(t)}{\mathrm{d}t} = -(k_a + k_b) \times \mathrm{PoCF}(t) \quad (1)$$

$$\mathrm{NPF}(t) = \mathrm{NPF}(0) \quad (2)$$

$$\mathrm{TPrF}(t) = \mathrm{TPrF}(0) \quad (3)$$

Note: TPrF is the total protected forests (see next)

$$\frac{\mathrm{dFPl}(t)}{\mathrm{d}t} = k_a \times \mathrm{PoCF}(t) \quad (4)$$

$$\mathrm{CFPl}(t) = f_c \times \mathrm{FPl}(t) \quad (5)$$

The total area of forest used, total production forest (TPF), for commercial purposes is thus $\mathrm{TPF}(t) = \mathrm{NPF}(t) + \mathrm{CFPl}(t)$. The assumption is that non-protected forest is being converted to either forest plantations or other uses proportional to its area by two distinct rates, with rate constants $k_a$ and $k_b$,

[2] We assumed that harvested wood reported in ITTO (1994)'s country report World Bank et al. (1996), World Bank et al. (2001), FD (1997) and Van (1998) was officially recorded wood, whilst actual wood harvested was estimated by multiplying officially recorded wood with illegal logging rates in individual countries in the region.

[3] Note: DAI (Development Alternatives, Inc.) is a US-based consultant company hired in 1997 by World Bank (IDA Credit 2664-KH) to conduct a national assessment of illegal forestry activities in Cambodia, evaluate present log tracking and timber revenue assessment systems, and recommend improved procedures within the context of a comprehensive forest law enforcement program.

respectively. The fraction of forest plantation being established for commercial purposes, $f_c$, is estimated to be 0.48 (FAO, 2001a). Data are available for total natural forest (NPF + PrF + PoCF), and total forest plantations by country (FAO, 2001a,b). Due to data unavailability for natural production forests in ASEAN countries in the same relevant year, areas of NPF in various years, e.g. 1992 for Cambodia (KimPhat et al., 2001), 1985 for Indonesia (FWI/GFW, 2002), 1991 for Malaysia and Thailand (ITTO, 1994), 1995 for Vietnam (Van, 1998) and Myanmar (FAO, 1997), and 1997 for Laos (World Bank et al., 2001) are assumed to be those of 1980. Areas of NPF in Philippines and Brunei are assumed to be 50% of their 1990s total forest areas, while NPF in Singapore is zero. Under business as usual (BAUSU) scenario, 1% of NPF is assumed to be deforested due to land encroachments by peasant farmers resulting from logging concessionaires' abandonment after NPF has been logged. Under long-term economic gains (LEGA) and climate beneficial option (CLIBO) scenarios, areas of NPF in individual countries are assumed to remain unchanged (in terms of area). After excluding 30% of inoperable areas such as villages, waterways (rivers, gullies, ponds, lakes, etc.), culturally, environmentally and scientifically important sites, steep slopes, and others, the amount of natural production forest at $t = 0$ (1980) suitable for commercial logging is estimated at 69.0 million ha. It is assumed that 0.5% or about 0.35 million ha of NPF is annually degraded due to overexploitation or logging damages. This 0.35 million ha is designated as protected forest, and the same amount is taken back from non-degraded PrF. Due to data unavailability on protected forests in ASEAN countries in the same relevant year, total area of PrF in this region obtained from database of UNEP-WCMC (2002) is assumed to be data of PrF in 1980. Since 30% of areas excluded from natural production forest is added to PrF, the total amount of protected forest (TPrF = PrF + inoperable areas) is 81.4 million ha. Under the governments' policy that may be changed over time, we assume that 0.35 million of non-degraded PrF is annually allocated to NPF. Therefore, in terms of area, NPF and TPrF will remain unchanged until 2050, the time horizon of this model (1980–2050). In the context of sustainable forest management, it is essential that the perpetual supplies of wood, goods and services from forests be ensured; thus at minimum, area of NPF should remain unchanged. The amount of PoCF is obtained by subtracting NPF, TPrF, FPl from the data on total forest for each reference year (Table 2). The parameters $k_a$ and $k_b$, as well as the initial conditions PoCF(0) and FPl(0), were determined by performing a least-squares fit to the data. (For PoCF, we linearized the equation by taking the natural logarithm, while after integrating Eqs. (1) and (4) is already linear in $k_b$. Values were then determined through linear regression.)

Table 2
Area of natural forests and forest plantation in ASEAN (1980–2000) (unit: million ha)

| ASEAN forests | 1980 | 1990 | 2000 |
|---|---|---|---|
| NPF[a] | 69.0 | 69.0 | 69.0 |
| TPrF[a] | 81.4 | 81.4 | 81.4 |
| PoCF[b] | 109.7 | 75.6 | 41.0 |
| FPl | 2.6 | 8.9 | 20.0 |
| TF = sum above | 262.7 | 234.9 | 211.4 |

[a] Assumed to be constant.
[b] Obtained by subtraction of FPl, NPF and PrF from TF.

### 3.2. Models for growing stock and carbon stock

The models presented in this section are applied to natural production forest as well as for commercial forest plantations. The purpose is to provide an estimate of changing carbon stocks on the managed forest lands whose future protected area changes are described by the land use model previously discussed.

#### 3.2.1. Modeling method and assumptions

Defining sustainable forest management as management of forest for sustainable wood production while at the same time fulfilling the environmental protection and the interests of all stakeholders, three scenarios of forest management are considered in this study:

(1) *Business as usual* (BAUSU): Harvesting the forests as usual including over-cut and illegal logging, with no plantings/reforestation, and with improperly planned logging practice. Although there is no or almost zero direct cost, this logging practice causes great damage to residuals and soils, and destruction of culturally important

sites and wildlife habitats. Logging companies or concessionaires are granted a short-term contract, i.e. less than one cutting cycle (30 years), under which term many concessionaires have no intention to invest in camp constructions for company workers and their families. Thus, companies are likely to leave after they have completed the initial harvest and cutover forests are occupied by peasant farmers.

(2) *Long-term economics gains* (LEGA): Harvest rates at a level equal to forest regeneration rates, with enrichment plantings/reforestation and with conventional logging (CVL) practice. Although there is little cost, conventional logging practices cause damages to residual stands and soils, and environmental degradation. Wood waste is also higher compared to RIL (see next, and Table 3). Under this scenario, growing stock is preserved and remains constant at a long-term average. Under LEGA and CLIBO, concessionaires are granted a long-term contract, i.e. more than one cutting cycle (30 years), under which term they have intention to construct camps and other infrastructures for company workers and their families. Thus, companies are likely to have long-term commitment to do logging business as well as sustainable forest management. Forest concessions can be then protected from being encroached by peasant farmers or the like.

(3) *Climate beneficial option* (CLIBO): Harvest as a proportion of growing stock at the same rate as under LEGA, with enrichment plantings and afforestation/reforestation, but with reduced-impact logging (RIL) practice. Improving wood processing technology, making utmost use of harvested wood and others are also included. RIL has a higher cost, but it is capable of reducing damages and wood waste and increasing annual increment (Tables 3 and 4). Under the

Table 3
Some studies on CVL and RIL

| Country | CVL | RIL |
|---|---|---|
| Tree damages (%) (as percentage of individual commercial residual stands with DBH > 35 cm) | | |
| Sabah, Malaysia[a] | 56.0 | 29.0 |
| Sarawak, Malaysia[b] | 54.0 | 28.0 |
| East Kalimantan, Indonesia[c] | 48.4 | 30.5 |
| Wood waste (%) (as percentage of volume of harvested commercial timber) | | |
| Sarawak, Malaysia | 20.0 | 0.0 |
| Eastern Brazil[d] | 24.0 | 8.0 |
| East Kalimantan, Indonesia | 46.2 | 26.2 |

[a] Costa and Tay (1996).
[b] FAO (2001c).
[c] Sist and Saridan, 1998.
[d] Holmes et al. (2002).

Table 4
Model assumptions for natural production forest, for forest plantations

| Assumptions | BAUSU | LEGA | CLIBO |
|---|---|---|---|
| (a) For natural forests | | | |
| TPrF | | | |
| VD ($t = 0$) ($m^3$ $ha^{-1}$) | 200.0 | 200.0 | 200.0 |
| PoCF | | | |
| VD ($t = 0$) ($m^3$ $ha^{-1}$) | 100.0 | 100.0 | 100.0 |
| NPF | | | |
| VD ($t = 0$) ($m^3$ $ha^{-1}$) | 200.0 | 200.0 | 200.0 |
| $G_{MAI}$ ($m^3$ $ha^{-1}$ per year) | 1.0 | 1.0 | 2.0 |
| CC (years) | 30.0 | 30.0 | 30.0 |
| $f_w$ (fraction of wood extraction) | 0.905[a] | 0.300 | 0.300 |
| $f_T$ (fraction of mature trees)[b] | 0.5 | 0.5 | 0.5 |
| $s$ (waste wood) | 0.5 | 0.3 | 0.1 |
| (b) For forest plantations | | | |
| nCFPl: management for fuelwood or poles | | | |
| VD ($t = 12$) ($m^3$ $ha^{-1}$) | 60.0 | 60.0 | 60.0 |
| CC (years) | 12.0 | 12.0 | 12.0 |
| CFPl: management for industrial purposes | | | |
| VD ($t = 30$) ($m^3$ $ha^{-1}$) | 150.0 | 150.0 | 150.0 |
| $G_{MAI}$ ($m^3$ $ha^{-1}$ per year) | 5.0 | 5.0 | 5.0 |
| CC (years) | 30.0 | 30.0 | 30.0 |
| $f_w$ (fraction of wood extraction) | 1.0 | 1.0 | 1.0 |
| $f_T$ (fraction of mature trees) | 1.0 | 1.0 | 1.0 |
| $s$ (waste wood) | 0.1 | 0.1 | 0.1 |

[a] 267.5 million $m^3$ wood harvest (including illegal)/88.7 million ha (of NPF) $\times$ CC/(VD $\times f_T$), cf. Eq. (7).

[b] By assuming that all trees with diameter at breast height (DBH) greater than 50 cm are mature, mature trees of lowland forests in East Kalimantan (Indonesia) was estimated at 0.56 in between 1989 and 1995 (Sist and Saridan, 1998). KimPhat et al. (2000, 2002) estimated $f_T$ at 0.54 and 0.55 for evergreen and mixed forests, respectively, in central Cambodia. Due to the fact that there had been illegal logging and over-cutting activities in almost all ASEAN forests, and since our model starts from the year 2000, $f_T$ is assumed at 0.5 for this study. Future adjustment for $f_T$ is essential when more data become available.

CLIBO scenario, growing stock is allowed to increase leading to higher harvest and creating a carbon sink as the direct result of additional investment in a more sustainable logging practice.

For modeling assumptions, please refer to Table 4a and b.

### 3.2.2. Growing stock model

Besides natural disasters, growing stock is influenced by management regimes, e.g. planting and harvesting practices. Harvesting practice is a focal point for this model, which is applied only to production forests (natural forests and commercial forest plantations) on a per-area basis. Growing stock in ASEAN can be estimated by

$$\frac{\mathrm{dVD}}{\mathrm{d}t} = G_{\mathrm{MAI}} - \mathrm{WH} \tag{6}$$

where dVD/d$t$ is the change of growing stock or volume density ($\mathrm{m^3\,ha^{-1}}$) over time $t$, $G_{\mathrm{MAI}}$ is the mean annual increment ($G_{\mathrm{MAI}}$ = growth − mortality) ($\mathrm{m^3\,ha^{-1}}$ per year), WH is wood harvested ($\mathrm{m^3\,ha^{-1}}$). WH is estimated by

$$\mathrm{WH} = \frac{f_{\mathrm{w}} \times f_{\mathrm{T}} \times \mathrm{VD}}{\mathrm{CC}} \tag{7}$$

where $f_{\mathrm{w}}$ is the fraction of wood extraction (the fraction of harvestable trees actually harvested), $f_{\mathrm{T}}$ is the fraction of mature trees (refer to Table 4a for study assumptions), VD is again growing stock ($\mathrm{m^3\,ha^{-1}}$), and CC is the cutting cycle, or rotation period.

The present average growing stock in natural forests in ASEAN was estimated as follows: at 176 $\mathrm{m^3\,ha^{-1}}$ (FAO and DFW, 1998) to 235 $\mathrm{m^3\,ha^{-1}}$ (KimPhat et al., 2000; World Bank et al., 1996) in Cambodia, 150 $\mathrm{m^3\,ha^{-1}}$ (Van, 1998) in Vietnam, and 76 $\mathrm{m^3\,ha^{-1}}$ (FAO, 2001a) to 402 $\mathrm{m^3\,ha^{-1}}$ (Sist and Saridan, 1998), in East Kalimantan, Indonesia. Allowable cuts in forests in some selected ASEAN countries are 25–40 $\mathrm{m^3}$ (KimPhat et al., 2000, 2002), 24 $\mathrm{m^3}$ (Van, 1998), 30 $\mathrm{m^3}$ (World Bank, 2002), 30 $\mathrm{m^3}$ (ITTO, 1994), 30–40 $\mathrm{m^3}$ (ITTO, 1994) in Cambodia, Vietnam, Laos, Thailand, and Malaysia, respectively. Based on a mean annual increment of 1 $\mathrm{m^3\,ha^{-1}}$ per year (FAO and UNEP, 1981), allowable cut for Indonesia's forest was estimated at 30 $\mathrm{m^3\,ha^{-1}}$ over a 30 cutting cycle. The mean annual increment for plantation of fast and slow growing species (Eucalypts, Acacias, pines (*Pinus spp.*), teak (*Tectona grandis*), etc.) varies from about 4 to 20 $\mathrm{m^3\,ha^{-1}}$ per year (FAO, 2001a). Depending on tree species and management purposes (i.e. for fuelwood, poles or pulpwood), rotation of forest plantations ranges from 6 to about 70 years (FAO, 2001a).

For this study, the initial growing stock of natural forests is assumed at 200 $\mathrm{m^3\,ha^{-1}}$ for the whole ASEAN, and the mean annual increment (=$G_{\mathrm{MAI}}$) 1 $\mathrm{m^3\,ha^{-1}}$ per year (after killed trees are deducted), giving an allowable cut of 30 $\mathrm{m^3\,ha^{-1}}$ over a selective cutting cycle of 30 years. For natural production forest under the LEGA scenario, that means (Table 4a) $\mathrm{WH} = (0.15 \times 200\,\mathrm{m^3\,ha^{-1}})/30\,\mathrm{years} = 1\,\mathrm{m^3\,ha^{-1}}$ per year = $G_{\mathrm{MAI}}$, so that growing stock is constant. For BAUSU, the rate of illegal logging was estimated as 53%, which was obtained from country-wise data of illegal logging from the following sources: DAI (1998), EIA (2001), Larsen (2002), Van (1998) and World Bank et al., (1996). Based on average legal harvested wood between 1977 and 2000 (Fig. 3), we estimated legal wood harvested at 42% above sustainable rates. The initial growing stock of commercial forest plantation is assumed at 5 $\mathrm{m^3}$, equivalent to mean annual increment (=$G_{\mathrm{MAI}}$) of 5 $\mathrm{m^3\,ha^{-1}}$ per year (see above). As a clear-cutting rotation of CC = 30 years is assumed, the maximum growing stock in CFPl is 150 $\mathrm{m^3\,ha^{-1}}$.

## 3.3. Wood production model

While the world's population is still growing, demands for wood and other products are expected to increase as well. Therefore, it is important that trees should be carefully cared, felled and utilized because it can produce more wood production from the same amount of wood that is harvested from the forest. Here, wood production is estimated by

$$\mathrm{WP} = \mathrm{WH} \times (1 - s) \tag{8}$$

where WP is the wood production in $\mathrm{m^3}$ per year, WH is the wood harvested in $\mathrm{m^3}$ per year, and $s$ is the fraction of wood waste caused by logging, skidding and tree-bole trimming, depending on the chosen scenario. Under current conditions (BAUSU), waste is about half of the harvest including illegal logging, but would be reduced to 30% under LEGA. Wood waste is expected to be even further reduced under the CLIBO scenario (Holmes et al., 2002; FAO, 2001c; Sist and Saridan, 1998; Costa and Tay, 1996) (see Table 3). Total annual WP in natural forest is simply estimated by WP per hectare in each year times the area of NPF. Due to the fact that trees planted in 1980 (assumed that area of forest plantation in 1980 is that of trees planted in 1980) will become harvestable 30 years later, WP from CFPl in ASEAN will be available from 2010.

Total wood harvested from natural production forests and commercial forest plantations in ASEAN can be thus estimated by

$$\mathrm{TWP}(t) = \mathrm{TWP}_{\mathrm{NPF}}(t) + \mathrm{TWP}_{\mathrm{CFPl}}(t) \quad (9)$$

$$\mathrm{TWP}_{\mathrm{NPF}}(t) = \mathrm{NPF}(t) \times \mathrm{WP}(t) \quad (10)$$

$$\mathrm{TWP}_{\mathrm{CFPl}}(t) = \mathrm{CFPl}_{(t-30)}\,\mathrm{WP} \quad (11)$$

Here, TWP($t$) is the total wood production at year $t$, $\mathrm{TWP}_{\mathrm{NPF}}(t)$ is the total wood production in natural production forest, $\mathrm{TWP}_{\mathrm{CFPl}}(t)$ is the total wood production in commercial forest plantation, CFPl($t-30$) is the total commercial forest plantation 30 years after establishing. WP($t$) in Eq. (10) is wood production of NPF, changing over time with growing stocks (VD), while WP in Eq. (11) is for CFPl and therefore constant.

### *3.4. Carbon stock model*

Under the three management scenarios defined in the previous section, this model considers only aboveground carbon (in live vegetation only), $C$, which is estimated by

$$C = \mathrm{CD} \times \mathrm{BEF} \times \mathrm{WD} \times \mathrm{VD} \quad (12)$$

where CD is the carbon density in dry matter ($\mathrm{CD} = 0.5$ for tropical forests (Brown, 1997)), BEF is the biomass expansion factor, determined from (Brown, 1997):

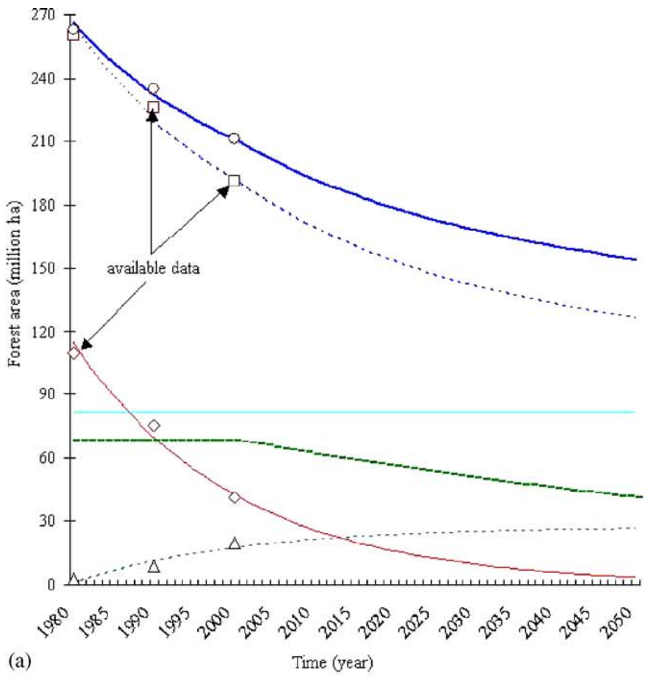
$$\mathrm{BEF} = \mathrm{e}^{3.213-0.506\ln(\mathrm{BV})} \quad (13)$$

where BV is the biomass of inventoried volume in Mg $\mathrm{ha}^{-1}$, calculated as the product of growing stock, VD ($\mathrm{m}^3\,\mathrm{ha}^{-1}$) and wood density, WD (Mg $\mathrm{m}^{-3}$). WD is 0.57 Mg $\mathrm{m}^{-3}$ for tropical forests (Brown, 1997).

## 4. Results

### *4.1. Future projections of forest land use (1980–2050)*

The forest land use model suggests that potential conversion forest declines sharply to 3.6 million ha in 2050 for all three scenarios (BAUSU, LEGA and CLIBO), representing an average loss of 1.6 million ha per year, or an annual rate of decline of 4.9% ($= k_a + k_b$) between 1980 and 2050. The rate of conversion to forest plantation, $k_a$, is 1.1% per year, i.e., conversion accounts for about 22.4% of the decline. Forest plantations are thus expected to increase by an average of 0.4 million ha per year from 1980 to 2050, up to a total of 27.3 million ha. The increase of FPl leads to an increase of commercial forest plantation as well as total production forest. Additional to PoCF, NPF (under BAUSU) declines 1% or 0.7 million ha annually from 2000 when management scenario (logging) began. It declines to 42.7 million ha in 2050 (Fig. 1a). Overall under BAUSU, total natural forests ($\mathrm{TNF} = \mathrm{NPF} + \mathrm{TPrF} + \mathrm{PoCF}$) declines from 264.6 to 126.8 million ha, represent an annual loss of 2.0 million ha or 0.7% between 1980 and 2050. However, since this loss is compensated by the increase in forest plantation ($\mathrm{FPl} = \mathrm{CFPl} + \mathrm{nCFPl}$), the annual loss of total forests ($\mathrm{TF} = \mathrm{TNF} + \mathrm{FPl}$) is estimated at about 1.6 million ha ($1.6 = -2.0 + 0.4$) between the same period. Under LEGA and CLIBO as, in terms of area, natural production forest and total protected forest (TPrF) are assumed to be constant at 69.0 and 81.4 million ha, respectively, during the forest land use modeling period (1980–2050), the only changes in PoCF and FPl are observed. In general under LEGA and CLIBO, total forest (TF) in ASEAN continues to decline at an average rate of 1.2 million ha ($= -1.6 + 0.4$) or 0.5% per year between 1980 and 2050 (Fig. 1b). The model shows that ASEAN deforestation seems to slow down from 2030 to 2050 due to unavailability of conversion forest land. If immediate measures are taken to prevent other natural forests (natural production and protected forests) from deforestation and degradation, deforestation in the region likely to slow down from the next 30 years. Otherwise, all natural forests in the region will be deforested and converted to agricultural lands, forest plantations and others. Such a scenario would



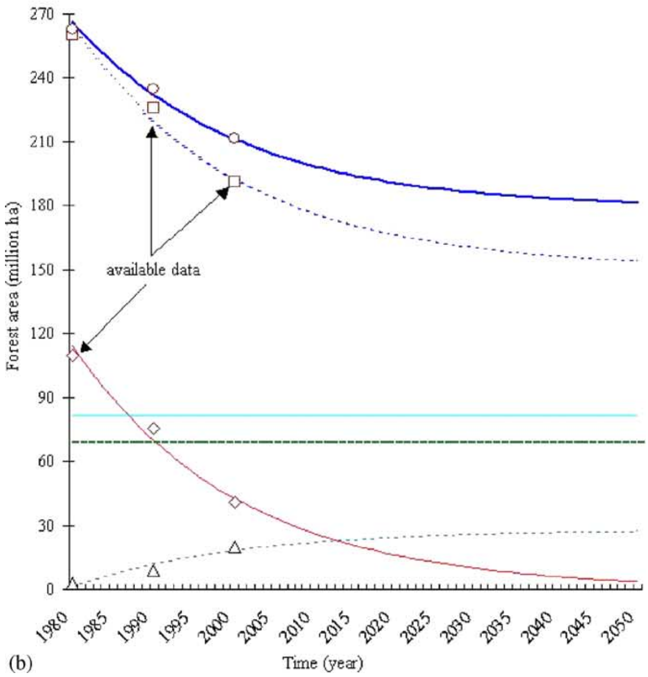




Fig. 1. (a) Forest land use in ASEAN under BAUSU (1980–2050); (b) forest land use in ASEAN under LEGA and CLIBO (1980–2050).

cause severe environmental problems, such as floods, droughts, underground water shortage, soil depletion and other unpredicted events. Severe floods and droughts have already occurred in Southeast Asia (Adventist Development and Relief Agency (ADRA, 2000); International Federation of Red Cross and Red Crescent Societies (IFRC, 2002)).

### 4.2. Projections of growing stock and forest carbon in ASEAN (2000–2050)

At the current rate of illegal logging of 53% (under business as usual), the model suggests that almost all mature trees in ASEAN would be logged in about 40 years because growing stock will fall below 50% of its value in 2000 (Fig. 2). Growing stock declines about 1.41 $m^3\,ha^{-1}$ per year under this scenario between 2000 and 2050. Under long-term economic gains, growing stock remains constant because harvest is equal to mean annual increment. Under CLIBO, as logging damages are significantly reduced, natural regeneration is taken care of, and enrichment planting is carried out when necessary (example when and where significant logging damages occur) growing stock rises significantly. Between 2000 and 2050, annual growing stock of natural forest increases at about 0.89 $m^3\,ha^{-1}$ per year (Fig. 2). Under this scenario, growing stocks of ASEAN forests reach near-equilibrium at about 400 $m^3\,ha^{-1}$ in approximately year 3000. This figure is almost the same or slightly greater than those in some natural forests with little or no illegal logging in ASEAN, e.g. 402 $m^3\,ha^{-1}$ (standard deviation is 61.0) in lowland mixed dipterocarp forest of East Kalimantan, Indonesia (Sist and Saridan, 1998), 348 $m^3\,ha^{-1}$ in lowland forest of Sandan district, Cambodia (KimPhat et al., 2000).

Since wood harvest (WH) and wood product (WP) are determined as percentages of growing stock or

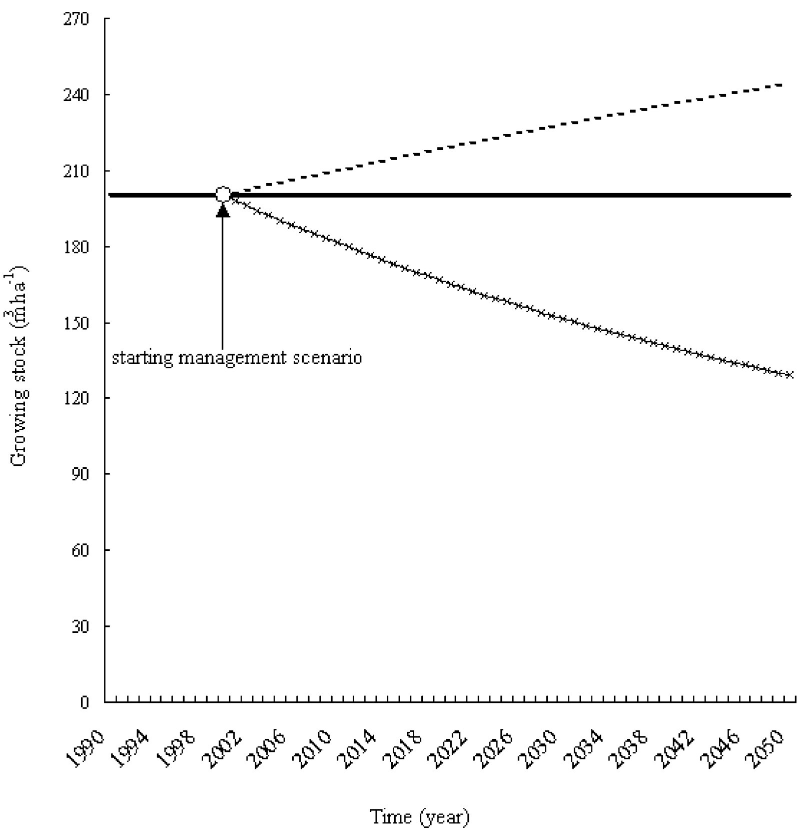



Fig. 2. Growing stock under three scenarios (2000–2050).

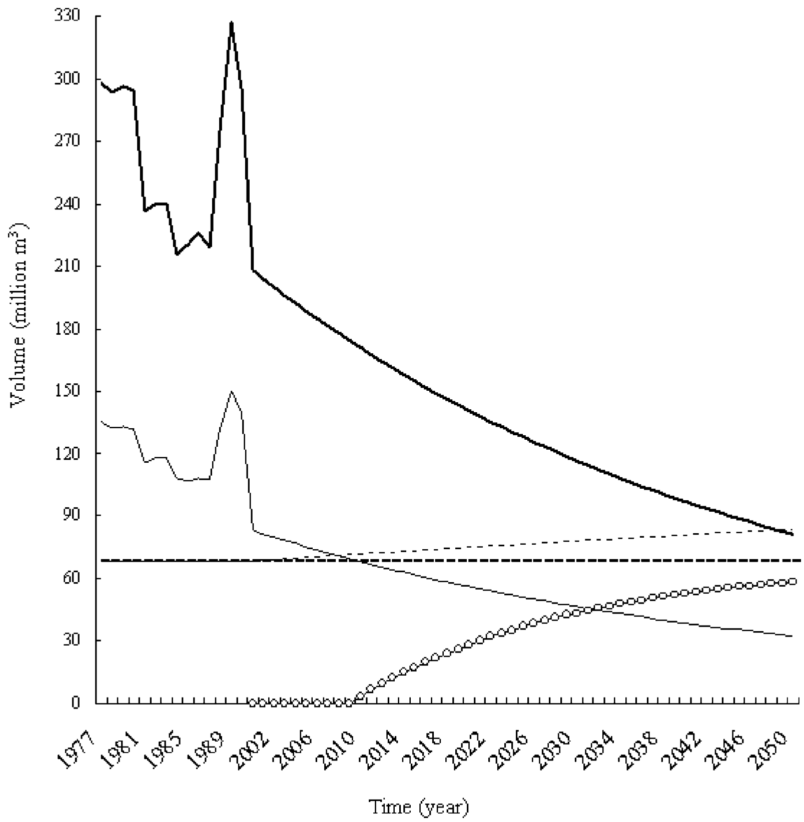



Fig. 3. Total wood harvested in ASEAN forests (1977–2050). BAUSU 1977–2000 are based on available data.

volume density (VD), the change in growing stock leads to the change in WH and WP as well. Under BAUSU scenario, total annual WH and WP decline from 208.2 (including illegal WH) and 104.1 million $m^3$ (including illegal WP) in 2000 to 81.3 and 40.7 million $m^3$, respectively, representing average annual loss of 2.5 and 1.3 million $m^3$, respectively. WH and WP remain constant at 69.0 and 48.3 million $m^3$, respectively under LEGA. There is a significant increase under CLIBO scenario; WH and WP increase from 69.0 and 62.1 million $m^3$ in 2000 to 84.3 and 75.8 million $m^3$, respectively in 2050 (Figs. 3 and 4). Besides WH and WP from natural production forest, commercial forest plantation is likely to become a major source of wood supply in the region. From 2010 when the first planted trees becomes harvestable, WH and WP sharply increase from 3.6 and 3.2 million $m^3$ in 2010 to 58.7 and 52.8 million $m^3$, respectively, under the three scenarios (Figs. 3 and 4).

The initial carbon stock in natural production forest in the year 2000 is 129 Mg C $ha^{-1}$. Results of this model suggest that carbon stock decreases from 129 Mg C $ha^{-1}$ in 2000 to 103.9 Mg C $ha^{-1}$ in 2050, representing a decline of about 0.5 Mg C $ha^{-1}$ per year under BAUSU, stays constant (129 Mg C $ha^{-1}$) under LEGA while it even increase to 142.3 Mg C $ha^{-1}$, representing an increase of about 0.3 Mg C $ha^{-1}$ per year under CLIBO. This figure (0.3 Mg C $ha^{-1}$ per year) is similar to the potential sinks in the tropics estimated by Sampson and Scholes (2000), namely about 0.2 Mg C $ha^{-1}$ per year in well-managed agroforests, 0.3–0.5 Mg C $ha^{-1}$ per year in managed forests. It is also similar to the potential sinks during 2008 through 2012 (first commitment period of the Kyoto protocol) as a result from intensive forest management estimated in Austria (0.6 Mg C $ha^{-1}$ per year), Norway (0.4 Mg C $ha^{-1}$ per year), Sweden (0.6 Mg C $ha^{-1}$ per year), UK (0.4 Mg C $ha^{-1}$ per year), Bulgaria (0.4 Mg C $ha^{-1}$ per year), Czech

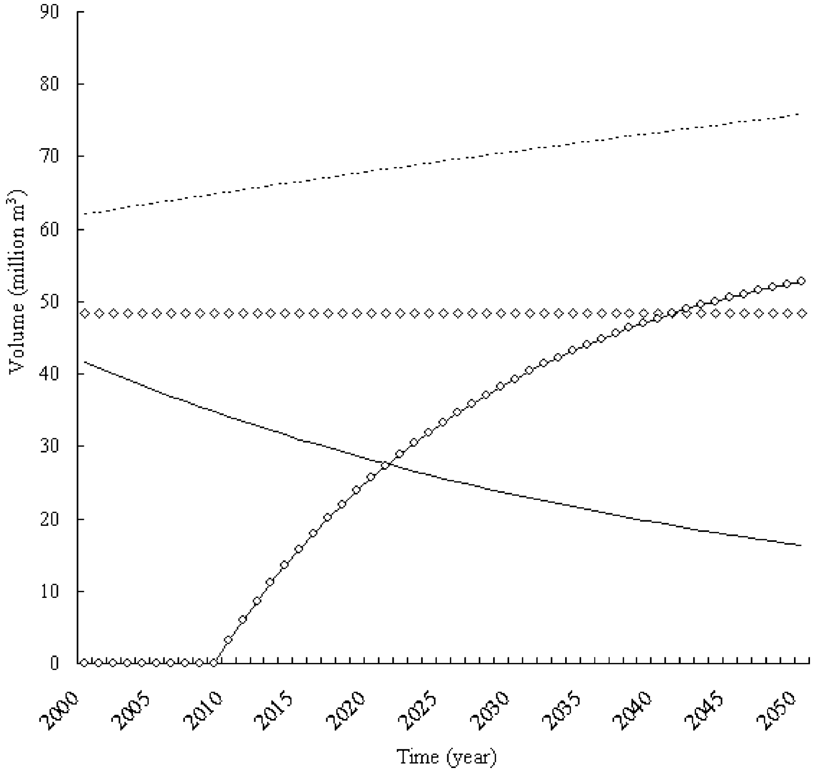



Fig. 4. Wood product without illegal logging in ASEAN forests (2000–2050).

Republic (0.3 Mg C ha$^{-1}$ per year), Hungary (0.3 Mg C ha$^{-1}$ per year), Latvia (0.3 Mg C ha$^{-1}$ per year), Lithuania (0.3 Mg C ha$^{-1}$ per year), Slovakia (0.5 Mg C ha$^{-1}$ per year) and Slovenia (0.4 Mg C ha$^{-1}$ per year) (UNFCCC, 2001) (Table 5). The maximum carbon stock under CLIBO would be 182 Mg C ha$^{-1}$ in the year 3550. Total carbon stock in live vegetation in undisturbed tropical forest in Asia was estimated at 250.0 Mg C ha$^{-1}$ (Houghton, 1999).

Table 5
Estimate of potential sinks during 2008 through 2012 as a result from intensive forest management n some selected countries

| Country | Potential sink (Mg C ha$^{-1}$ per year) |
|---|---|
| Czech republic | 0.3 |
| Hungary | 0.3 |
| Latvia | 0.3 |
| Lithuania | 0.3 |
| Bulgaria | 0.4 |
| Norway | 0.4 |
| Slovenia | 0.4 |
| United Kingdom | 0.4 |
| Slovakia | 0.5 |
| Austria | 0.6 |
| Sweden | 0.6 |

*Source*: UNFCCC (2001).

### 4.3. Regional integration and carbon balance

Since forest management takes place in production forest only, only changes in carbon stocks in total production forests (natural production forest and commercial forest plantation) under three different scenarios are presented. Under BAUSU between 2000 and 2050, carbon stock in natural production forest declines from 8.9 to 4.3 PgC, equaling an annual loss of 91.2 Tg C. As carbon stock in commercial forest plantation increases by 13.3 Tg C per year, the loss is reduced to 77.9 Tg C per year. Under LEGA, only increase of carbon stock in FPl could be seen over the same period as BAUSU. Under CLIBO, however, carbon stock increases from 8.9 PgC in 2000 to 9.8 PgC in 2050, equivalent to an increase of

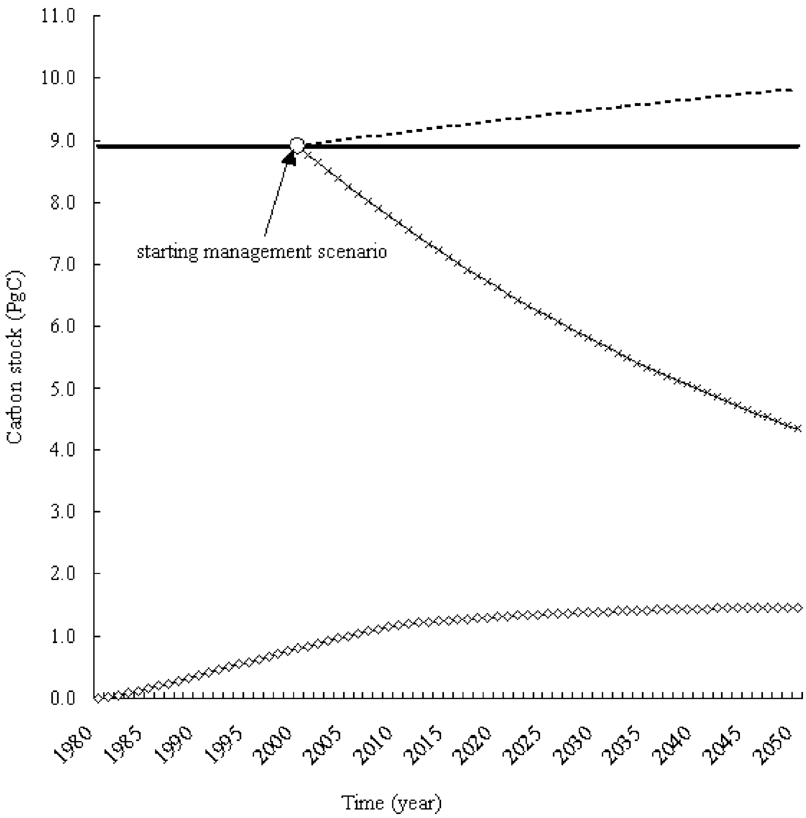



Fig. 5. Carbon stock in total production forest (1980–2050).

18.5 Tg C per year. Thus, total carbon stock increase under CLIBO is 31.8 Tg C per year over the same period as BAUSU and LEGA (Fig. 5).

Although carbon stock in total forest plantation (commercial and non-commercial plantations) increases about 20.1 Tg C per year between 2000 and 2050, ASEAN forests are still a source of atmospheric carbon. This is because natural forests in ASEAN still decline. Land use change leads to the loss of carbon stock from natural forest of 162.7, 71.5 and 53.0 Tg C per year under BAUSU, LEGA and CLIBO scenarios, respectively. However, since these figures are compensated by increased carbon in forest plantations, total carbon loss (aboveground carbon) from ASEAN forests between 2000 and 2050 is 142.6, 51.4 and 33.0 Tg C per year under BAUSU, LEGA and CLIBO scenarios, respectively (Fig. 6). Due to the fact that the loss of forest cover would lead to the loss not only of aboveground tree carbon, but also of belowground (roots), undergrowth, and soil carbon, it is expected that additional carbon would be released to the atmosphere over this period.

## 5. Scope for carbon sequestration

As far as environmental protection, demand for wood and non-wood products, and other goods and services are concerned, forests should not be left unmanaged. Sound forest management is capable of providing hard currency for economic development and jobs for million peoples, protecting the environment and interests of all stakeholders, improving the forest stands that can lead to more productivity in terms of wood and non-wood products, and thus increase forest capacity to sequester atmospheric carbon. Only carbon gains resulting from forest management are discussed in this section. This carbon gain is

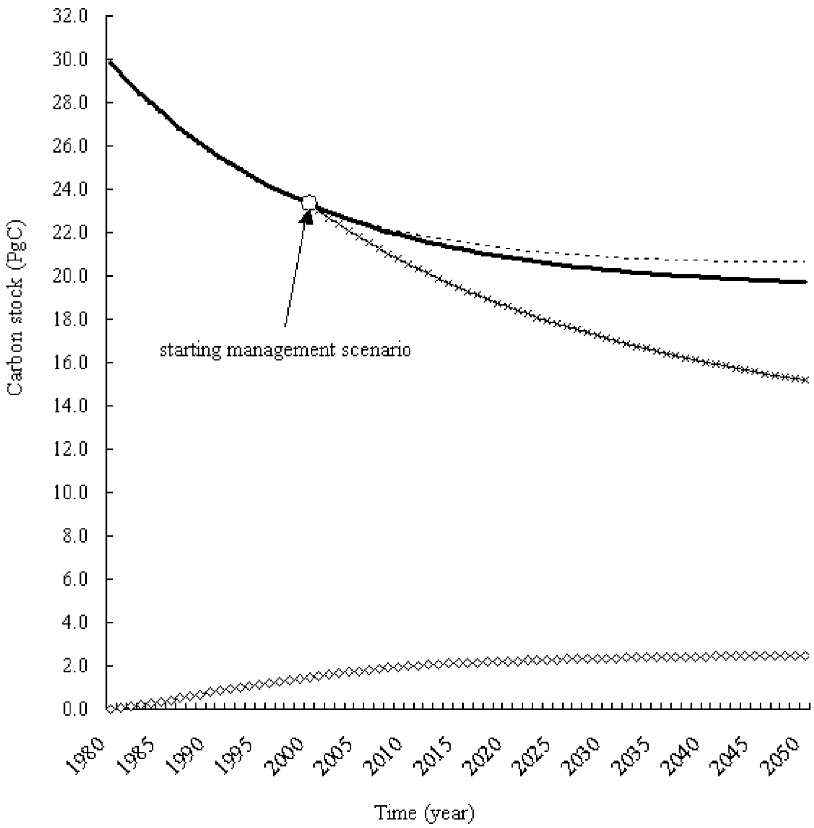



Fig. 6. Carbon stock in total forests in ASEAN (1980–2050).

estimated as the difference in carbon fluxes between CLIBO and LEGA, because LEGA constitutes a baseline scenario that is motivated by other considerations than carbon sequestration (Fig. 5). (Applying a similar principle of additionality as is required under the Kyoto protocol.)

## 5.1. Legal framework

Under article 12 (clean development mechanism) of the Kyoto protocol, Annex I countries are allowed to invest in carbon trading with non-Annex I countries (mostly developing countries). All human-induced activities that lead to a reduction in carbon release to the atmosphere (for instance, slowing down or stopping deforestation), and to enhance carbon sinks, e.g. through afforestation, reforestation and sound management practices, could, in principle, be eligible for carbon credits. Although forest management and conservation in non-Annex I countries are not included for the first commitment period (2008–2012), they are likely to be included in later commitment periods, since otherwise forest degradation and deforestation may not be minimized.

## 5.2. Cost estimates for carbon sequestration

Recent studies on the cost of reduced impact logging (RIL) give an estimate of extra cost of RIL at US$ 0.08 $m^{-3}$ $ha^{-1}$ (refer to Table 6 for various costs) in Eastern Amazon, Brazil (Holmes et al., 2002), US$ 4.04 (refer to Table 6 for various costs) in Sarawak, Malaysia (FAO, 2001c), and US$ 5.0 in Sabah, Malaysia (Costa and Tay, 1996) for every cubic meter of wood harvested. For this study, we assume at US$ 4.0 $m^{-3}$. There is an extra cost for forest certification (fee to certify that forest is sustainably managed in order that its products can be sold at a very competitive

Table 6
Costs in CVL and RIL in Sarawak and Eastern Amazon (unit: US\$ $m^{-3}$ wood harvested)

| Operation description | Sarawak, Malaysia | | | Eastern Amazon, Brazil | | |
|---|---|---|---|---|---|---|
| | CVL | RIL | Differences | CVL | RIL | Differences |
| Training | 0.00 | 1.59 | 1.59 | 0.00 | 0.21 | 0.21 |
| Pre-harvest and harvest planning: coupe/block layout, inventory, tree marking, data processing, road and log stockpile planning, others | 0.13 | 1.15 | 1.02 | 0.14 | 1.34 | 1.20 |
| Harvesting operations: road construction, log stockpile preparation, felling, skidding, others | 7.22 | 8.34 | 1.12 | 5.06 | 3.73 | −1.33 |
| Post-harvest operation: damage assessment and RIL compliance assessment, others | 0.00 | 0.30 | 0.30 | NA | NA | NA |
| Total | 7.35 | 11.38 | 4.03 | 5.20 | 5.28 | 0.08 |

*Note*: costs for logging in Sarawak was converted to US\$ from Ringitt (RM) at the exchange rate of US\$ 1.0 = RM 3.8. NA is information not applicable. *Source*: Costa and Tay (1996), Holmes et al. (2002).

price and it can be qualified for carbon credit incentive) and for improving wood processing and other technologies, such that the additional cost for introducing RIL under CLIBO would be US\$ 5.9 $m^{-3}$ (Table 7). Since natural production forest is capable of sequestering 0.3 Mg C $ha^{-1}$ per year, a cost of carbon can be estimated at around US\$ 19.7 per Mg C (Table 8).

Table 7
Extra cost per $m^3$ of harvested wood in reduced-impact logging under CLIBO

| Measure | Cost (US\$ $m^{-3}$) | Remarks |
|---|---|---|
| Reduce impact logging | 4.0 | |
| Forest certification | 1.4 | 1% of US\$ 140 $m^{-3}$ of wood harvested (Sarawak, January 2000) |
| Others | 0.5 | Wood processing technology and other technology transfer |
| Total | 5.9 | |

The cost of carbon per ton (US\$ 19.7 per Mg C) found in this study lies well within the range of other scientists' assumptions for their studies of forest carbon sequestration. For instance, Kirschbaum (2001) assumed a cost of US\$ 10 per Mg C for his estimation of correspondence of costs for indefinite carbon savings into different arbitrary accounting periods, Missfeldt and Haites (2002) used a 1995 cost of US\$ 15 per Mg C for sink enhancement scenarios, and Tschakert (2002) used a cost of US\$ 15 per Mg C for her study in Senegal. In some studies, the value per Mg C ranges between US\$ 1 and 100 (CIDA, 2001; Missfeldt and Haites, 2002; Niles et al., 2002; Healey et al., 2000). Carbon credit prices in Australia range from US\$ 10–700 per Mg C (Australian National University, 2000).

## 6. Conclusions

Although the rate of deforestation in natural forests in ASEAN is still high, ASEAN has replaced part of its degraded and deforested lands with forest plantation.

Table 8
carbon credit in 1 $m^3$ wood harvested

| Scenario | Harvested wood (A) ($m^3$ $ha^{-1}$ per year) | Sequestered carbon (B) (Mg C $ha^{-1}$ per year) | Extra cost (C) (US\$ $ha^{-1}$) | Carbon credit (D = C/B) (US\$ $Mg^{-1}$ C) |
|---|---|---|---|---|
| LEGA | 1.0 | 0.0 | 0.0 | 0.0 |
| CLIBO | 1.0 | 0.3 | 5.9 | 19.7 |

Plantation is likely to play an increasingly important role in wood supply and climate change mitigation. A long-term political commitment to stopping illegal logging, and legal over-logging, slowing deforestation, and managing and protecting remaining natural forests (natural production forests and protected areas) and plantations is required as a high priority. Reducing or eliminating illegal logging will have significant impacts not only on growing stocks, but also on wood harvest and wood production, as well as the government revenues.

From this study, climate beneficial option is certainly the best option for sound sustainable forest management in terms of increase in wood production, environmental protection and protecting the rights of uses of forests of all stakeholders, and could lead to considerable preservation of carbon stocks in ASEAN countries compared to the business as usual scenario. Because of the additional cost of reduced-impact logging, only carbon credit incentives would facilitate wide-spread introduction of CLIBO. The effectiveness of such incentives would, however, depend on the eligibility of forestry measures under a future climate protection regime that includes ASEAN countries. It will be decisive that carbon credits be either tied to, or given for conservation measures, since stopping overcutting and illegal logging would have the largest impact on ASEAN carbon stocks.

## Acknowledgements

Authors would like to thank Karl-Georg Schnitzler, Christian Reick, and Luca Criscuolo of Max Planck Institute for Biogeochemistry and Marko Scholze of Max Planck Institute for Meteorology for their invaluable comments and suggestions. Authors also thank to anonymous reviewers and editor for their comments and suggestions.

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