A thesis for doctor's degree (Human Sciences)
博士（人間科学）学位論文

Evaluation of industrial plantation forests and rehabilitated forests for restoring degraded lands in the tropics of Southeast Asia

東南アジアの熱帯地域における荒廃地修復を目指した産業植林および環境造林の評価

January 2006
2006 年 1 月

Motoshi HIRATSUKA
平塚 基志

Graduate School of Human Sciences, WASEDA UNIVERSITY
早稲田大学大学院 人間科学研究科

Supervisor: Prof. Yasushi MORIKAWA
研究指導教員： 森川 靖 教授

Motoshi HIRATSUKA (Supervisor: Prof. Yasushi MORIKAWA)

A thesis for doctor's degree (Human Sciences)

Evaluation of industrial plantation forests and rehabilitated forests for restoring degraded lands in the tropics of Southeast Asia

---

January 2006

Graduate School of Human Sciences, WASEDA UNIVERSITY

Acknowledgments

The research activities in this thesis were conducted by collaboration projects among Center for International Forestry Research (CIFOR), Forest Research Development Agency of Indonesia (FORDA), Japan International Forestry Promotion & Cooperation Center (JIFPRO), Japan Overseas Plantation Center for Pulpwood (JOPP), and Royal Forestry Department of Thailand (RFD).

The researches in Benakat of South Sumatra and Jumber of East Java, Indonesia were carried out as collaboration between FORDA and JIFPRO. I joined to this research as researcher of JIFPRO. I thank Dr. Takeshi Toma (CIFOR) for his valuable comments to researches in Indonesia. I also thank the researchers and staffs of FORDA and JIFPRO for their supports and encouragements of these researches.

The research in northern Thailand was carried out as collaboration between JIFPRO and RFD. I joined to this research as researcher of JIFPRO. I thank Dr. Takeshi Toma (CIFOR) for his valuable comments to draft paper. I also thank the researchers and staffs of JIFPRO and RFD for their supports and encouragements of this research.

The researches of *Acacia mangium* Willd. plantation forests in Southeast Asia and Papua New Guinea were carried out as collaboration among CIFOR, FORDA, JIFPRO, JOPP, and Waseda University, Japan. We greatly appreciate the helpful insights obtained in discussions on carbon sequestration of plantation forests with members of the project “Demonstration Study on Carbon Fixing Forest Management in Indonesia” by the Japan International Cooperation Agency (JICA). I am also very grateful to Dr. Masahiro Amano (Waseda University, Japan) and Dr. Daniel Murdiyarso (CIFOR) for their valuable comments on these researches. These researches were financially supported by the Ministry of Environment of Japan (B-60: Development of Evaluation Model for Carbon Sink).

The research in East Kalimantan, Indonesia was carried out as collaboration among CIFOR, Mulawarman University, Indonesia, and Waseda University, Japan. This research was financially supported by the Ministry of Environment of Japan (B-60: Development of Evaluation Model for Carbon Sink).

The researches in West Java, Indonesia were carried out as collaboration research among CIFOR, FORDA, and Waseda University, Japan, and were an activity of the CIFOR/Japan research project “Rehabilitation of degraded tropical forest ecosystems”. I thank Dr. Masahiro Amano (Waseda University, Japan), Dr. Markku Kanninen (CIFOR), Dr. Daniel Murdiyarso (CIFOR), Dr. Hiroshi Tanaka (Forestry and Forest Products Research Institute, Japan, FFPRI) and Dr. Atsushi Ishida (FFPRI) for their valuable comments. I also thank scientists and staffs of FORDA and CIFOR for their supports and encouragements. These researches were financially supported by the Ministry of Environment of Japan (B-60: Development of Evaluation Model for Carbon Sink).

Special thanks are also due to Dr. Yasushi Morikawa (Waseda University, Japan), who gave me great chances of field researches in the tropics. His teaching was the valuable opportunity for not only my research activities but also my university life. Finally, I would like to express my special thanks to my colleagues of CIFOR, FORDA, RFD, and members of Environmental Ecology Laboratory and Environmental Planning laboratory of Waseda University, Japan.

Motoshi HIRATSUKA

- Contents -

I. Introduction

This chapter is divided into three sections, as follows:

I-1. Deforestation, forest degradation, and human impact

I-2. Industrial plantation forests and rehabilitated forests in the tropics

I-3. Forest productivity in the tropics of Southeast Asia

I-4. Objectives

I-1. Deforestation, forest degradation, and human impact

I-1-1. Deforestation and/or forest degradation in the tropics

Tropical forests have clearly been degraded since the mid-20th century. Forest cover has declined markedly in Southeast Asian countries; 23 million ha was lost in the 1990s, which is almost equal to the land area of the United Kingdom. In Indonesia, 13,000 ha of forest cover (approximately 11% of the cover in 1990) was lost in the decade (Food and Agriculture Organization, FAO 2005), and the rate of forest cover decline has accelerated since the 1980s. Similar patterns of losses, albeit with slight differences in rates, have occurred in other countries in Southeast Asia that had relatively large forest resources in the mid-20th century.

Recent deforestation and/or forest degradation in Southeast Asia has been spurred by commercial logging, large-scale agricultural exploitation, illegal logging, and forest fires. Deforestation and/or forest degradation have resulted in losses of forest productivity in terms of both wood and non-wood products and environmental services (Evans and Turnbull, 2004). Complex factors with diverse, interacting effects, such as human activities and related climate change following the industrial revolution of the 18th century, are involved in deforestation and/or forest degradation.

I-1-2. Human impact on forest ecosystems in the tropics

Human activities have had a serious impact on deforestation and/or forest degradation in the tropics due to commercial logging, large-scale agricultural exploitation, illegal logging, and forest fires.

In commercial logging activities, foresters or forester groups have built temporary logging roads in primary forests, and logging is generally focused on a few commercially useful large trees. Road construction has caused the destruction of about 26% of the forest cover and subsequent soil erosion in Brunei (Kobayashi 1990), and tractor paths have destroyed about 20% of the forest cover in East Kalimantan, Indonesia (Okimori and Matius, 2000). Commercial logging damages primary forest ecosystems even when reduced impact logging techniques or conventional techniques with regeneration measures are applied (Sist et al., 1998; Sist et al., 2003). Thus, when assessing the effects of commercial logging in the tropics it is important to consider not only its direct effects, but also the secondary effects on the forest ecosystems.

When logging roads have been constructed, they often facilitate access to forests that were previously difficult to penetrate. In such cases, local people or even people from other regions or countries may move into the forest, and convert it to degraded secondary forest through inappropriate, non-sustainable, and non-traditional slash-and-burn agriculture or logging. Prasetyo and Kumazaki (1995) reported that most forest losses in South Sumatra, Indonesia were not due to logging activities, but to other factors such as the introduction of cash crops at the end of the 19th century, road construction for oil exploration, and mining at the beginning of the 20th century. They also found indications that secondary effects of established roads were substantial in this region.

Large-scale agricultural exploitation and related forest fires have the potential to change forest areas to degraded lands. When large areas have been burned by fire, natural regeneration is unlikely to lead to the original climax forest, one of the main reasons being the lack of parent trees to provide seeds. Therefore, degraded lands or degraded secondary forests are unlikely to revert to former primary forest states if they are left to natural processes (Tanimoto 1981; Wunderle 1997) and artificial rehabilitation efforts are not applied.

Illegal logging is one of the major obstacles impeding various programs seeking to prevent deforestation and/or forest degradation, and it has one of the strongest impacts on forests with respect to losses in biodiversity and effective parent trees for forest regeneration. In Indonesia, the Ministry of Forestry and Plantations acknowledged that illegal logging damaged 1.6 million ha of forest between January and July 2000, causing losses of US$ 360 million in annual tax revenues to the Indonesian Government (Jakarta Post 2000). Other impacts of illegal logging include socio-economic effects such as reductions in sources of agricultural implements, construction materials, medicines, and fuelwoods for people living in the vicinity of the forest (Contreras-Hermosilla 2001). The availability of illegally harvested woods on the market also decreases the profitability of legally harvested timber and the industries that depend upon it.

The potential impact of global climate changes on tropical forest has also been discussed. Climate changes associated with prolonged drought linked to particularly strong El Niño-Southern Oscillation (ENSO) events during last two decades of the 20^{th} century, especially in the years 1982 to 1983 and 1997 to 1998 (Mori 2000), also caused degradation of forest ecosystem in the tropics. The frequency of ENSO events has been increasing since the 1950s and could be related to climate changes that have occurred since the industrial revolution of the 18^{th} century (Intergovernmental Panel on Climate Change, IPCC 2001). In addition, forest fires sparked by slash-and-burn agriculture can be major problems in areas with high population densities. Furthermore, deforestation and/or forest degradation lead to the release of carbon dioxide (CO_2) stored in the forest biomass, and may thus exacerbate global warning.

In coming years, therefore, it is important to reduce the risk of further carbon releases through changes in the forest ecosystem. Stabilization of the climate and/or reductions in atmospheric CO_2 levels, as the most important greenhouse gas (GHG) is required, involving as many countries as possible, since deforestation and/or forest degradation are essentially global environmental issues that require effective long-term solutions (Buchner et al., 2005).

I-1-3. References

Buchner B., Gass A. C., and Tazdaït T., 2005. The Clean Development Mechanism and ancillary benefits. In: Bothe M., and Rehbinder E., (eds.). Climate Change Policy. Eleven International

Publishing, 131-148.

Contreras-Hermosilla A., 2001. Law compliance in the forestry sector: an overview. World Bank Institute Working Papers, pp 41.

Evans J., and Turnbull J., 2004. Plantation forestry in the tropics. Third Edition. Oxford University Press, pp 467.

FAO, 2005. State of the world's forests 2005. Available at FAO's web site, http://www.fao.org/forestry/index.jsp. Cited in October 25, 2005.

IPCC, 2001. Climate change 2001. Synthesis report. Available at http://www.ipcc.ch/index.html. Cited in October 25, 2005.

Jakarta Post, 2000. Illegal logging involves central government officials. Jakarta Post, August 19, 2000.

Kobayashi S., 1993. Harvesting impacts and rehabilitation in tropical rainforest. Journal of Agricultural Meteorology, 48: 663-666.

Mori T., 2000. Effects of droughts and forest fires on dipterocarp forest in East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Studies, Vol. 140, Springer, Tokyo, 29-45.

Okimori Y., and Matius P., 2000. Impact of different intensities of selective logging on a low-hill dipterocarp forest in Pasir, East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Studies, Vol. 140, Springer, Tokyo, 209-217.

Prasetyo L. B., and Kumazaki M., 1995. Land-use changes and their causes in the tropics: A case study in South Sumatra, Indonesia in 1969-1988. Tropics, 5: 115-128.

Sist P., Nolan T., Bertault J-G., and Dykstra D., 1998. Harvesting intensity versus sustainability in Indonesia. Forest Ecology and Management, 108: 251-260.

Sist P., Sheil D., Kartawinata K., and Priyadi H., 2003. Reduced-impact logging in Indonesian Borneo: some results confirming the need for new silvicultural prescriptions. Forest Ecology and Management, 179: 415-427.

Tanimoto T., 1981. Vegetation of the alang-alang grassland and its succession in the Benakat district of South Sumatra, Indonesia. Bulletin of the Forest & Forest Products Research Institute, 314: 11-19.

Wunderle Jr. J. M., 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. Forest Ecology and Management, 99: 223-235.

I-2. Industrial plantation forests and rehabilitated forests in the tropics

I-2-1. Industrial plantation forests

Industrial plantation forests worldwide are important to both developed and developing countries as sources of roundwoods, fibers, fuelwoods, and non-wood forest products. The sustainability, energy efficiency, and environmental friendliness of these forests are expected to be generally high. Industrial plantation forests also play major roles in preserving social and cultural values attached to forests, particularly since natural forests are decreasing in size through deforestation (especially in developing countries in the tropics and sub-tropics) or are designated for conservation or other purposes (especially in developed countries in temperate zones).

Industrial plantation forests are generally expected to be highly productive under short rotations (six to eight years) in the tropics compared to temperate forests. For these reasons, there have been substantial investments in plantation forests and tree-planting in the tropics in recent years. In this thesis, industrial plantation forest is defined as the forest in expectation of direct income though planting and harvesting with short rotation. The area of plantation forests increased more than 13-fold between 1965 (6.6 million ha) and 2000 (88 million ha), and the rate of planting in the 1990s was double that of the 1980s (Evans and Turnbull, 2004). In 2000, the estimated area covered by natural forests and plantation forests in the world was 3.8 billion ha, equivalent to about 30% of the earth's surface, and the area of plantations amounted to 187 million ha. The total wood volume and wood biomass in the world's forest were estimated at 386 billion m^3 and 422 trillion g, respectively (Food and Agriculture Organization, FAO 2005).

I-2-2. Rehabilitated forests

The importance of rehabilitated forests to the local community is not sufficiently recognized because they generally provide little income for local people. However, great efforts have also been made to establish rehabilitated forests for environmental conservation or socio-economic reasons. Identifying, defining, and characterizing rehabilitated forests are important for global assessments of their productive, protective, conservational, or socio-economic functions, which are key criteria for sustainable forest management.

Rehabilitation of degraded forest has been defined as the restoration of any converted or damaged forestland to a functioning forest (Brown and Lugo, 1994). In this thesis, rehabilitation is considered synonymous with the recovery of forest ecosystem functions, including environmental conservation (soil erosion control, water availability, habitat preservation, etc.), wood or timber supply, and carbon sequestration. The extent of such rehabilitated forests in the tropics has increased since the 1970s by various programs funded by developed countries, including a number of collaborative projects between Japan and various host countries designed to promote forest rehabilitation in severely degraded areas. The first of these projects was based in Pantabangan in the Philippines (Sakurai 1994) and the next in Benakat in Indonesia (Okabe 1986; Sakurai 1994).

I-2-3. Current and future forest resources

Several studies have attempted to quantify current and future global supplies of and demand for wood products, and various related factors. Sedjo and Lyon (1996) estimated that the mean annual demand for industrial roundwood would increase from 1.7 billion m^3 in 1995 to about 2.3 billion m^3 in 2045. Sedjo (2001) predicted that most industrial woods could come from a small area of plantation forests, much of it in tropical and sub-tropical developing countries, while natural forests could be retained for environmental and other non-wood services. He also predicted that 75% of industrial woods will come from planted forests, and about 50% from plantation forests of fast-growing tree species by 2050.

Southeast Asian countries are still dependent on forest products such as fuelwoods, agricultural implements, construction materials, fibers, and medicines, even through the natural forest resources are limited in remote and isolated areas. Resources from primary forest will clearly be limited or unobtainable in the near future in the tropics of Southeast Asia, so established forests will play an important role in meeting the demands for resources that primary forests used to supply.

I-2-3. References

Brown S., and Lugo A. E., 1994. Rehabilitation of tropical lands: a key to sustaining development. Restoration Ecology, 2: 97-101.

Evans J., and Turnbull J., 2004. Plantation forestry in the tropics. Third Edition. Oxford University Press, pp 467.

FAO, 2005. State of the world's forests 2005. Available at FAO's web site, http://www.fao.org/forestry/index.jsp. Cited in October 25, 2005.

Okabe H., 1986. Afforestation activities in Benakat, Indonesia. The tropical forestry, 7: 50-57 (in Japanese).

Sakurai S., 1994. Tree growth and productivity in degraded forest land. JIRCAS International Symposium Series 1, 64-71.

Sedjo R., and Lyon K., 1996. Timber supply model 96: a global timber supply model with a pulpwood compartment. Discussion paper 96-15. Resources for the Future, Washington D.C..

Sedjo R., 2001. From foraging to cropping: the transition to plantation forestry, and implications for wood supply and demand. Unasylva, 52: 24-32.

I-3. Forest productivity in the tropics of Southeast Asia

I-3-1. Estimates of forest productivity in the tropics of Southeast Asia obtained in the International Biological Program

Data on forest productivity in various types of forest in the tropics of Southeast Asia were gathered in Japanese projects included in the International Biological Program (IBP) in the 1960s.

Kato et al. (1978) quantitatively evaluated forest biomass in lowland rain forest and the productive structure of the forest in Peninsular Malaysia through the destructive sampling of 156 trees and subsequent development of allometric equations for estimating primary forest biomass. Their allometric equations, based on trunk diameter and tree height, were subsequently used by Hoshizaki et al. (2004) and Niiyama et al. (2003), who found that biomass increases remained low for at least about 25 years following harvests. Other valuable information has been gathered on the biomass in tropical rain forests and sub-tropical forests in Thailand (Kira et al., 1964; Ogawa et al., 1965; Ogino et al., 1964; Yoda 1967). The cited authors collected data on forest biomasses in southern (tropical rain forests) and northern areas (sub-tropical forests) which they related to primary productivity parameters and leaf area indexes in each forest type in the areas they examined.

Since the completion of the IBP, further important studies have continued in Southeast Asia. For instance, Yamakura et al. (1986a) estimated the lowland rain forest biomass in East Kalimantan, Indonesia, and assessed the productive structure of the mature primary forest in the same manner as Kato et al. (1978). They also measured the trunk volume and dry mass of the trunk-, branch-, leaf-fractions of 76 felled sample trees (Yamakura et al., 1986b). Information on factors for converting trunk volume to tree biomass provided by these authors is important because such information was lacking for primary trees in Southeast Asia. Such conversion factors are valuable for predicting forest biomass from trunk volume information at various sites and for extrapolating remote sensing data.

I-3-2. Estimation of biomass in large-scale forest ecosystems since the 1980s

Since the 1980s, attention has focused on the large-scale relationships between natural forest productivities and quantitative biomass distribution in the forest. The total forest biomass in the Amazonian forest has been evaluated in a remote sensing analysis by Houghton et al. (2000), who demonstrated the importance of Amazonian forests to the global terrestrial carbon balance. Recent remote sensing analysis is a useful tool for estimating various regional and national phenomena. For instance, the area deforested by scattered forests fire in the Kalimantan region of Indonesia has been evaluated in remote analyses reported by Fuller and Fulk (2001) and Siegert and Hoffmann (2000). According to their evaluations, such areas were concentrated in particular districts in Kalimantan. Forest fire is considered to be a major cause of carbon release to the atmosphere, and forest fires that burned large areas of peat in Indonesia released substantial amounts of carbon in Southeast Asia (Page et al., 2002). Since the 1980s, data sets on forest cover and stocked trunk volume have been accumulated. Brown and Lugo (1984) and Hall and Uhlig (1991) estimated the total tropical forest biomass of the world using regional trunk volume data sets and expansion factors for converting trunk volume to tree biomass.

Estimates of forest biomass in given stands are generally based on allometric relationships derived from destructively sampled trees. Destructive methods can be more accurate than use of conversion factors. Furthermore, conversion factors (usually for estimating tree biomass from trunk volume) vary substantially between different species and from site to site, so factors for specific species and sites may be difficult to predict accurately. However, destructive methods require laborious field work, scales, measures, drying ovens, etc., and these measuring procedures may be difficult to carry out in developing countries.

Non-destructive sampling methods have been introduced in developing countries from the 1980s onwards to increase information on trunk volumes. However, it may be difficult to estimate the biomass of branch, leaf, and root fractions from these data, so additional factors for converting trunk biomass to the biomass of other organs are required for diverse species.

Remote sensing techniques for estimating forest biomass have been introduced recently (e.g., Yamagata et al., 2001), including the use of laser profilers to predict biomass distribution on small scales such as stands, compartments, small basins, etc., for determining biomass changes that would be difficult to estimate by remote sensing using Landsat satellite imagery. This approach is suitable for estimating the effects of large-scale events, such as forest fires, on regional or national carbon releases to the atmosphere.

I-3-3. Studies of carbon sequestration in forest ecosystems in the current decade

In the current decade, studies on the accumulation of forest biomass have focused on carbon sequestration in forest ecosystems. In 2005, the Kyoto Protocol (United Nations Framework Convention on Climate Change, UNFCCC 1997) came into force to promote the stabilization of greenhouse gas (GHG) concentrations in the atmosphere. This protocol includes an afforestation or reforestation Clean Development Mechanism (AR-CDM); a flexible mechanism designed to promote cost-effective sequestration of atmospheric carbon in forests. Land-uses, land-use change, and forestry (LULUCF) activities that qualify for consideration under the CDM are limited to afforestation or reforestation activities, or AR-CDM (UNFCCC 1997). Under the AR-CDM, biomass increases accrue carbon credits, after accounting for the “baseline biomass”. This baseline is defined as the carbon sequestrated in the original vegetation in the AR-CDM project area before forest establishment. When an AR-CDM project is planned for a particular site by developed countries, information on the likely increase in biomass at the site is required. However, there is a little information on biomass increases in industrial plantation forests or rehabilitated forests in developing countries. Recent studies of biomass accumulation in established forests have focused on AR-CDM practices (e.g., Hiratsuka et al., 2005; Morikawa et al., 2001; Morikawa et al., 2002; Yamada et al., 2004).

I-3-4. References

Brown S., and Lugo A. E., 1984. Biomass of tropical forests: a new estimate based on forest volumes. Science, 223: 1290-1293.

Fuller D. O., and Fulk M., 2001. Burned area in Kalimantan, Indonesia mapped with NOAA-AVHRR and Landsat TM imagery. International Journal of Remote Sensing, 22: 691-697.

Hall C. A. S., and Uhlig J., 1991. Refining estimates of carbon released from tropical land-use change. Canadian Journal of Forest Research, 21: 118-131.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Hoshizaki K., Niiyama K., Kimura K., Yamashita T., Bekku Y., Okuda T., Quah E. S., and Nur Supardi M. N., 2004. Temporal and spatial variation of forest biomass in relation to stand dyanamics in mature, lowland tropical rainforestm Malaysia. Ecological Research, 19: 357-363.

Houghton R. A., Skole D. L., Nobre C. A., Hackler J. L., Lawrence K. T., and Chomentowski W. H., 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature, 403: 301-304.

Kato R., Tadaki Y., and Ogawa H., 1978. Plant biomass and growth increment studies in Pasoh forest. Malayan Nature Journal, 30: 211-224.

Kira T., Ogawa H., Yoda K., and Ogino K., 1964. Primary production by a tropical rain forest of southern Thailand. Botanical magazine of Tokyo, 77: 428-42.

Niiyama K., Abdul Rafman K., Iida S., Kimura K., Ripin A., and Appanah S., 2003. Regeneration of a clear-cup plot in lowland dipterocarp forest in Pasoh forest reserve, Peninsular Malaysia. In: Okuda T., Manokaran N., Matsumoto Y., Niiyama K., Thomas S. C., and Ashton P. S., (eds.), Pasoh, Springer Tokyo, 559-568.

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

Ogawa H., Yoda K., Ogino K., and Kira T., 1965. Comparative ecological studies on three main types of forest vegetation in Thailand II. plant biomass. Nature & Life in Southeast Asia. 4: 49-80.

Ogino K., Sabhasri S., and Shidei T., 1964. The estimation of the standing crop of the forest in northern Thailand. The Southeast Asian Studies, 4: 89-97.

Page S. E., Siegert F., Rieley J. O., Boehm H-D. V., Jaya A., and Limin S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature, 420: 61-65.

Siegert F., and Hoffmann A. A., 2000. The 1998 forest fires in East Kalimantan (Indonesia): quantitative evaluation using high resolution, multitemporal ERS-2 SAR images and NOAA-AVHRR hotspot data. Remote Sensing of Environment, 72: 64-77.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. available at UNFCCC's web site, http://unfccc.int. Cited in October 25, 2005.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

Yamagata Y., Oguma H., Tsuchida S., Sekine H., and Rokugawa S., 2001. The role of remote sensing for monitoring and verification of the carbon sinks under the Kyoto Protocol. Journal of Remote Sensing Society of Japan, 21: 43-57.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986a. Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio, 68: 71-82.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986b. Tree size in a mature dipterocarp forest stand in Sebulu, East Kalimantan, Indonesia. Southeast Asian Studies, 23: 452-478.

Yoda K., 1967. Comparative ecological studies on three main types of forest vegetation in Thailand III. community respiration. Nature & Life in Southeast Asia, 5: 83-148.

I-4. Objectives

As mentioned in Chapter I-3-1, most evaluations of forest biomass associated with International Biological Program (IBP) projects were based on destructive sampling in primary forests in the tropics of Southeast Asia. Such data have provided valuable information on the productivity of forests. However, the biomass of secondary forests influenced by human activities (logging, slash-and-burn agriculture, or forest fire) has not been thoroughly evaluated, because their biomass varies from site to site and there is little historical information on human land uses, so it would be difficult to draw scientifically sound general conclusions, even if biomasses were measured in these areas. Furthermore, little information is available on the biomass of established forests (industrial plantation forests or rehabilitated forests). Studying biomass and productivity in most of these forests may be difficult, because of the lack of detailed history of the sites, their small size and/or illegal nature and the complex effects of mixed planting, canopy opening and supplemental planting.

The work underlying this thesis focused on forest productivity in industrial plantation forests and rehabilitated forests to obtain information on biomass accumulation and growth characteristics of timber tree species in the tropics of Southeast Asia, which may be useful for sustainable forest management and use of forest resources.

Chapter I provides background information and describes the objectives of the work underlying this thesis, including: (i) an analysis of deforestation and/or forest degradation caused by human activities, (ii) the state of industrial plantation forests and rehabilitated forests, (iii) a historical review of studies on forest productivities, and (iv) a consideration of the importance of biomass studies in industrial plantation forests and rehabilitated forests, and timber supply in the tropics.

In the studies described in Chapter II, biomass in industrial plantation forests in the tropics of

Southeast Asia was quantitatively estimated to obtain information on: (i) biomass and biomass allocation to each organ (trunk, branch, leaf, and root) in the industrial plantation forests in South Sumatra and East Java, Indonesia, for prospective AR-CDM projects, and (ii) soil carbon storage relative to tree biomass in industrial plantation forests in northern Thailand. A general allometric equation for estimating the above ground biomass of *Acacia mangium* Willd. plantation forests using tree census data was also developed. The general allometric equation should reduce the cost of biomass estimation and harvest impacts in growing stands because no destructive sampling is required.

In chapter III, biomass increases are described from the results of two studies in Indonesia, which estimated: (i) biomass recovery in naturally regenerated secondary forests after forest fires in East Kalimantan, Indonesia, and (ii) the biomass of established forests of indigenous and commercial timber tree species accumulated over 40 years in West Java, Indonesia. The results indicate that the biomass growth of these forests may be sufficient to maintain them for long periods, provided that planting, supplemental planting, and appropriate management measures, such as protection from illegal logging and forest fires are applied.

In Chapter IV, growth patterns of timber tree species and the potential timber supply from established forests were highlighted. The data were derived from: (i) trunk diameter and tree height growth of established forest of timber trees, and (ii) equations for estimating commercial trunk volumes (merchantable trunk bole volumes) of timber trees. The data may provide useful quantitative wood productivity data for prospective projects to establish forests for timber production in the tropics.

Chapter V discusses the prospects for industrial plantation forests, rehabilitated forests and timber supply potential of established forests, and considers issues related to sustainable forest management and the sustainability of forest resources in the tropics.

Scientifically assessing the environmental benefits and woods production potential of efforts to establish and manage forests on degraded lands is not straightforward because of the complex relationships between environmental factors, forest or tree growth and long-term management strategies involved, and the need for continuous monitoring. Therefore, quantitative evaluations of rehabilitated forests from various perspectives related to growth processes and biomass accumulation are urgently required. In addition, such evaluations may provide incentives for local people to establish and manage their own forests.

II. Biomass in industrial plantation forests

This chapter is divided into three sections, as follows:

II-1. Biomass evaluation in industrial plantation forests in South Sumatra and East Java, Indonesia

Part of research in South Sumatra was conducted by Motoshi Hiratsuka, Yasushi Morikawa, Yoichi Nagatsuka, and Yasuo Osumi and research in East Java is conducted by Motoshi Hiratsuka, Yoshiyuki Shioyama, Akinobu Sato, Yasushi Morikawa, and Yoichi Nagatsuka.

II-2. Tree biomass and soil carbon in 17- and 22-year-old stands of teak (*Tectona grandis* L.f.) in northern Thailand

This research was conducted by Motoshi Hiratsuka, Viriyabuncha Chingchai, Peawsa-ad Kantinan, Janmahasatien Sirirat, Akinobu Sato, Yusuke Nakayama, Chika Matsunami, Yasuo Osumi, and Yasushi Morikawa.

II-3. A general allometric equation for estimating the above ground biomass of *Acacia mangium* Willd. plantations

This research was conducted by Motoshi Hiratsuka, Takeshi Toma, Makino Yamada, Ika Heriansyah, and Yasushi Morikawa.

II-1. Biomass evaluation in industrial plantation forests in South Sumatra and East Java, Indonesia

Key words: fast-growing tree species, timber tree species, trunk volume, tree biomass

II-1-1. Introduction

Since 1980s, industrial plantations of fast-growing tree species such as *Acacia mangium* Willd., *A. auriculiformis* A. Cunn. ex Benth., *Eucalyptus camaldulensis* Dehnh., and *E. grandis* W. Hill ex Maidenother were established in the tropical and/or sub-tropical regions. Aims of establishment of those plantation forests were mainly wood chip productions and environmental protections (environmental services) were expected as secondary effectiveness.

Recent important concern with plantation forests is due to carbon sequestration in relation to the Kyoto Protocol (United Nations Framework Convention on Climate Change, UNFCCC 1997). The Kyoto Protocol provides integrative measures based on flexible mechanisms. The most relevant mechanism in this regard is the Clean Development Mechanism (CDM) defined in Article 12, which stipulates that countries included in Annex I of the UNFCCC can respect their GHG limitation commitments (to reduce emissions by at least 5% by 2008 to 2012, the "first commitment period") compared to 1990 levels by obtaining emission reduction certification for investments in emission reduction projects in developing countries.

Land-use, land-use change, and forestry (LULUCF) activities that qualify for such CDM certification are limited to afforestation or reforestation (AR), or AR-CDM (UNFCCC 1997). For instance, if the quantity of carbon in forests established in a project in a developing country (Annex III) undertaken by a developed country (Annex I) is greater than the baseline quantity, defined as the carbon stock in the original vegetation in the area before the forest was established, an

AR-CDM project can accrue carbon credits (certified emissions reduction, CER). The definition of established forest for AR-CDM projects was detailed in the seventh conference of the parties to the UNFCCC (COP7) in Marrakesh, Kingdom of Morocco. Afforestation and reforestation were also defined; as the establishment of forests on land that has not been forested for at least 50 years and on land that did not contain forest on 31 December 1989, respectively (UNFCCC 2001).

In the study reported here, we focus on biomass accumulation in relation to carbon sequestration in industrial plantation forests and supply information for conducting AR-CDM activities.

II-1-2. Study sites

This study was carried out in Benakat of South Sumatra and Jumber of East Java, Indonesia.

Benakat is located on 130 km southwest from Palembang city of South Sumatra province. In this area, primary forests were disappeared and changed to grasslands dominated by *Imperata cylindrical* (L.) Beauv. as the result of slash-and-burn agriculture (Tanimoto 1981). Collaboration project between Japan International Cooperation Agency (JICA) and Indonesian government had been conducted to rehabilitate this area since 1980. Planting tree species were fast-growing trees of *Acacia auriculiformis* A. Cunn. ex Benth., *A. mangium* Willd., *Paraserianthes falcataria* (L.) I. C. Nielsen, and timber trees of *Dalbergia latifolia* Roxb., *Pinus merkusii* Jungh. & de Vriese, and *Swietenia macrophylla* King, and so on. Total planting area had reached to 2,500 ha (Okabe 1986) in 1986. Annual rainfall ranged from 1,890 to 3,330 mm between 1991 to 1998. Soil type is typically red-yellow podsolic or kandiudult (Hardiyanto et al., 1999).

Jumber is located on 150 km southeast from Surabaya city of East Java province. In this area, Perum Perhutani (The state forestry corporation of Indonesia) managed plantation forests intensively for timber products supply. Planting tree species were almost timber trees of *Tectona grandis* L.f., *S. macrophylla*, and *P. merkusii*. This area is on a hilly land at an elevation of 320 to

570 m above sea level.

II-1-3. Methods

II-1-3.1. Field measurement

We investigated 6-year-old *A. mangium*, 20-year-old *S. macrophylla* in Benakat and 14-year-old *P. merkusii*, 16-year-old *S. macrophylla* in Jumber. The initial tree density (planted spacing) of Benakat was 1,000 ha^{-1} (2.5 × 4 m) and 1,667 ha^{-1} (1.5 × 4 m), respectively (Table II-1-1.a) and those of Jumber were 1,111 ha^{-1} (3 × 3 m) and 1,111 ha^{-1} (3 × 3 m), respectively (Table II-1-1.b). The trunk diameter at 1.3 m above the ground (*D*, cm) was measured on all the trees in each plot. When trunk was divided into two or three under the height 1.3 m, we measured each trunk and regarded them as each trunk. Additionally, four sub-plots measuring 2 × 2 m on the forest floor were laid out for evaluating the biomass of the forest floor vegetation. Field investigations in Benakat were carried out in September 2001 and those of Jumber were in August 2003.

II-1-3.2. Estimation of above ground biomass

The above ground dry mass of the trees in the plots was estimated using allometric relationships. The allometric equations were constructed by selecting four or five sample trees from each plot. The *D* of sample trees were spanned the range of *D* at the respective site. After felling, the sample trees were separated into the trunk, bark, branches, and leaves, and each organ was weighed separately. Those organs were weighed fresh and then converted to dry weights. For the conversion, small samples of each organ were oven-dried for 96 hours (48 hours in the case of the leaf sample) at 80°C in order to acquire the dry matter ratios. The dry mass of each organ was calculated from these ratios. To calculate the trunk volume (with bark and without bark), the diameter of the trunk was measured at intervals of 2 m. The trunk volume of each sample tree was calculated using the

Smalian's equation.

Allometric equations for estimating the trunk volume and dry mass were developed for each organ.

$$V_T = a(D)^b \quad (1)$$

$$M = a(D)^b \quad (2)$$

where V_T (m^3) is trunk volume and M (kg) is the dry mass of each organ, while a and b are the coefficients specific to each equation.

We harvested all of the forest floor vegetation in each sub-plot. One part was oven-dried by the same procedure mentioned above in order to calculate the fresh to dry weight ratio. The biomass of the forest floor vegetation in each sub-plot was calculated from this ratio. The above ground biomass of the plot was the summation of the above ground dry mass of all individual trees in the plot. The total biomass of the plot was defined as above ground and root dry mass of all individual trees in the plot. Root biomass was estimated by the method given below. Forest floor vegetation was not added to total biomass in this study.

II-1-3.3. Estimation of below ground biomass

After felling the sample trees, the roots were excavated using heavy shovel machinery. However, we could not sample the entire root systems of the sample trees. The amount of roots remaining in the soil was estimated by following procedure. First, to estimate the dry mass of severed roots from the root diameters at the cut points, an allometric equation was constructed by cutting the complete small root samples from the excavated root systems. Second, the diameters of the roots remaining in the soil were measured at their cut points in the pit. Finally, we used the allometric equation to estimate the amount of roots remaining in the soil. In benakat, we could not conducted estimation of small root biomass because of time consuming.

The below ground biomass is the sum of the excavated roots and the severed roots remaining in the soil.

II-1-4. Results and discussion

The actual tree density of Benakat was 822 trees ha^{-1} in the 6-year-old *A. mangium* and 1,383 trees ha^{-1} in the 20-year-old *S. macrophylla* (Figure II-1-1 and Table II-1-1.a) and those of Jumber was 600 trees ha^{-1} in the 14-year-old *P. merkusii* and 544 trees ha^{-1} in the 16-year-old stand *S. macrophylla*, respectively (Figure II-1-1 and Table II-1-1.b), with tree mortalities of 17.8 and 23.0% in Benakat and 46.0 and 51.0% in Jumber, respectively.

The allometric equations constructed from the tree samples (Appendix II-1-1.a and II-1-1.b) for estimating the dry mass of each organ in each plot showed high correlation (adjusted r^2 = 0.228 to 0.997) (Table II-1-2.a and II-1-2.b). The allometric equation for estimating the small root biomass in the soil of the 14-year-old *P. merkusii* and 16-year-old *S. macrophylla* was as follows;

$$M_{SR} = 1.520\times10^3(D_R)^{1.526},\ \text{adjusted}\ r^2 = 0.935,\ n = 4 \quad (3)$$

$$M_{SR} = 2.425\times10^3(D_R)^{1.895},\ \text{adjusted}\ r^2 = 0.770,\ n = 5 \quad (4)$$

where M_{SR} (g) is the dry mass of severed roots, D_R (cm) is root diameter at the cut points, and *a* and *b* are coefficients of the regression function. These relationships also showed high correlation (adjusted r^2 = 0.770 and 0.935).

The trunk volume with bark of Benakat was 246.7 m^3 ha^{-1} in the 6-year-old *A. mangium* and 368.7 m^3 ha^{-1} in the 20-year-old *S. macrophylla*, respectively (Table II-1-3.a) and those of Jumber was 277.5 m^3 ha^{-1} in the 14-year-old *P. merkusii* and 151.6 m^3 ha^{-1} in the 16-year-old *S. macrophylla*, respectively (Table II-1-3.b). The total biomass (above and below ground biomass) of the trees was 162.4 and 342.5 Mg ha^{-1}, respectively in Benakat (Table II-1-3.a) and 257.7 and 139.1 Mg ha^{-1}, respectively in Jumber (Table II-1-3.b). The mean annual increment (MAI) of the trunk volume with bark was 41.1 and 18.4 m^3 ha^{-1} yr^{-1}, and the total biomass increase was 27.1 and 17.1 Mg ha^{-1} yr^{-1}, respectively in Benakat and 19.8 and 9.5 m^3 ha^{-1} yr^{-1} and 18.4 and 8.7 Mg ha^{-1} yr^{-1}, respectively in Jumber. These values are similar to the results of other industrial plantation forest (Yamada et al., 2004). The MAI values may be sufficient for silvicultural systems in this area. The biomass of the forest floor vegetation was quite small in each forest.

The ratio of below to above ground biomass in each forest was 15.3, 27.2, 38.2, and 13.5%, respectively. The values of *S. macrophylla* are obviously larger than others or those for younger fast-growing species such as *A. mangium, A. auriculiformis, Eucalyptus camaldulensis,* and *E. grandis* (Hiratsuka et al., 2005; Morikawa et al., 2001; Morikawa et al., 2002; Yamada et al., 2004).

The evaluation of tree biomass in this study showed a prospect of industrial plantations as the wood products supply and carbon pool in Indonesia and suitable management of forest bring high silvicultural benefits and environmental services including carbon sequestration in relation to AR-CDM under the Kyoto Protocol.

II-1-5. References

Hardiyanto E. B., Ryantoko A., and Anshori S., 1999. Effects of site management in *Acacia mangium* plantations at PT. Musi Hutan Persada, South Sumatra, Indonesia. In: Nambiar E. K. S., Tiarks A., Cossalter C., and Ranger J., (eds.), Proceedings of International Workshop on site management and productivity in tropical plantation forest, Kerala, India. Center for International Forestry Research, Bogor, Indonesia, pp 41-49.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

Okabe H., 1986. Afforestation activities in Benakat, Indonesia. The tropical forestry, 7: 50-57 (in Japanese).

Tanimoto T., 1981. Vegetation of the alang-alang grassland and its succession in the Benakat district of South Sumatra, Indonesia. Bull. Forest & Forest Products Research Institute, 314: 11-19.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. available at UNFCCC's web site, http://unfccc.int. Cited in October 25, 2005.

UNFCCC, 2001. Report of the conference of the parties on its seventh session, held at Marrakesh from 29 October to 10 November 2001. available at UNFCCC's web site, http://unfccc.int. Cited in October 25, 2005.

Table II-1-1.a.

General information on investigated forests in Benakat, Indonesia

Tree species	*Acacia mangium*	*Swietenia macrophylla*
Age (year)	6	20
Planting spacing (m)	2.5 × 4	1.5 × 4
Tree density (trees ha^{-1})		
Initial	1,000	1,667
Actual	822	1,283
Trunk diameter (cm)		
Minimum	11.5	0.7
Maximum	27.2	44.6
Mean	19.5	17.6
Basal area (m^2 ha^{-1})	25.5	43.9

Table II-1-1.b.

General information on investigated forests in Jumber, Indonesia

Tree species	*Pinus merkusii*	*Swietenia macrophylla*
Latitude	S08'15"02.0"'	S08'07"03.9"'
Longitude	E113'55"32.2"'	E113'30"47.4"'
Above sea level (m)	571	323
Age (year)	14	16
Planting spacing (m)	3 × 3	3 × 3
Tree density (trees ha^{-1})		
Initial	1,111	1,111
Actual	600	544
Trunk diameter (cm)		
Minimum	18.2	15.0
Maximum	38.5	28.5
Mean	27.3	21.5
Basal area (m^2 ha^{-1})	35.8	20.2

Table II-1-2.a.

Coefficients of allometric equations[*1] between trunk diameter (D, cm) and trunk volume (V_T, m^3) or dry mass of each organ (M, kg) in Benakat, Indonesia

Tree species	*Acacia mangium*			*Swietenia macrophylla*		
Coefficients	a	b	adjusted r^2	a	b	adjusted r^2
Trunk volume						
With bark	4.200×10^{-4}	2.196	0.986	1.685×10^{-4}	2.412	0.984
Without bark	2.965×10^{-4}	2.258	0.995	1.326×10^{-4}	2.436	0.983
Dry mass						
Trunk without bark	1.459×10^{-1}	2.218	0.965	9.279×10^{-2}	2.346	0.972
Bark	2.399×10^{-2}	2.218	0.965	9.708×10^{-3}	2.450	0.937
Living branch	3.512×10^{-4}	3.720	0.959	2.332×10^{-5}	4.544	0.938
Dead branch	3.350×10^{-2}	1.892	0.228	-	-	-
Leaf	6.115×10^{-5}	3.823	0.955	4.749×10^{-3}	2.342	0.906
Root	3.436×10^{-2}	2.218	0.965	3.995×10^{-2}	2.360	0.969
Total above ground	1.288×10^{-1}	2.402	0.949	5.058×10^{-2}	2.674	0.993
Total tree	1.602×10^{-1}	2.377	0.951	8.241×10^{-2}	2.601	0.990

[*1]Allometric equations are $V_T = a(D)^b$ and $M = a(D)^b$

Table II-1-2.b.

Coefficients of allometric equations[*1] between trunk diameter (D, cm) and trunk volume (V_T, m^3) or dry mass of each organ (M, kg) in Jumber, Indonesia

Tree species	*Pinus merkusii*			*Swietenia macrophylla*		
Coefficients	a	b	adjusted r^2	a	b	adjusted r^2
Trunk volume						
With bark	1.106×10^{-3}	1.821	0.300	4.131×10^{-6}	3.592	0.969
With bark[*2]	9.591×10^{-4}	1.859	0.294	-	-	-
Without bark	2.159×10^{-3}	1.554	0.203	1.219×10^{-5}	3.170	0.889
Dry mass						
Trunk without bark	1.775×10^{-2}	2.849	0.797	7.192×10^{-2}	2.437	0.975
Bark	8.529×10^{-4}	3.185	0.685	8.474×10^{-3}	2.442	0.997
Living branch	9.565×10^{-7}	5.471	0.776	3.887×10^{-4}	3.634	0.723
Dead branch	1.949×10^{-6}	4.676	0.954	4.910×10^{-15}	10.473	0.795
Leaf	2.474×10^{-4}	3.313	0.645	2.273×10^{-4}	3.300	0.798
Root	3.455×10^{-3}	2.888	0.783	3.841×10^{-2}	2.437	0.981
Total above ground	5.094×10^{-3}	3.364	0.814	4.978×10^{-2}	2.667	0.984
Total tree	7.120×10^{-3}	3.303	0.812	8.379×10^{-2}	2.603	0.991

[*1]Allometric equations are $V_T = a\,(D)^b$ and $M = a\,(D)^b$

[*2]These values were trunk volume without ditch for gathering resin

Table II-1-3.a.

Trunk volume (m^3 ha^{-1}), biomass of each organ (Mg ha^{-1}), and their mean annual increment (MAI, m^3 ha^{-1} yr^{-1} or Mg ha^{-1} yr^{-1}) in Benakat, Indonesia

Tree species	*Acacia mangium*		*Swietenia macrophylla*	
	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})
With bark	246.7	41.1	368.7	18.4
Without bark	209.7	35.0	313.3	15.7
	Dry mass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})	Dry mass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})
Trunk without bark	91.4	15.2	163.0	8.1
Bark	15.0	2.5	24.1	1.2
Living branch	21.5	3.6	74.0	3.7
Dead branch	7.8	1.3	-	-
Leaf	5.1	0.9	8.2	0.4
Root	21.5	3.6	73.3	3.7
Total above ground	140.9	23.5	269.3	13.5
Total tree	162.4	27.1	342.5	17.1
Floor vegetation (Mg ha^{-1}) *1	1.0	0.2	1.7	0.1
Leaf area index	4.2	-	11.0	-
Imperata grassland (Mg ha^{-1}) *1		4.1		

*1 These values were average on two plots in each site

Table II-1-3.b.

Trunk volume (m^3 ha^{-1}), biomass of each organ (Mg ha^{-1}), and their mean annual increment (MAI, m^3 ha^{-1} yr^{-1} or Mg ha^{-1} yr^{-1}) in Jumber, Indonesia

Tree species	*Pinus merkusii*		*Swietenia macrophylla*	
	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})
With bark	277.5	19.8	151.6	9.5
With bark[*1]	272.9	19.5	-	-
Without bark	222.7	15.9	119.8	7.5
	Dry mass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})	Dry mass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})
Trunk without bark	138.0	9.9	71.8	4.5
Bark	20.5	1.5	8.6	0.5
Living branch	52.3	3.7	16.3	1.0
Dead branch	7.2	0.5	0.6	0.0
Leaf	9.1	0.7	3.3	0.2
Root	30.6	2.2	38.4	2.4
Total above ground	227.1	16.2	100.6	6.3
Total tree	257.7	18.4	139.1	8.7
Floor vegetation (Mg ha^{-1})[*2]	2.1	0.2	4.3	0.3
Litter (Mg ha^{-1})[*2]	9.9	0.7	5.7	0.4
Leaf area index	-	-	6.3	-

[*1]These values were trunk volume without ditch for gathering resin

[*2]These values were average on four plots in each site

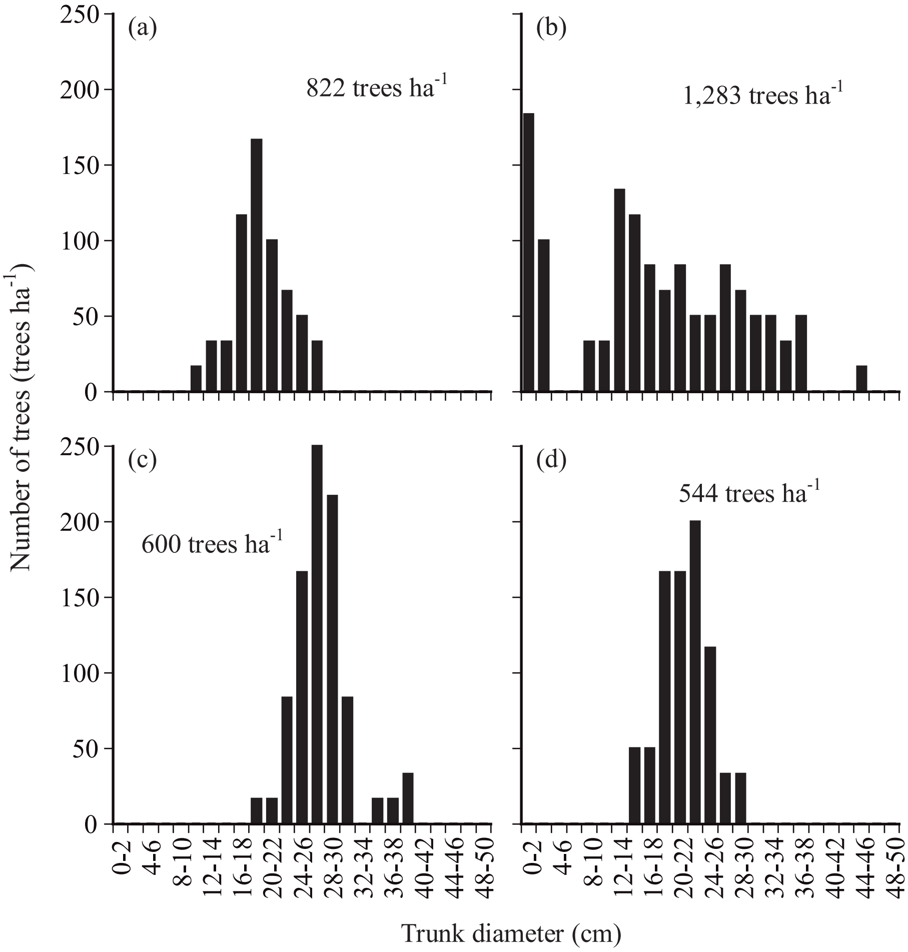

Figure II-1-1.

Frequency distribution of trunk diameter (cm) of 6-year-old *Acacia mangium* (a), 20-year-old *Swietenia macrophylla* (b) in Benakat and 14-year-old *Pinus merkusii* (c), 16-year-old *S. macrophylla* (d) in Jumber, Indonesia

Appendix II-1-1.a.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees in Benakat, Indonesia

Tree species	*Acacia mangium*				*Swietenia macrophylla*				
Sample tree number	1	2	3	4	1	2	3	4	5
Age (year)	6	6	6	6	20	20	20	20	20
Tree height (m)	22.0	22.4	19.9	23.8	15.5	21.2	12.4	22.7	19.5
Trunk diameter (cm)	18.7	20.1	11.5	23.4	19.3	25.7	11.7	37.4	17.6
Trunk volume (10^{-3} m^3)									
With bark	274.5	278.5	90.1	444.4	184.9	464.5	61.1	999.1	196.5
Without bark	224.4	245.5	74.1	377.9	158.7	379.7	49.6	857.0	172.1
Dry mass (kg)									
Trunk without bark	108.1	98.6	32.6	163.9	86.5	210.1	26.7	412.2	95.6
Bark	17.8	16.2	5.4	27.0	10.1	33.5	3.7	62.8	14.6
Living branch	24.1	19.8	3.0	43.9	33.4	64.8	1.3	255.2	7.5
Dead branch	10.6	4.1	3.8	22.1	-	-	-	-	-
Leaf	6.0	4.8	0.7	10.0	6.6	9.7	1.7	23.2	2.5
Root[*1]	25.5	23.2	7.7	38.6	37.8	95.4	11.9	186.0	43.1
Total above ground	166.5	143.5	45.5	266.8	136.7	318.1	33.5	753.4	120.1
Total tree	192.0	166.8	53.2	305.4	174.5	413.5	45.4	939.4	163.3

[*1]We estimated root biomass by the ratio of root to above ground biomass of one sample tree which were sample tree one in *A. mangium* and sample tree five in *S. macrophylla* forests

Appendix II-1-1.b.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees in Jumber, Indonesia

Tree species	*Pinus merkusii*				*Swietenia macrophylla*			
Sample tree number	1	2	3	4	1	2	3	4
Age (year)	14	14	14	14	16	16	16	16
Tree height (m)	23.7	19.1	21.4	21.8	19.0	20.4	20.0	17.5
Trunk diameter (cm)	24.5	21.0	24.4	29.4	22.5	28.4	20.5	17.4
Trunk volume（10^{-3} m^3）								
With bark	464.5	225.6	450.5	433.4	333.5	626.1	226.6	105.9
With bark[*1]	455.8	218.0	444.9	424.7	-	-	-	-
Without bark	382.0	196.7	374.6	344.8	290.6	425.3	194.2	87.9
Dry mass (kg)								
Trunk without bark	179.6	89.0	186.2	239.3	132.0	251.3	122.7	73.7
Bark	28.1	11.1	26.7	33.8	17.5	29.4	13.6	8.9
Living branch	59.6	12.7	37.4	83.9	54.1	58.7	19.5	10.7
Dead branch	7.0	2.9	5.2	14.3	2.5	4.4	0.2	0.0
Leaf	13.5	4.7	10.9	14.9	9.8	12.1	4.1	2.6
Root[*2]	40.2	19.4	41.2	52.9	71.4	134.1	65.2	39.4
Total above ground	287.9	120.4	266.4	386.3	215.8	355.8	160.2	95.8
Total tree	328.1	139.8	307.6	439.2	287.2	489.9	225.4	135.2

[*1]These values were trunk volume without ditch for gathering resin

[*2]We estimated root biomass by the ratio of root to above ground biomass of one sample tree which were sample tree one in each forest

II-2. Tree biomass and soil carbon in 17- and 22-year-old stands of teak (*Tectona grandis* L.f.) in northern Thailand

Key words: *Tectona grandis* L.f. stand, trunk volume, tree biomass, soil carbon

II-2-1. Introduction

In the year 2000, the total size of the world's plantation forests of various tree species was over 180 million ha (ca. 4.8% of total forested area), with about 20 million ha (ca. 9.4% of total forested area) in the Association of Southeast Asian Nations (ASEAN) countries of Southeast Asia (Food and Agriculture Organization, FAO 2003). Such plantations are expected to decrease human harvesting pressure on primary forests for wood products. Teak (*Tectona grandis* L.f.) is native to India, Myanmar, Thailand, and Laos, and is the most important silviculture tree species in the tropics because the high timber quality is suitable for furniture and other wood products. Thailand has intensively established teak plantation forests and the total area of teak plantation forests attained to 255,000 ha in 1996 (Viriyabuncha and Reawsa-ad, 2001).

Thailand experienced heavy deforestation in the 20^{th} century. The annual loss of forest cover was 500,000 ha in the mid 1970s, or approximately 2.5% of total forest area. Accordingly, intensive reforestation efforts have been conducted for the domestic supply of timber (Niskanen 1998). Teak has been planted because it is one of the most valuable timber trees.

Recently, plantation forests have taken on another role, that of carbon sequestration through projects of afforestation or reforestation Clean Development Mechanism (AR-CDM) under the Kyoto Protocol (United Nations Framework Convention on Climate Change, UNFCCC 1997). As a consequence, it has become important to estimate the trunk volume and biomass or carbon stock for the purpose of carbon sequestration calculations. Some studies have estimated the biomass or carbon stock for timber tree species at various sites (Hiratsuka et al., 2005; Kraenzel at al., 2003; Morikawa et al., 2001; Morikawa et al., 2002; Yamada et al., 2004), and other studies developed yield models for these plantation tree species (Bermejo et al., 2004; Corona et al., 2002; Nunifu and Murchison, 1999). However, few studies have been done on below ground biomass and carbon stock in the soil because the investigations are time-consuming and laborious, and involve destruction of the investigated site. Data on the below ground biomass and carbon stock in the soil is important because the carbon in those compartments of the forest ecosystems was added to the sequestrated carbon in the AR-CDM of the Conference of Parties 9 (COP9) in December, 2003 (United Nations Framework Convention on Climate Change, UNFCCC 2003).

In this study, we evaluate the biomass of teak plantation forests in northern Thailand, including the below ground biomass and the carbon stock in the soil, from the viewpoint of carbon sequestration.

II-2-2. Study site

This study was carried out at the Mae Chang plantation, 30 km east of Lampang in northern Thailand. This plantation forest was established in 1968 and comprises 13 stands with trees of different ages (17 to 30 years). Since its establishment, the plantation forest has been managed by the Forest Industry Organization of Thailand (FIO) and the Royal Forestry Department of Thailand (RFD). It is on a hilly site at an elevation of 340 to 400 m above sea level. The annual rainfall in Lampang is about 1,034 mm, and the mean temperature is 26.2°C. The natural vegetation in this area is poor in structure due in part to the soil of limestone origin.

II-2-3. Methods

II-2-3.1. Field measurement

We investigated 17- and 22-year-old stands of teak. Plots measuring 40 × 40 m (0.16 ha) were established in each stand. The initial density (planted spacing) was 1,250 trees ha^{-1} (2 × 4 m) and 625 trees ha^{-1} (4 × 4 m), respectively (Table II-2-1). The trunk diameter at 1.3 m above the ground (*D*, cm) was measured on all the trees in each plot. Additionally, four sub-plots measuring 2 × 2 m on the forest floor were laid out for evaluating the biomass of the forest floor vegetation in the plot of 17-year-old stand. There was little forest floor vegetation in the plot of 22-year-old stand due to the strong influence of the limestone origin soil. Therefore, we skipped the biomass measurement for the floor vegetation in the plot. Soil pits for estimating the carbon stock in the soil were laid out in each plot. Four pits were excavated in the 17-year-old plot. Three pits were excavated in the 22-year-old plot. Soil samples for analyzing physical and chemical properties were taken from each horizon down to a depth of 50 cm. Field investigations were carried out in July 2002.

II-2-3.2. Estimation of above ground biomass

The above ground dry mass of the trees in the plots was estimated using allometric relationships. The allometric equations were constructed by selecting five sample trees from each plot. The *D* of sample trees were spanned the range of *D* at the respective site. After felling, the sample trees were separated into the trunk, branches, and leaves, and each organ was weighed separately. Those organs were weighed fresh and then converted to dry weights. For the conversion, small samples of each organ were oven-dried for 96 hours (48 hours in the case of the leaf sample) at 80°C in order to acquire the dry matter ratios. The dry mass of each organ was calculated from these ratios. To calculate the trunk volume (with bark and without bark), the diameter of the trunk was measured at intervals of 2 m. The trunk volume of each sample tree was calculated using the Smalian’s equation. Allometric equations for estimating the trunk volume and dry mass were developed for each organ.

$$V_T = a(D)^b \quad (1)$$

$$M = a(D)^b \quad (2)$$

where V_T (m^3) is trunk volume and M (kg) is the dry mass of each organ, and a and b are the coefficients specific to each equation.

We harvested all of the forest floor vegetation in each sub-plot. One part was oven-dried by the same procedure mentioned above in order to calculate the fresh to dry weight ratio. The biomass of the forest floor vegetation in each sub-plot was calculated from this ratio. The above ground biomass of the plot was the summation of the above ground dry mass of all individual trees in the plot. The total biomass of the plot was defined as above ground and root dry mass of all individual trees in the plot. Root biomass was estimated by the method given below. Forest floor vegetation was not added to total biomass in this study.

II-2-3.3. Estimation of below ground biomass

After felling the sample trees, the roots were excavated using heavy shovel machinery. However, we could not sample the entire root systems of the sample trees. The amount of roots remaining in the soil was estimated by following procedure. First, to estimate the dry mass of severed roots from the root diameters at the cut points, an allometric equation was constructed by cutting the complete small root samples from the excavated root systems. Second, the diameters of the roots remaining in the soil were measured at their cut points in the pit. Finally, we used the allometric equation to estimate the amount of roots remaining in the soil.

The below ground biomass is the sum of the excavated roots and the severed roots remaining in the soil.

II-2-3.4. Soil analysis

All of the soil samples were air-dried and passed through a sieve with a 2 mm mesh in the laboratory at RFD. The bulk density and carbon content of each soil layer were analyzed using the nitrogen-carbon (NC) analyzer (SUMIGRAPH NC-90A, SCAS Co. Ltd.) through combustion at a high temperature (around 900°C). The soil carbon of each horizon was the product of the bulk density (g cm^{-3}) and carbon contents (%); the summation of these values was the carbon stock in the soil (down to a depth of 50 cm).

II-2-4. Results and discussion

The actual tree density was 844 trees ha^{-1} in the 17-year-old stand and 544 trees ha^{-1} in the 22-year-old stand (Figure II-2-1 and Table II-2-1), with tree mortalities of 32.5 and 13.0%, respectively.

The allometric equations constructed from the tree samples (Appendix II-2-1) for estimating the dry mass of each organ in each plot showed high correlation (adjusted r^2 = 0.841 to 0.999) (Table II-2-2). The allometric equation for estimating the small root biomass in the soil of the 17- and 22-year-old stands was as follows;

$$M_{SR} = 1.266 \times 10 (D_R)^{2.265},\ r^2 = 0.713,\ n = 56 \qquad (3)$$

where M_{SR} (g) is the dry mass of severed roots, D_R (cm) is root diameter at the cut points, and *a* and *b* are coefficients of the regression function. This relationship also showed high correlation (r^2 = 0.713).

The trunk volume was 116.9 m^3 ha^{-1} in the 17-year-old stand and 139.6 m^3 ha^{-1} in the 22-year-old stand. The total biomass (above and below ground biomass) of the trees was 89.3 and 98.8 Mg ha^{-1}, respectively (Table II-2-3). These values were smaller than those for stands of nearly the same age in West Java, Indonesia (Purwanto et al., 2002). The difference might be due to site conditions, such as the predominance of parent limestone in the soil and the seasonal tropical climate. The mean annual increment (MAI) of the trunk volume was 6.9 and 6.3 m^3 ha^{-1} yr^{-1}, and the total biomass increase was 5.3 and 4.5 Mg ha^{-1} yr^{-1}, respectively. These values are obviously smaller than those for plantations of fast-growing tree species such as *Acacia mangium* Willd., *A. auriculiformis* A. Cunn. ex Benth., *Eucalyptus camaldulensis* Dehnh., and *E. grandis* W. Hill ex Maidenother (Yamada et al., 2004). However, the MAI values may be sufficient for silvicultural systems in this area. The biomass of the forest floor vegetation was 2.5 Mg ha^{-1}, amounting to about 3.5% of the above ground biomass of the teak.

The ratio of below ground to above ground biomass was 25.5% in the 17-year-old stand and 20.0% in the 22-year-old stand. These values are obviously larger than those for younger fast-growing species such as *A. mangium* and *E. grandis* (Morikawa et al., 2002; Yamada et al., 2004).

The average carbon stock in the soil was 211.4 MgC ha^{-1} (ranging from 153.2 to 251.8 MgC ha^{-1}) in the 17-year-old stand and 137.2 MgC ha^{-1} (ranging from 122.7 to 157.9 MgC ha^{-1}) in the 22-year-old stand (Table II-2-4). The carbon stock in the soil is important compartment of carbon sequestration in the forest ecosystems from the viewpoint of AR-CDM in the Kyoto Mechanism because these values were about three times larger than the carbon stock of the trees themselves; 44.6 and 49.4 MgC ha^{-1} assuming 50% carbon content of tree biomass in 17- and 22- year-old plots, respectively.

The evaluation of tree biomass and soil carbon in this study showed a prospect of teak plantation forests as the carbon pool in northern Thailand. These results suggested that the importance of estimating the below ground carbon pool consisted of root and soil carbon.

II-2-5. References

Bermejo I., Cañellas I., and Miguel A. S., 2004. Growth and yield models for teak plantations in Costa Rica. Forest Ecology and Management, 189: 97-110.

Corona P., Marziliano P. A., and Scotti R., 2002. Top-down growth modeling: a prototype for poplar plantation in Italy. Forest Ecology Management, 161: 65-73.

FAO, 2003. State of the world's forests 2003. Available at FAO's web site, http://www.fao.org/forestry/index.jsp. Cited in October 25, 2005.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Kraenzel M., Castillo A., Moore T., and Potvin C., 2003. Carbon storage of harvest-age teak (*Tectona grandis*) plantations, Panama. Forest Ecology Management, 173: 213-225.

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

Niskanen A., 1998. Financial and economic profitability of reforestation in Thailand. Forest Ecology and Management, 104: 57-68.

Nunifu T. K., and Murchison H. G., 1999. Provisional yield models of teak (*Tectona grandis* Linn F.) plantations in northern Ghana. Forest Ecology and Management, 120: 171-178.

Purwanto R. H., Simon H., and Ohata S., 2003. Estimation of net primary productivity of young teak plantations under the intensive *Tumpangsari* system in Madium, East Java. Tropics, 13: 9-16.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change.

available at UNFCCC's web site, http://unfccc.int. Cited in October 25, 2005.

UNFCCC, 2003. Report of the conference of the parties on its ninth session, held at Milan from 1 to 12 December 2003. available at UNFCCC's web site, http://unfccc.int. Cited in October 25, 2005.

Viriyabuncha C., and Reawsa-ad K., 2001. Assessment of the potentiality of re-afforestation activities in climate change mitigation: Annual report Nov. 2000-Mar. 2001. Royal Forest Department of Thailand, pp 3.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

Table II-2-1.

General information on planted spacing (m), tree density (trees ha^{-1}), trunk diameter (D, cm), and basal area (BA, m^2 ha^{-1}) of 17- and 22-year-old *Tectona grandis* stands in northern Thailand

	17-year-old stand	22-year-old stand
Planting spacing (m)	2 × 4	4 × 4
Tree ensity (trees ha^{-1})		
Initial	1,250	625
Actual	844	544
Trunk diameter (cm)		
Minimum	4.5	9.2
Maximum	25.7	27.5
Mean	14.4	18.4
Basal area (m^2 ha^{-1})	15.3	15.2

Table II-2-2.

Coefficients of allometric equations[*1] between trunk diameter (D, cm) and trunk volume (V_T, m^3) or dry mass of each organ (M, kg) of 17- and 22-year-old *Tectona grandis* stands in northern Thailand

	17-year-old stand			22-year-old stand		
	a	*b*	adjusted r^2	*a*	*b*	adjusted r^2
Trunk volume						
With bark	3.202×10^{-4}	2.221	0.994	3.149×10^{-4}	2.276	0.954
Without bark	1.700×10^{-4}	2.324	0.984	1.598×10^{-4}	2.394	0.948
Dry mass						
Trunk without bark	8.663×10^{-2}	2.317	0.999	1.265×10^{-1}	2.247	0.948
Bark	3.801×10^{-2}	2.080	0.963	1.820×10^{-2}	2.345	0.923
Living branch	5.334×10^{-4}	3.628	0.934	1.507×10^{-3}	3.317	0.872
Dead branch	4.121×10^{-4}	3.385	0.925	5.983×10^{-7}	5.135	0.932
Leaf	3.393×10^{-3}	2.659	0.930	5.240×10^{-4}	3.215	0.841
Root	2.264×10^{-2}	2.498	0.991	2.599×10^{-2}	2.276	0.989
Total above ground	7.798×10^{-2}	2.544	0.992	9.303×10^{-2}	2.509	0.955
Total tree	9.979×10^{-2}	2.538	0.997	1.225×10^{-1}	2.479	0.963

[*1]Allometric equations are $V_T = a\ (D)^b$ and $M = a\ (D)^b$

Table II-2-3.

Trunk volume (m^3 ha^{-1}), biomass of each organ (Mg ha^{-1}), and their mean annual increment (MAI, m^3 ha^{-1} yr^{-1} or Mg ha^{-1} yr^{-1}) of 17- and 22-year-old *Tectona grandis* stands in northern Thailand

	17-year-old stand		22-year-old stand	
	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})	Trunk volume (m^3 ha^{-1})	MAI (m^3 ha^{-1} yr^{-1})
With bark	116.9	6.9	139.6	6.3
Without bark	83.1	4.9	100.9	4.6
	Biomass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})	Biomass (Mg ha^{-1})	MAI (Mg ha^{-1} yr^{-1})
Trunk without bark	41.6	2.4	51.4	2.3
Bark	9.3	0.5	9.9	0.5
Living branch	11.4	0.7	15.5	0.7
Dead branch	4.3	0.3	1.6	0.1
Leaf	4.3	0.3	4.0	0.2
Root	18.2	1.1	16.4	0.7
Total above ground	70.8	4.2	82.4	3.7
Total tree	89.0	5.2	98.9	4.5
Floor vegetation	2.5	0.1	-	-
Leaf area index	3.7	-	4.4	-

Table II-2-4.

Bulk density (g cm^{-3}), carbon content (%), and carbon stock (MgC ha^{-1}) in the soil of 17- and 22-year-old *Tectona grandis* stands in northern Thailand

Stand age (years)	Pit no.	Sampling Soil depth (cm)	Bulk density (g cm^{-3})	Carbon content (%)	Carbon stock (MgC ha^{-1})	Carbon stock down to a 50 cm depth (MgC ha^{-1})
17-year-old	1	0-20	1.46	3.45	100.7	153.2
		20-50	1.62	1.08	52.5	
	2	0-18	1.52	4.38	119.8	251.8
		18-50	1.69	2.44	132.0	
	3	0-20	1.52	3.90	118.6	211.8
		20-50	1.57	1.98	93.3	
	4	0-20	1.56	4.24	132.3	228.8
		20-50	1.65	1.95	96.5	
22-year-old	1	0-10	1.31	1.92	25.2	131.1
		10-30	1.23	1.54	37.9	
		30-50	1.46	2.33	68.0	
	2	0-20	1.24	2.71	67.2	157.9
		20-50	1.26	2.40	90.7	
	3	0-20	1.22	2.24	54.7	122.7
		20-50	1.26	1.80	68.0	

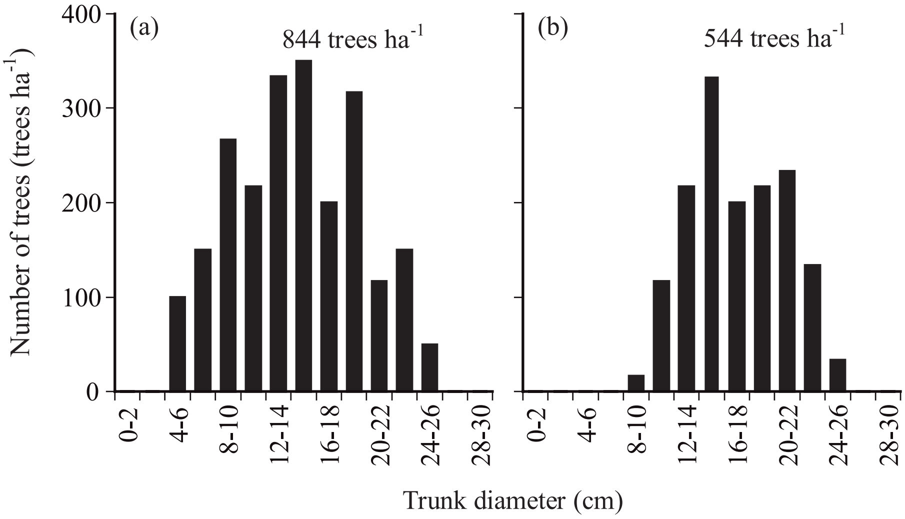

Figure II-2-1.

Frequency distribution of trunk diameter (cm) of 17- (a) and 22- (b) year-old *Tectona grandis* stands in northern Thailand

Appendix II-2-1.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees of 17- and 22-year-old *Tectona grandis* stands in northern Thailand

	17-year-old					22-year-old				
Sample tree number	1	2	3	4	5	1	2	3	4	5
Age (years)	17	17	17	17	17	22	22	22	22	22
Tree height (m)	14.5	16.9	12.6	15.5	14.3	19.5	17.7	14.2	18.9	15.9
Trunk diameter (cm)	16.0	22.9	9.4	19.7	13.1	20.0	26.9	12.4	23.2	15.9
Trunk volume (10^{-3} m^3)										
With bark	138.8	345.9	46.7	241.8	101.8	337.7	476.7	91.5	446.5	165.1
Without bark	92.4	246.9	30.7	183.2	73.7	244.0	346.1	60.8	336.0	120.2
Dry mass (kg)										
Trunk without bark	52.5	125.4	15.7	85.5	33.7	123.4	172.8	32.4	160.3	67.0
Bark	12.2	30.0	4.3	15.8	7.6	27.8	39.2	6.3	24.6	11.6
Living branch	11.5	63.4	1.8	17.4	7.4	37.9	77.7	4.5	39.6	23.2
Dead branch	4.7	12.0	0.6	12.9	3.5	2.6	10.4	0.2	7.1	1.5
Leaf	7.3	13.9	1.1	7.2	3.5	10.2	15.5	1.1	12.7	6.1
Total above ground	88.2	244.8	23.6	138.9	55.6	201.8	315.8	44.5	244.3	109.4
Root	25.1	52.0	6.0	41.1	13.3	34.6	64.8	10.6	51.2	21.9
Total tree	113.3	296.7	29.6	180.0	68.9	236.3	380.6	55.0	295.6	131.3

II-3. A general allometric equation for estimating the above ground biomass of *Acacia mangium* Willd. plantation forests

Key words: *Acacia mangium* Willd., AR-CDM, above ground biomass, allometric equation

II-3-1. Introduction

Plantation forests of fast-growing tree species such as *Acacia mangium* Willd., *A. auriculiformis* A. Cunn. ex Benth., *Eucalyptus camaldulensis* Dehnh., and *E. grandis* W. Hill ex Maidenother have been spreading rapidly in Southeast Asia over recent decades (Cossalter and Pye-Smith, 2003). Such plantation forests covered about 20 million ha (ca. 9.4% of the total forested area) in the Association of Southeast Asian Nations (ASEAN) countries in 2000 (Food and Agriculture Organization, FAO 2003). These species are also used for rehabilitating degraded land as the initial planting in the process of returning the land to forest, and in some areas there have been success stories of degraded land being returned to productive use (Morikawa et al., 2002). Such plantation forests of fast-growing tree species have been established on many secondary forest and grassland sites across the region. Evaluating the biomass as productivity of these plantation forests is important for their effective management and the achievement of economic goals, particularly obtaining high returns in short periods. In addition, evaluating biomass becomes important recently as a measure of the amount of carbon sequestered in projects of afforestation or reforestation Clean Development Mechanism (AR-CDM) under the Kyoto Mechanism.

Biomass data of *A. mangium* plantation forests have been gathered by many researchers (Hardyanto et al., 1999; Heriansyah et al., 2003; Hiratsuka et al., 2005; Morikawa et al., 2001; Morikawa et al., 2002; Tanouchi et al., 1994; Tsai and Hamzah, 1985; Yamada et al., 2004) and the information obtained is obviously important for each respective site. Those studies estimated biomass by allometric equations developed by destructive sampling conducted in each site. In addition, destructive sampling may have negative impacts to the target plantation forest and be time-consuming and laborious for the researchers on the filed. If the biomass can be estimated without the destructive sampling, it would reduce the cost of biomass estimation and also negative impacts on the plantation.

In this study, we present a general allometric equation for estimating above ground biomass of *A. mangium* plantation forests at harvest age (six to eight years) with ordinary spacing. We applied datasets of destructive sampling and tree census data conducted at four *A. mangium* plantation forests for developing general allomettic equation.

II-3-2. Study sites

Field investigations were carried out at four sites in Southeast Asia and Papua New Guinea (PNG): Sonbe in Vietnam, Benakat and Bogor in Indonesia, and Madang in PNG. All investigated sites were planted with almost the same initial spacing (816 to 1,429 trees ha^{-1}) and at almost the same time (6- to 8-year-old). The climate classification of Madang, Benakat, and Bogor is tropical wet, while Sonbe has a tropical wet monsoon climate. Description of the sites is as follows;

Madang, PNG: Field investigations were carried out from late August to early September 1999. A 7-year-old plantation forest on level terrain was selected. The spacing here was 3.5 × 3.5 m (816 trees ha^{-1}) (Table II-3-1). Detailed information of this site is on Morikawa et al. (2001).

Sonbe, Vietnam: Field investigations were carried out in late August 1998. A 6-year-old plantation forest on level terrain was selected. The spacing here was 3 × 3 m (1,111 trees ha^{-1}) (Table II-3-1). Detailed information of this site is on Morikawa et al. (2001).

Benakat, South Sumatra, Indonesia: Field investigations were carried out in early September 2001. A number of 6-year-old plantation forests with several different spacings were selected: 2.5 ×

4 m (1,000 trees ha^{-1}), 3.5 × 2 m (1,429 trees ha^{-1}), 3 × 4 m (833 trees ha^{-1}), and 3.5 × 3 m (952 trees ha^{-1}) (Table II-3-1). All were on level terrain. Detailed information of these sites is on Hardyanto et al. (1999).

Bogor, West Java, Indonesia: Field investigations were carried out in early August 2001. Four 8-year-old plantation forests on level terrain were selected. The tree spacing on all selected plots was 3 × 3 m (1,111 trees ha^{-1}) (Table II-3-1). Detailed information of this site is on Heriansyah et al. (2003).

II-3-3. Field Measurements

The trunk diameter at 1.3 m above the ground (*D*, cm) was measured for all trees in each plot at each site. When trees had separated into two or three trunks below the 1.3 m point, each was measured separately, and they were all treated as single trunks. There was one plot each in Madang and Sonbe, five in Benakat, and four in Bogor.

Four to twelve sample trees were selected at each site, spanning the range of *D* at the respective site, and at intervals that were consistent with the *D* distribution. The range of *D* for all sample trees was 11.5 to 30.5 cm. After felling, each sample tree was separated into trunk, branches, and leaves. Those organs were weighed fresh and then converted to dry weights. For the conversion, small samples of each organ were oven-dried for 96 hours (leaves for 48 hours) at 80°C to acquire the dry matter ratios.

II-3-4. Biomass estimation

At each site, we calculated the above ground dry matter contributed by each sample tree as the summation of trunk, branch, and leaf dry matter. The above ground dry matter contributed by the remaining non-sampled trees in the plot was estimated using an allometric equation relating the above ground dry matter to the D value of the sample trees:

$$M = a(D)^b \qquad (1)$$

where, M is the above ground dry matter contained in an individual tree, and a and b are the coefficients of the regression function. The above ground biomass (AGB) of the plot is the summation of the above ground dry matter for all individual trees in the plot.

We estimated the AGB of each plantation forest using two different allometric equations: a site-specific equation derived separately for each investigated site and a general equation derived from all 26 sample trees taken from the four investigated sites.

II-3-5. Results

The mean value of D ranged from 14.6 to 21.8 cm at the various sites (Table II-3-1). The actual density of trees at each site was less than the initial planted density, except at Sonbe. In Sonbe, some trees were separated into two or three trunks. Actual density of trees in Bogor was particularly less than initial planted density, because selected cutting had been carried out just one year before our investigation.

Each site-specific equation for AGB was highly accurate, and the deviations were small (Table II-3-2). The general allometric equations for estimating individual values of trunk, branch, and above ground dry matter were also highly accurate. However, the equation for leaf afforded lower accuracy. This might have resulted from carrying out investigations during different seasons.

The AGB estimates obtained by the site-specific and general allometric equations were tested for variance, and the deviation was not found to be significant ($p < 0.001$; X^2 test for goodness of fit) (Figure II-3-1). The difference between the two results ranged from -5.2 to 13.5%). The values for the Benakat plot (initial density: 877 trees ha^{-1}) from the two equations were almost identical: 172.8 and 172.6 Mg ha^{-1}, respectively, while the estimates in Madang resulted in the largest deviation:

113.2 and 99.7 Mg ha^{-1}, respectively (Table II-3-4).

II-3-6. Discussion

In general, allometric equations for estimating biomass are based on trunk diameter, tree height, and plant dry matter (e.g., Kato et al., 1978; Yamakura et al., 1986). Poungparn et al. (2003) indicated that it is better for general allometric equation to estimate biomass by the parameter of D^2H (tree height, H) and D_B^2 (trunk diameter at the height of the lowest branch, D_B) in the case of primary and secondary mangrove forests. However, it is often difficult to measure such parameters accurately, except D, in forests with closed canopies. In addition, it is expected that plantation forests of harvest age (six to eight years) with same tree species and ordinary spacing are composed of trees with similar sharp. From these reasons, we took the approach used only D as a parameter for the allometric relationship. In this study, the results showed allometric relationship based on D is sufficient for predicting biomass in *A. mangium* plantation forests at harvest age. Tree diameter D is the most commonly and easily measured parameter in plantation forests. However, this general allometric equation may only be valid for harvest aged plantation forest which is ordinary spacing and constructed with same tree species and same age.

The general allometric equation proposed in this study would be useful for evaluating the biomass of *A. mangium* plantation forest at any sites because no significant site-specific differences in calculated values were found. We suggest that biomass differences among sites do not reflect allometric differences, and that trees with both low and high biomass appear to conform to the general allometric equation. The results suggest that it is not necessary to cut down sample trees at target sites in order to obtain site-specific allometric relationship, since accurate information on biomass can be derived from the general allometric equations for *A. mangium* plantation forests.

II-3-7. References

Cossalter C., and Pye-Smith C., 2003. Fast-wood forestry: myths and realities. CIFOR, Indonesia, pp 50.

FAO, 2003. State of the world's forests 2003. Available at FAO's web site, http://www.fao.org/forestry/index.jsp. Cited in October 25, 2005.

Hardiyanto E. B., Ryantoko A., and Anshori S., 1999. Effects of site management in *Acacia mangium* plantations at PT. Musi Hutan Persada, South Sumatra, Indonesia. In: Nambiar E. K. S., Tiarks A., Cossalter C., and Ranger J., (eds.), Proceedings of International Workshop on site management and productivity in tropical plantation forest, Kerala, India. Center for International Forestry Research, Bogor, Indonesia, pp 41-49.

Heriansyah I., Heriyanto N. M., Siregar C. A., and Miyakuni K., 2003. Estimating carbon fixation potential of plantation forests: Case study of *Acacia mangium* plantations. Buleten of Penelitian Hutan, 634: 1-14.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Kato R., Tadaki Y., and Ogawa H., 1978. Plant biomass and growth increment studies in Pasoh forest. Malayan Nature Journal, 30: 211-224.

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

Poungparn S., Komiyama A., Patanaponpaipoon P., Jintana V., Sangtiean T., Tanapermpool P., Piriyayota S., Maknual C., and Kato S., 2003. Site-independent allometric relationships for estimating above-ground weights of mangroves. Tropics, 12: 147-158.

Tanouchi H., bin Mohammad A., bin Abdullah MD. F., bin O. K. Jilli, R., and Kobayashi S., 1994. Size distribution and production structure of a secondary forest after selective cutting in the mixed dipterocarp forest, Brunei Darussalam. Bulletin of Forest & Forest Products Research Institute, 366: 17-30.

Tsai L. M., and Hamzah M. B., 1985. Biomass accumulation in a naturally regenerating lowland secondary forest and an *Acacia mangium* stand in Sarawak. Pertanika, 8: 237-242.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986. Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio, 68: 71-82.

Table II-3-1.
General information on tree density (trees ha^{-1}), trunk diameter (*D*, cm), and basal area (BA, m^2 ha^{-1}) in each *Acacia mangium* plantation forests

Sites	Tree density		Trunk diameter		Basal area
	Initial (trees ha^{-1})	Actual (trees ha^{-1})	Mean (cm)	S.D. (cm)	(m^2 ha^{-1})
Madang, Papua New Guinea	816	506	21.0	4.9	18.4
Sonbe, Vietnam	1,111	1,289	14.6	4.2	23.4
Benakat, Indonesia	1,000	822	19.5	3.7	25.5
Benakat, Indonesia	1,429	1,369	16.8	3.7	31.9
Benakat, Indonesia	833	787	19.6	4.8	25.2
Benakat, Indonesia	952	877	21.2	3.9	32.1
Benakat, Indonesia	1,000	903	19.4	3.8	27.6
Bogor, Indonesia	1,111	250	20.8	3.4	8.7
Bogor, Indonesia	1,111	283	20.8	4.1	10.0
Bogor, Indonesia	1,111	317	21.1	3.0	11.3
Bogor, Indonesia	1,111	283	21.8	3.4	10.9

Table II-3-2.

Coefficients of site-specific allometric equations[*1] between trunk diameter (*D*, cm) and dry mass of each organ (*M*, kg) in each *Acacia mangium* plantation forests

Site-specific equations	*n*	*a*	*b*	adjusted r^2
Madang, Papua New Guinea				
Trunk with bark	6	1.308×10^{-1}	2.352	0.894
Living branch	6	3.170×10^{-3}	2.909	0.535
Leaf	6	2.154×10^{-2}	1.962	0.496
Total above ground	6	1.467×10^{-1}	2.380	0.975
Sonbe, Vietnam				
Trunk with bark	4	5.767×10^{-1}	1.833	0.989
Living branch	4	1.117×10^{-3}	3.223	0.979
Leaf	4	6.845×10^{-3}	2.196	0.724
Total above ground	4	4.382×10^{-1}	1.977	0.997
Benakat, Indonesia				
Trunk with bark	4	1.699×10^{-1}	2.218	0.965
Living branch	4	3.512×10^{-4}	3.720	0.959
Leaf	4	6.115×10^{-5}	3.823	0.955
Total above ground	4	1.106×10^{-1}	2.432	0.962
Bogor, Indonesia				
Trunk with bark	12	1.282×10^{-1}	2.286	0.902
Living branch	12	3.171×10^{-4}	3.762	0.838
Leaf	12	3.991×10^{2}	-1.376	-0.0230
Total above ground	12	1.070×10^{-1}	2.426	0.905

[*1]Allometric equations are $V_T = a(D)^b$ and $M = a(D)^b$

Table II-3-3.

Coefficients of general allometric equation[*1] between trunk diameter (D, cm) and dry mass of each organ (M, kg) by the four *Acacia mangium* plantation forests

General equation	n	a	b	r^2
Trunk with bark	26	2.506×10^{-1}	2.094	0.906
Living branch	26	6.928×10^{-4}	3.464	0.833
Leaf	26	7.522×10^{-3}	2.212	0.427
Total above ground	26	1.876×10^{-1}	2.262	0.951

[*1]Allometric equations are $V_T = a(D)^b$ and $M = a(D)^b$

Table II-3-4.

Total above ground biomass (Mg ha^{-1}) estimated by site-specific and general allometric equations and error (%) associated with two equations in each *Acacia mangium* plantation forests

Sites	Total above ground biomass		Error associated with two equations
	Site-specific equation (Mg ha^{-1})	General equation (Mg ha^{-1})	(%)
Madang, Papua New Guinea	113.2	99.7	13.5
Sonbe, Vietnam	122.4	116.1	5.5
Benakat, Indonesia	132.6	134.3	- 1.2
Benakat, Indonesia	157.5	162.9	- 3.3
Benakat, Indonesia	133.2	134.0	- 0.6
Benakat, Indonesia	172.8	172.6	0.1
Benakat, Indonesia	143.5	145.4	- 1.3
Bogor, Indonesia	44.2	46.6	- 5.2
Bogor, Indonesia	51.0	53.6	- 4.8
Bogor, Indonesia	57.2	60.3	- 5.2
Bogor, Indonesia	56.1	58.7	- 4.5

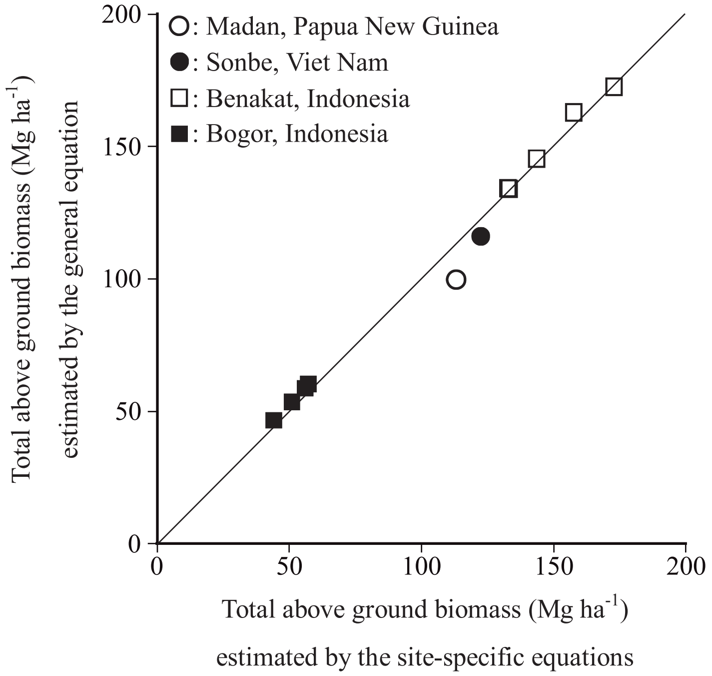

Figure II-3-1.

The relation between above ground biomass estimated by the site-specific and general equations at the four *Acacia mangium* plantation forests. The line shows $Y = X$.

Appendix II-3-1.a.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees of 4- and 7-year-old *Acacia mangium* plantation forests in Madang, Papua New Guinea

Sample tree number	1	2	3	4	5	6
Age (year)	4	4	4	7	7	7
Trunk diameter (cm)	22.4	14.7	18.1	25.2	30.5	15.9
Tree height (m)	19.8	20.2	19.3	29.4	31.1	25.3
Trunk volume ($10^3 \times m^3$)						
With bark	320.0	180.0	240.0	830.0	1000.0	280.0
Without bark	280.0	160.0	210.0	750.0	900.0	250.0
Dry mass (kg)						
Trunk without bark	126.9	65.4	92.2	276.3	416.1	99.2
Bark	15.3	8.4	9.9	22.8	32.0	9.8
Living branch	53.9	8.0	31.0	26.6	50.3	4.2
Leaf	8.8	4.5	7.5	25.8	10.5	3.3
Total above ground	204.9	86.3	140.6	351.5	508.9	116.5

Appendix II-3-1.b.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees of 6-year-old *Acacia mangium* plantation forest in Sonbe, Viet Nam

Sample tree number	1	2	3	4
Age (year)	6	6	6	6
Trunk diameter (cm)	23.9	19.1	14.2	11.9
Tree height (m)	21.3	21.5	19.9	18.2
Trunk volume ($10^3 \times m^3$)				
With bark	330.0	263.0	152.0	106.0
Without bark	294.0	241.0	135.0	93.0
Dry mass (kg)				
Trunk without bark	160.7	119.3	62.3	45.1
Bark	24.4	18.1	12.7	7.4
Living branch	33.5	14.1	5.0	3.7
Leaf	8.3	4.3	1.5	2.2
Total above ground	226.9	155.8	81.5	58.4

Appendix II-3-1.c.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees of 6-year-old *Acacia mangium* plantation forests in Benakat, Indonesia

Sample tree number	1	2	3	4
Age (year)	6	6	6	6
Trunk diameter (cm)	18.7	20.1	11.5	23.4
Tree height (m)	22.0	22.4	19.9	23.8
Trunk volume ($10^3 \times m^3$)				
With bark	274.5	278.5	90.1	444.4
Without bark	224.4	245.5	74.1	377.9
Dry mass (kg)				
Trunk without bark	108.1	98.6	32.6	163.9
Bark	17.8	16.2	5.4	27.0
Living branch	24.1	19.8	3.0	43.9
Leaf	6.0	4.8	0.7	10.0
Total above ground	156.0	139.4	41.7	244.7

Appendix II-3-1.d.

General information, trunk volume (10^{-3} m^3), and dry mass of each organ (kg) of sample trees of 8-year-old *Acacia mangium* plantation forests in Bogor, Indonesia

Sample tree number	1	2	3	4	5	6	7	8	9	10	11	12
Age (year)	8	8	8	8	8	8	8	8	8	8	8	8
Trunk diameter (cm)	21.1	18.0	20.0	22.5	18.8	24.0	19.8	22.9	25.3	17.2	22.0	22.1
Tree height (m)	18.7	17.7	18.3	19.0	17.2	19.0	18.3	19.6	18.2	16.2	19.6	20.4
Trunk volume ($10^3 \times m^3$)												
With bark	302.6	226.2	254.2	356.6	229.6	386.6	262.8	395.3	425.9	182.7	370.1	353.6
Without bark	-	-	-	-	-	-	-	-	-	-	-	-
Dry mass (kg)												
Trunk with bark	145.8	110.9	115.2	155.1	91.0	175.5	125.1	174.0	195.6	78.1	162.5	151.6
Bark	-	-	-	-	-	-	-	-	-	-	-	-
Living branch	32.0	19.9	23.1	41.5	16.1	42.2	37.4	43.2	62.9	11.5	31.3	33.9
Leaf	8.1	8.0	7.3	7.8	8.0	8.1	5.7	1.1	3.5	5.4	10.6	8.0
Total above ground	186.0	138.8	145.5	204.4	115.1	225.8	168.2	218.3	262.1	95.1	204.4	193.5

III. Biomass in rehabilitated forests

This chapter is divided into two sections, as follows:

III-1. Biomass recovery of naturally regenerated vegetation after the 1998 forest fire in East Kalimantan, Indonesia

This research was conducted by Motoshi Hiratsuka, Takeshi Toma, Rita Diana, Deddy Hadriyanto, and Yasushi Morikawa.

III-2. Biomass of an artificial forest of timber tree species in the humid tropics of West Java, Indonesia

This research was conducted by Motoshi Hiratsuka, Takeshi Toma, Nina Mindawati, Ika Heriansyah, and Yasushi Morikawa.

III-1. Biomass recovery of naturally regenerated vegetation after the 1998 forest fire in East Kalimantan, Indonesia

Keywords: above ground biomass, pioneer tree species, short-lived tree species

III-1-1. Introduction

During the last two decades of the 20th century, a large area of East Kalimantan, Indonesia was burned twice, by forest fires that occurred in 1982 to 1983 and 1997 to 1998 after prolonged dry spells caused by strong El Niño Southern Oscillation (ENSO) events. The fires in 1997 to 1998 burned estimated areas of over 26,000 ha in 1997 and 500,000 ha in 1998 (Mori 2000). Forest degradation and/or fragmentation after the fires affected many organisms (Cleary 2003; Makihara et al., 2000; Oka et al., 2000) and the fires resulted in significant emissions of carbon into the atmosphere (Auclair and Carter, 1993; Page et al., 2002).

Recent concerns about global warning and the carbon sequestration potential of tropical rainforests highlight the importance of regenerated secondary forests and their role as a carbon sink. In the humid tropics, however, if fire kills large primary tree species and the burned area becomes dominated by a few pioneer tree species, the lost biomass is unlikely to be completely restored (Toma et al., 2005). In addition, degraded lands without parent trees may not have the potential for succession leading to replacement (Tanimoto 1981; Wunderle 1997). Therefore, biomass recovery in such areas is quite slow (Kiyono and Hastaniah, 1997) and there may be limits to the potential AGB accumulation in secondary forest composed of pioneer tree species.

Evaluations of forest ecosystems after the fires have been undertaken by some research projects (Guhardia et al., 2000). There are also some reports of forest structure and species composition in such areas (Woods 1989). However, information on naturally regenerated vegetation at an early stage after fires, in relation to biomass recovery, is still limited (Hashimoto et al., 2000; Nykvist 1996).

In the study reported here, we focused on the early biomass recovery in several types of secondary forest. Our aim was to acquire information on initial secondary succession patterns in the area of East Kalimantan, Indonesia, that had been affected by several forest fires and was subsequently dominated by pioneer tree species.

III-1-2. Study site

This study was conducted in the Bukit Soeharto Education Forest (BSEF), Mulawarman University (0°52′S, 117°01′E, alt. 10 to 100 m) (Figure III-1-1). The area was originally covered by a lowland dipterocarp forest. The mean annual rainfall is approximately 2,000 mm; the annual mean daily maximum and minimum temperatures are 29.9 and 21.4°C, respectively (Toma et al., 2000a); and the soils are Ultisols (Ohta and Effendy, 1992). This area was subjected to selective logging prior to 1978 (Toma et al., 2000b). During the dry period in 1982 to 1983, a large-scale forest fire occurred in East Kalimantan and the BSEF was affected by it. A prolonged dry spell in 1997 to 1998 also resulted in a large-scale forest fire in 1998. As a result of the two forest fires within just 15 years, some patches formed of pioneer tree species without any canopy species above them (Mori 2000).

III-1-3. Field measurements

In September 2000, we established eight research plots (100 m^2, 10 × 10 m each) in an area dominated by the pioneer tree species *Homalanthus populneus* (Geiseler) Pax (Hom), *Macaranga gigantea* (Reichb. F. & Zoll.) Muell Arg and *M. hypoleuca* (Rchb.f. & Zoll.) Mull. Arg. (Mac), *Mallotus paniculatus* Muell Arg (Mal), *Melastoma malabathricum* L. (Mel), *Piper aduncum* L. (Pip), and *Trema cannabina* Lour. and *T. orietalis* (L.) Blume (Tre) by tree number base in each plot. Other pioneer tree species within, but not dominating, the plots included *Ficus* sp. (unidentified), *Geunsia pentandra* Merr, and *Vernonia arborea* Ham., which are common colonizers following forest fires in this area (Hashimoto et al., 2004; Mori 2000).

We conducted an annual tree census in each September from 2000 to 2003. All trees over 1.3 m in height were labeled and identified to at least genus level. The trunk diameter at 1.3 m above ground (*D*, cm) of all labeled trees in each plot was measured and recorded. In each tree census, new trees that just exceeded 1.3 m in height were labeled, identified and their *D* was measured and recorded.

III-1-4. Biomass estimation

Above ground tree dry mass was estimated using allometric equations. For *Ficus* sp., *G. pentandra*, and *P. aduncum*, above ground dry mass was estimated using empirical allometric equations (Hashimoto et al., 2004), as follows:

for *Ficus* sp.;

$$M = 7.50 \times 10^{-2} (D)^{2.60},\ r^2 = 0.95,\ n = 26 \qquad (1)$$

for *G. pentandra*;

$$M = 5.56 \times 10^{-2} (D)^{2.62},\ r^2 = 0.91,\ n = 20 \qquad (2)$$

for *P. aduncum*;

$$M = 8.89 \times 10^{-2} (D)^{2.39},\ r^2 = 0.92,\ n = 37 \qquad (3)$$

where *M* is the total above ground dry mass of an individual tree (kg) and *D* is the diameter of the tree (cm). For *M. gigantea* and *M. hypoleuca*. and other pioneer species, we draw allometric equations from inventory data (Hashimoto et al., 2004) based on destructive sampling, as follows:

for *M. gigantea* and *M. hypoleuca*;

$$M = 5.64 \times 10^{-2} (D)^{2.47},\ r^2 = 0.96,\ n = 30 \qquad (4)$$

for other pioneer species;

$$M = 1.49\times10^{-1}(D)^{2.09},\ r^2 = 0.68,\ n = 77 \qquad (5)$$

Above ground biomass (AGB) in each plot is the summation of the above ground dry mass of all individual trees with 1.3 m height.

III-1-5. Results and discussion

Total tree numbers averaged 67.0 trees 100 m^{-2} in the eight plots (ranging from 43.0 to 97.0 trees 100 m^{-2}) in 2000 and 40.1 trees 100 m^{-2} (ranging from 28.0 to 52.0 trees 100 m^{-2}) in 2003 (Figure III-1-2 and Table III-1-1). Thus, the mean value of total tree number in each plot decreased between these two dates, but in plot Tre-1, there was evidently an increase from 2002 onwards as *M. gigantea* invaded. Changes in the dominant tree species in each plot differed. Where the initially dominant tree species were *H. populneus*, *M. malabathricum*, or *T. cannabina* and *T. orietalis*, they tended to disappear from the plot, to be replaced by *M. gigantea* and *M. hypoleuca*. Where the initially dominant tree species were *M. gigantea* and *M. hypoleuca*, *M. paniculatus*, or *P. aduncum*, especially the former, they continued to dominate in the plot. They also became dominant in plots Hom-1, Hom-2, Mel-1, and Tre-1.

In 2000, AGB averaged 12.3 Mg ha^{-1} in the eight plots (ranging from 9.2 to 17.0 Mg ha^{-1}) and in 2003 it averaged 15.9 Mg ha^{-1} (ranging from 7.4 to 25.0 Mg ha^{-1}) (Figure III-1-3 and Table III-1-1). There were both increases and decreases in AGB between 2000 and 2003. In the plots dominated by *M. gigantea* and *M. hypoleuca*, in the five years after the fire, AGB increased and reached over 20 Mg ha^{-1}. In plot Mel-1, AGB also increased to over 20 Mg ha^{-1} onwards as the proportion of *M. gigantea* and *M. hypoleuca* increased. The trends in this plot may be similar to the AGB dynamics of a plot Mac-2 where initially dominated by *M. gigantea* and *M. hypoleuca*. The AGB dynamics for five years after the fire depended on the replacement of trees.

A secondary forest composed of *M. gigantea* and *M. hypoleuca* can only accumulate AGB up to 40 Mg ha^{-1} in East Kalimantan, Indonesia, and there may be a limit to biomass accumulation in the secondary forests dominated by pioneer tree species (Toma et al., 2005). In old secondary forests in East Kalimantan, Indonesia, accumulated AGB values have been found to remain small (Table III-1-2), totaling 44.2 to 55.3 Mg ha^{-1} in approximately 11-year-old forests (Hashimoto et al., 2000). The replacement of pioneer tree species with primary tree species is required for AGB to accumulate to the same level as in a primary forest.

On former study, pioneer trees were divided into two types (Whitmore 1984): short-lived tree species (about 15 to 30 years) and long-lived tree species (more than 80 years); that also mentioned very short-lived tree species (less than 15 years). The tree population changes during the five years after the fire (Figure III-1-2) indicate that the most short-lived trees account for the greatest population decreases. Tree species such as *M. malabathricum* and *T. cannabina* and *T. orietalis*, which almost disappeared from our study area, must be extremely short-lived (surviving less than five years).

In this study, the early stage of secondary forest development after forest fire was investigated and the regeneration pattern of secondary forests in the humid tropics was evaluated. The results indicate that the AGB dynamics soon after forest fires depend on the type of tree species (short-lived or extremely short-lived) that dominate after the fires at each site. Pioneer trees in this area included some extremely short-lived species (surviving less than five years). In addition, secondary forests consisting of only a few pioneer tree species without primary trees (parent trees) around the forest could not accumulate large quantities of AGB which was reported over 500 Mg ha^{-1} at about 50 km northwest from the BSEF if dominant tree species in primary forest do not grow in the secondary forest.

III-1-6. References

Auclair A. N. D., and Carter T. B., 1993. Forest wildfires as a recent source of CO_2 at northern latitudes. Canadian Journal of Forest Research, 23: 1528-1536.

Cleary D. F. R., 2003. An examination of scale of assessment, logging and ENSO-induced fires on butterfly diversity in Borneo. Oecologia, 135: 313-321.

Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., 2000. Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, pp.330.

Hashimoto T., Kojima K., Tange T., and Sasaki S., 2000. Changes in carbon storage in fallow forests in the tropical lowland of Borneo. Forest Ecology and Management, 126: 331-337.

Hashimoto T., Tange T., Masumori M., Yagi H., Sasaki S., and Kojima K., 2004. Allometric equations for pioneer tree species and estimation of the aboveground biomass of a tropical secondary forest in East Kalimantan. Tropics, 14: 123-130.

Kiyono Y., and Hastaniah, 1997. Slash-and-burn agriculture and succeeding vegetation in East Kalimantan. PUSREHUT special publication Vol. 6, Mulawarman University, Samarinda, Indonesia, pp 177.

Makihara H., Kinuura H., Yahiro K., and Soeyamto C., 2000. The effect of droughts and fires on coleopteran insects in lowland dipterocarp forests in Bukit Soeharto, East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 153-163.

Mori T., 2000. Effects of droughts and forest fires on Dipterocarp forest in East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 29-45.

Nykvist N., 1996. Regrowth of secondary vegetation after the ‘Borneo fire’ of 1982-1983. Journal of Tropical Ecology, 12: 307-312.

Ohta S., and Effendy S., 1992. Ultisols of ‘Lowland Dipterocarp Forest’ in East Kalimantan, Indonesia, I. Morphology and physical properties. Soil Science and Plant Nutrient, 38: 197-206.

Oka T., Iskandar E. and Ghozali D. I., 2000. Effects of forest fragmentation on the behavior of Bornean gibbons. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 229-241.

Page S. E., Siegert F., Rieley J. O., Boehm H-D. V., Jaya A., and Limin S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature, 420: 61-65.

Tanimoto T., 1981. Vegetation of the alang-alang grassland and its succession in the Benakat district of South Sumatra, Indonesia. Bull. Forest & Forest Products Research Institute, 314: 11-19.

Toma T., Marjenah, and Hastaniah, 2000a. Climate in Bukit Soeharto, East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 13-27.

Toma T., Matius P., Hastaniah, Kiyono Y., Watanabe R., and Okimori Y., 2000b. Dynamics of burned lowland dipterocarp forest stands in Bukit Soeharto, East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 107-119.

Toma T., Ishida A., and Matius P., 2005. Long-term monitoring of post-fire aboveground biomass recovery in a lowland dipterocarp forest in East Kalimantan, Indonesia. Nutrient Cycling in Agroecosystems, 71: 63-72.

Whitmore T. C., 1984. Tropical rain forests of the Far East (second edition). Clarendon Press, Oxford, pp 352.

Woods P., 1989. Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. Biotropica, 21: 290-298.

Wunderle Jr. J. M., 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. Forest Ecology and Management, 99: 223-235.

Table III-1-1.

Dominated tree species in each year, tree density (trees 100 m^{-2}), mean trunk diameter (*D*, cm) with S.D., basal area (BA, m^2 ha^{-2}), and above ground biomass (AGB, Mg ha^{-2}) of each plot in East Kalimantan, Indonesia

Plot		Year after the fire			
		Two years	Three years	Four years	Five years
Hom-1	Tree density (trees 100 m^{-2})	70	78	53	43
	Mean *D* (cm) with S.D.	2.8 (1.9)	2.8 (2.0)	3.6 (2.3)	3.6 (2.2)
	Basal area (m^2 ha^{-2})	6.0	7.3	7.5	6.0
	Above ground biomass (Mg ha^{-2})	12.8	15.5	16.1	12.6
Hom-2	Tree density (trees 100 m^{-2})	97	101	49	52
	Mean *D* (cm) with S.D.	2.5 (1.3)	2.7 (1.4)	3.1 (1.5)	2.7 (1.5)
	Basal area (m^2 ha^{-2})	6.0	7.3	4.6	3.9
	Above ground biomass (Mg ha^{-2})	12.6	15.1	9.4	7.8
Mac-1	Tree density (trees 100 m^{-2})	63	51	43	29
	Mean *D* (cm) with S.D.	3.6 (2.1)	4.6 (2.6)	5.4 (3.2)	5.9 (3.8)
	Basal area (m^2 ha^{-2})	8.3	11.2	13.2	11.2
	Above ground biomass (Mg ha^{-2})	17.0	24.1	28.8	24.7
Mac-2	Tree density (trees 100 m^{-2})	65	69	56	45
	Mean *D* (cm) with S.D.	3.0 (2.1)	3.5 (2.5)	4.3 (2.8)	4.8 (3.2)
	Basal area (m^2 ha^{-2})	6.7	10.2	11.4	11.6
	Above ground biomass (Mg ha^{-2})	11.8	19.3	22.6	23.9

Table III-1-1.

Continued

Plot		Year after the fire			
		Two years	Three years	Four years	Five years
Mal-1	Tree density (trees 100 m^{-2})	43	48	39	28
	Mean *D* (cm) with S.D.	4.1 (1.9)	4.2 (2.2)	4.7 (2.4)	4.6 (2.4)
	Basal area (m^2 ha^{-2})	6.8	8.5	8.4	5.8
	Above ground biomass (Mg ha^{-2})	14.7	18.4	18.2	12.3
Mel-1	Tree density (trees 100 m^{-2})	53	52	36	29
	Mean *D* (cm) with S.D.	2.9 (1.8)	3.5 (2.3)	4.8 (3.1)	5.7 (3.9)
	Basal area (m^2 ha^{-2})	4.9	7.2	9.1	10.8
	Above ground biomass (Mg ha^{-2})	9.6	14.9	20.2	25.0
Pip-1	Tree density (trees 100 m^{-2})	57	50	44	45
	Mean *D* (cm) with S.D.	3.0 (1.7)	3.3 (1.8)	4.1 (1.9)	3.8 (1.7)
	Basal area (m^2 ha^{-2})	5.3	5.6	6.9	6.2
	Above ground biomass (Mg ha^{-2})	10.9	11.5	14.7	13.0
Tre-1	Tree density (trees 100 m^{-2})	88	92	42	50
	Mean *D* (cm) with S.D.	2.3 (1.1)	2.4 (1.3)	3.1 (1.6)	2.4 (2.0)
	Basal area (m^2 ha^{-2})	4.4	5.5	3.9	3.8
	Above ground biomass (Mg ha^{-2})	9.2	11.3	8.0	7.4

Table III-1-2.

Years after the fire, recovered above ground biomass (AGB, Mg ha^{-1}), and mean annual increment (MAI, Mg ha^{-1} yr^{-1}) of AGB in East Kalimantan of Indonesia and Sabah of Malaysia in Borneo Island

Forest type and Regions	Years after the fire	AGB Mg ha^{-1}	MAI[*1] Mg ha^{-1} yr^{-1}
Secondary forest after the fire	1	7.5-9.9	8.7
Sebulu, East Kalimantan, Indonesia	3	12.1	4.0
	3-4	18.9-23.6	6.1
	4-5	22.5-26.6	5.5
	6-8	35.0	5.0
	8-9	33.5-45.5	4.6
	10-12	44.2-55.3	4.5
Secondary forest after the fire	2	1.3	0.7
Sipitang, Sabah, Malaysia	5	20.2	4.0
	8	58.0	7.3

[*1]Median value range of years after the fire and AGB were used for calculating MAI

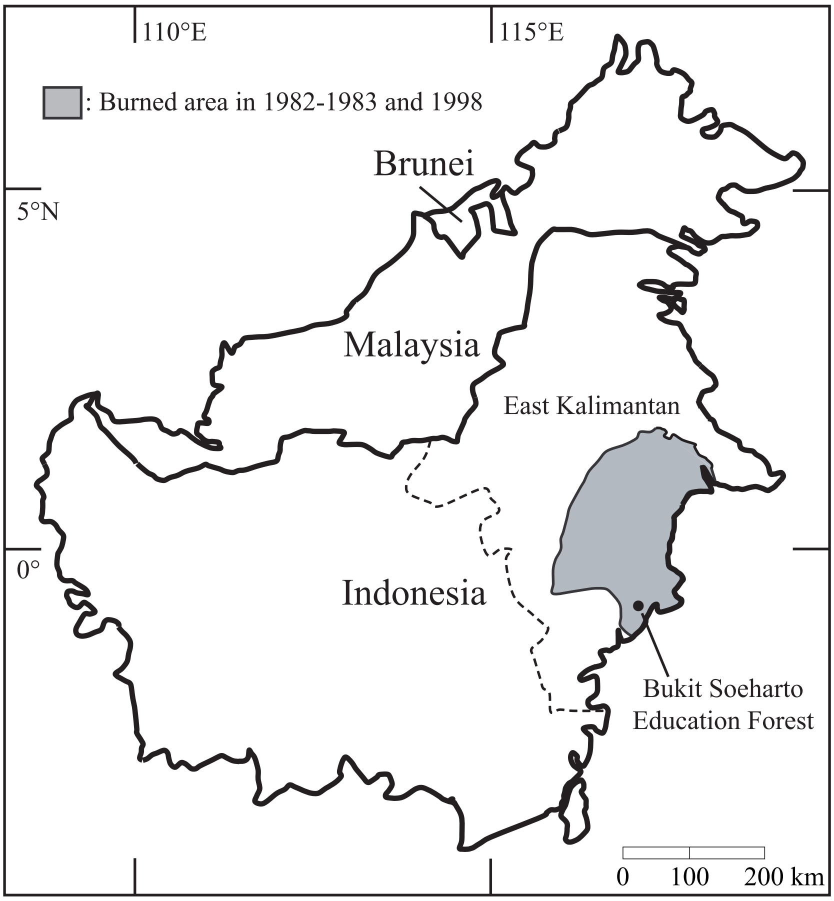

Figure III-1-1.

Map of Kalimantan Island including burned area in 1982 to 83 and 1998 (modified from Mori 2000)

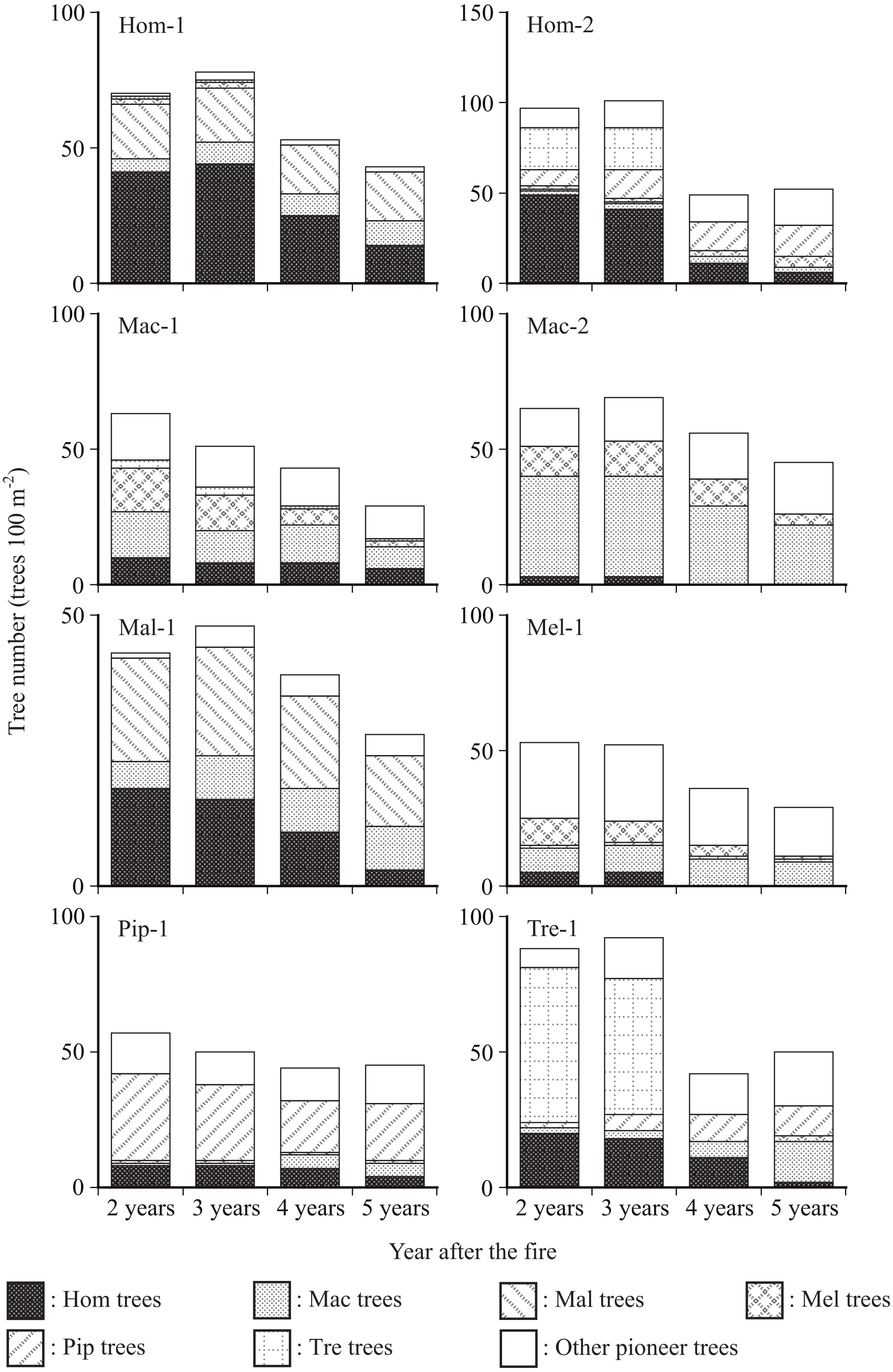

Figure III-1-2.

Tree population changes after the forest fire in each plot. The designation of each plot refers to the species that dominated at the beginning of the survey, namely *Homalanthus populneus* (Hom), *Macaranga gigantea* and *M. hypoleuca* (Mac), *Mallotus paniculatus* (Mal), *Melastoma malabathricum* (Mel), *Piper aduncum* (Pip), and *Trema cannabina* and *T. orietalis* (Tre).

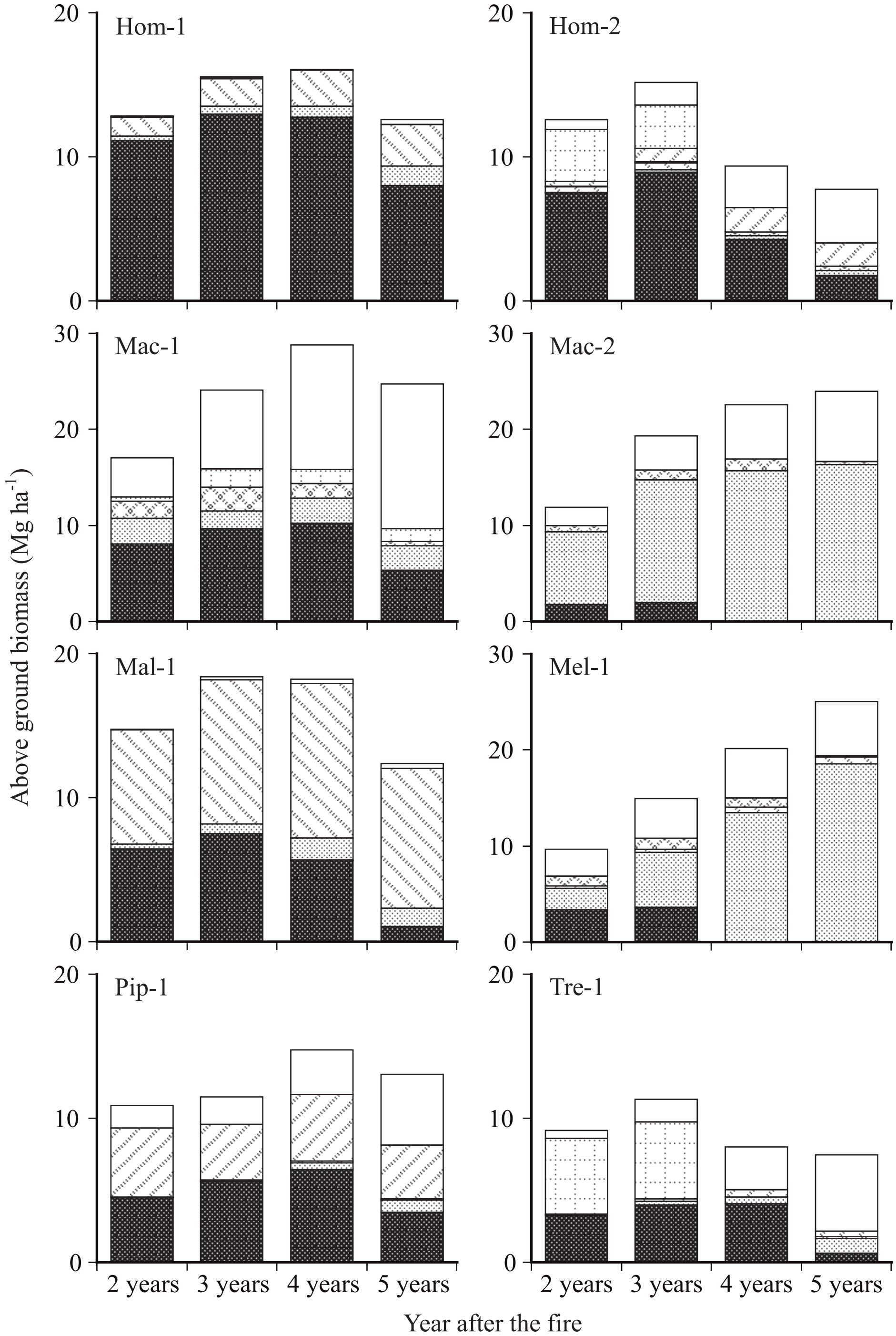

Figure III-1-3.

Dynamics of above ground biomass (AGB) after the forest fire. Plot names are same as in Figure III-2-1.

III-2. Biomass of an artificial forest of timber tree species in the humid tropics of West Java, Indonesia

Keywords: Biomass, Carbon sequestration, Artificial forest, Timber tree species

III-2-1. Introduction

Degradation in tropical rainforests has increased carbon dioxide (CO_2) emissions to the atmosphere (Fearnside 1996; Hall and Uhlig, 1991; Houghton 1991; Houghton et al., 2000; Page et al., 2002), because the large carbon stock harvested from the forests has been released into the atmosphere. Establishing and managing artificial forests on former forested lands may mitigate the effects of global warming by sequestration of atmospheric CO_2 in the forests. The carbon pool in these forests will be maintained if the forest are managed in a sustainable fashion with a long-rotation cycle.

Information on biomass of industrial plantation forests with short-rotation periods has been reported (e.g., Hardiyanto et al., 1999; Morikawa et al., 2001; Morikawa et al., 2002; Yamada et al., 2004). However, there are few reports on the biomass of mature artificial forests (>30 years old) in the humid tropics, and available information is limited to the trunk diameter and tree height (e.g., Ahmad Zuhaidi and Mahat, 1997; Ahmad Zuhaidi and van Gardingen, 1999; Ahmad Zuhaidi et al., 1999; Masano and Alrasjid, 1991;). Therefore, accumulation of data on the productivity and biomass of mature artificial forests is urgently required. This study sought to estimate the biomass of a mature artificial forest to calculate the carbon sequestration potential of plantation forest in the humid tropics.

III-2-2. Study site

This study was carried out in the Dramaga experimental forest of the Forest Research and

Development Agency, Ministry of Forestry of Indonesia (FORDA), in West Java, Indonesia. The annual rainfall at the site is about 3,550 mm and soil type is a brown-reddish latosol (Subiakto et al., 2001). The forest was established in 1954 to evaluate the growth characteristics, fruiting pattern, and silvicultural potential of timber tree species (Masano and Alrasjid, 1991). The total area of the forest is 60 ha comprising 120 plots with an area 0.25 ha (50 × 50 m) on flat land. One to several tree species were planted in each plot in 1954. The spacing of initial planting was 3 × 3 m (1,111 trees ha^{-1}) in most plots. Because supplementary trees were planted when the originally planted trees died, each plot was composed of different-aged individuals of one to six tree species.

III-2-3. Field measurements

Field investigations were carried out in July and August 2002. We selected 20 plots with closed canopies. Each plot was about 45 years old and had one to two tree species. We measured the trunk diameter (*D*, cm) of all trees with *D* of 10 cm or over at 1.3 m above the ground in each plot. For trees with a buttress over 1.3 m high, the diameter was measured at 30 cm above the upper ridge of the buttress. In each plot, the tree height (*H*, m) was measured by using a laser height measure (Laser Rangefinder, Opti-Logic Co. Ltd.) for trees for which the top could be seen from the ground (20 to 40% of the total trees). An empirical equation between *D* and *H* (Curtis 1967) was constructed from these sample trees for each tree species:

$$H = a + b\log(D) \quad (1)$$

where *a* and *b* are coefficients of the regression function for each tree species. The *H* of all trees were predicted from this relationship.

III-2-4. Allometric relationship

Trunk dry mass of individual trees was estimated in two steps. First, trunk volume was estimated by allometric equation drawn from the inventory data with 76 sample trees in a primary rainforest in Indonesia (Yamakura et al., 1986b) (Figure III-2-1).

$$V_T = 6.045\times10^{-5}(D^2H)^{0.960},\ r^2 = 0.993,\ n = 76 \qquad (2)$$

where V_T is the trunk volume with bark (m^3). In this case, we used D^2H as the parameter as same as Yamakura et al. (1986a) which used inventory data mentioned above (Yamakura et al., 1986b). If we used D as the parameter, similar accurate equation was developed (r^2 = 0.986). Second, the dry mass of the trunk of individual trees was calculated by:

$$M_T = V_T \times S \qquad (3)$$

where M_T is the dry mass of trunk (kg), and S is its bulk density (Mg m^{-3}). The bulk density of trunks was obtained from the database of the World Agroforestry Centre (2005). Trunk volume (TV, m^3 ha^{-1}) and trunk biomass (TB, Mg ha^{-1}) of each plot is the summation of the trunk volume with bark (V_T) and the trunk dry mass (M_T) of individual trees with D equal to 10 cm or over, respectively.

III-2-5. Results

In the 20 measured plots, there were 19 planted tree species including nine Dipterocarpaceae, and a few tree species that regenerated naturally. All Dipterocarpaceae tree species were native to Indonesia and a number of others were introduced from South America and Africa as timber tree species. Maximum D (121.5 cm) was observed for a planted 46-year-old *Khaya grandifoliola* C. DC. tree, and the estimated maximum H (50.6 m) was for a planted 46-year-old *Shorea selanica* (DC.) Blume. Natural regeneration from seeds of planted trees was observed in most of the plots, but all had D less than 10 cm. Pioneer tree species also colonized in most of the plots, some with D over 10 cm.

The TB of measured plots ranged from 260.5 to 911.1 Mg ha^{-1} (Table III-2-1); the largest TB was for the plot composed of 46-year-old *K. grandifoliola* and *K. senegalensis* (Desr.) A. Juss., and the smallest TB was for the plot composed of 40-year-old *Vatica pauciflora* (Korth.) Blume. Among the plots of Dipterocarpaceae species, the range of TB was from 260.5 to 635.0 Mg ha^{-1}; the largest was for the plot composed of 46-year-old *Hopea odorata* Roxb., and the smallest was for the plot composed of 40-year-old *V. pauciflora* as mentioned above.

The mean annual increment (MAI) of TB was over 10 Mg ha^{-1} yr^{-1} in eight plots with either one species or two species of the same age. Five high values of MAI of TB (i.e., above 13 Mg ha^{-1} yr^{-1}) were observed in plots of 46-year-old *K. grandifoliola* and *K. senegalensis*, 46-year-old *Hymenaea courbaril* L, 45-year-old *Dipterocarpus retusus* Blume, 46-year-old *H. odorata*, and 46-year-old *K. grandifoliola* and *S. selanica*.

III-2-6. Discussion

In general, allometric equations are best determined by destructive sampling for each site and species but destructive sampling was prohibited in the Dramaga experimental forest. In the humid tropics, information on growth potential of long-term artificial forest is still limited. To our knowledge, this is the first study to evaluate the biomass of such forest. Thus, it will be necessary to conduct the destructive sampling to confirm the validity of non-destructive sampling sampling.

To estimate V_T from D and H of an individual tree, we drew a relationship between V_T and D^2H from a data set obtained in a primary forest (Yamakura et al., 1986b), which covered the size of trees at our study site. Tree stocking in our plots decreased from 1,111 trees ha^{-1} at planting to between 172 and 489 trees ha^{-1} in 2002 though supplemental planting was performed at an early stage (under 20 years) (Table III-2-1). This decrease of stocking in old artificial forest suggests competition between trees occurred as it would in primary forests, and a similarity in the V_T and D^2H relationship. We limited our estimation only to TB because of possible differences in the biomass ratio of branch and leaf to trunk between primary forest and our study site. Assuming a similar tree form between the primary forest and our study site, the above ground biomass of trees was about 123% of TB.

Sixteen plots out of selected 20 plots had a large TB (i.e., above 400 Mg ha^{-1}) comparable with the primary forests in the humid tropics. Primary forests were 403.3 Mg ha^{-1} in East Kalimantan (Yamakura et al., 1986a), and 522.2 and 367.5 Mg ha^{-1} in Peninsular Malaysia (Kato et al., 1978). Additionally, the range of MAI of TB observed in the Dramaga experimental forest was larger than those of industrial plantation forests of fast-growing tree species in the humid tropics. Even well-known fast-growing industrial plantation tree species, such as *Acacia mangium* Willd., *A. auriculiformis* A. Cunn. ex Benth. seldom exceed 18 Mg ha^{-1} yr^{-1} MAI of TB in seven to nine years rotation (Table III-2-2).

This study showed the potential of the artificial forest to function as a terrestrial carbon pool comparable with the natural primary forests in the favorable region. Large MAIs at stand age over 40 years, which is comparable to the fast-growing industrial plantation forests with short rotations (seven to nine years), also suggest the great potential productivity of plantation forests of native tree species.

III-2-7. References

Ahmad Zuhaidi Y., and Mahat M. N., 1997. An assessment of the growth of plantation grown *Pentaspadon motleyi* (PELONG). Journal of Tropical Forest Science, 10: 133-136.

Ahmad Zuhaidi Y., and van Gardingen P., 1999. Stand growth structure and yield of plantation grown *Dryobalanops aromatica* in Peninsular Malaysia: >50 years after planting. Journal of Tropical Forest Science, 11: 205-217.

Ahmad Zuhaidi Y., Mahat M. N., and A. Rasip A. G., 1999. Growth of plantation grown *Khaya ivorensis* in Peninsular Malaysia. Journal of Tropical Forest Science, 11: 849-851.

Curtis R. O., 1967. Height-diameter and height-diameter-age equations for second-growth

Douglas-fir. Forest Science, 13: 365-375.

Fearnside P. M., 1996. Amazonian deforestation and global warming: carbon stocks in vegetation replacing Brazil's Amazon forest. Forest Ecology Management, 80: 21-34.

Hall C. A. S., and Uhlig J., 1991. Refining estimates of carbon released from tropical land-use change. Canadian Journal of Forest Research, 21: 118-131.

Hardiyanto E. B., Ryantoko A., and Anshori S., 1999. Effects of site management in *Acacia mangium* plantations at PT. Musi Hutan Persada, South Sumatra, Indonesia. In: Nambiar E. K. S., Tiarks A., Cossalter C., and Ranger J., (eds.), Proceedings of International Workshop on site management and productivity in tropical plantation forest, Kerala, India. Center for International Forestry Research, Bogor, Indonesia, pp 41-49.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Houghton R. A., 1991. Tropical deforestation and atmospheric carbon dioxide. Climatic Change, 19: 99-118.

Houghton R. A., Skole D. L., Nobre C. A., Hackler J. L., Lawrence K.T., and Chomentowski W.H., 2000. Annual fluxes of carbon from deforestation and regrowth in the Brazilian Amazon. Nature, 403: 301-304.

Kato R., Tadaki Y., and Ogawa H., 1978. Plant biomass and growth increment studies in Pasoh forest. Malayan Nature Journal, 30: 211-224.

Masano, and Alrasjid H., 1991. Planting trial of *Shorea platyclados* at Pasir Hantap experimental garden. BIOTROP Special Publication, 41: 471-477.

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on

BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

Ogawa H., Yoda K., Ogino K., and Kira T., 1965. Comparative ecological studies on three main types of forest vegetation in Thailand II. plant biomass. Nature & Life in Southeast Asia. 4: 49-80.

Page S. E., Siegert F., Rieley J. O., Boehm H-D. V., Jaya A., and Limin S., 2002. The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature, 420: 61-65.

Subiakto A., Hendromono, and Sunaryo, 2001. *Ex-situ* conservation of dipterocarp species in West Java and Banten. In; Proc. Inter. Conference on *in-situ* and *ex-situ* conservation of commercial tropical trees. Thielges B. A., Sastrapradja S. D., and Rimbawanto A., (eds.), Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia, pp 183-191.

World Agroforestry Centre, 2005. Wood density database. available at World Agroforestry Centre's web site, http://www.worldagroforestrycentre.org/-sea/Products/AFDbases/WD/Index.htm. Cited in October 25, 2005.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986a. Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio, 68: 71-82.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986b. Tree size in a mature dipterocarp forest stand in Sebulu, East Kalimantan, Indonesia. The Southeast Asian Studies, 23: 452-478.

Table III-2-1.

Basal area (BA, m^2 ha^{-1}), trunk volume (TV, m^3 ha^{-1}), trunk biomass (TB, Mg ha^{-1}), mean annual increment (MAI) of TB (Mg ha^{-1} yr^{-1}), and some related characteristics of each plot with planted trees and natural regenerated trees (others) in the Dramaga experimental forest in West Java, Indonesia

Plot no.	Tree species	Age	Tree density	D^{*1}	H^{*1}	Basal area	TV with bark	TB	MAI of TB^{*2}
		year	trees ha^{-1}	cm	m	m^2 ha^{-1}	m^3 ha^{-1}	Mg ha^{-1}	Mg ha^{-1} yr^{-1}
1	*Khaya grandifoliola*	46	104	102.1	45.4	38.7	724.3	579.4	12.6
	Khaya senegalensis	46	117	83.1	44.6	24.6	414.6	331.7	7.2
	total		221	-	-	63.3	1138.9	911.1	19.8
2	*Hymenaea courbaril*	46	224	89.5	48.3	48.0	928.2	686.9	14.9
	other		16	22.7	24.1	0.5	5.3	3.7	-
	total		240	-	-	48.5	933.5	690.5	15.0
3	*Khaya grandifoliola*	46	96	121.5	48.5	27.6	522.2	417.7	9.1
	Shorea selanica	46	76	82.7	50.6	19.5	416.8	191.7	4.2
	other		4	10.8	10.5	0.0	0.1	0.1	-
	total		176	-	-	47.1	939.0	609.6	13.3
4	*Dipterocarpus retusus*	45	277	81.9	45.7	42.2	818.0	613.5	13.6
	other		212	25.0	17.4	4.5	35.6	16.5	-
	total		489	-	-	46.7	853.5	630.0	14.0
5	*Syzygium polyanthum*	45	356	61.6	41.8	43.7	738.6	491.2	10.9
	other		89	31.6	19.3	2.2	18.6	8.5	-
	total		445	-	-	45.9	757.3	499.7	11.1
6	*Hopea odorata*	46	324	76.7	43.8	45.1	813.3	630.3	13.7
	other		16	25.9	26.6	0.6	7.1	4.7	-
	total		340	-	-	45.7	820.4	635.0	13.8
7	*Shorea leprosula*	43	80	92.5	45.7	32.3	657.5	383.1	8.9
	Hopea mengarawan	32	106	54.4	43.0	10.2	177.8	126.2	3.9
	other		21	26.1	25.8	0.4	4.0	1.3	-
	total		207	-	-	42.8	839.3	510.6	-

Table III-2-1.
(*continued*)

Plot no.	Tree species	Age	Tree density	D^{*1}	H^{*1}	Basal area	TV with bark	TB	MAI of TB^{*2}
		year	trees ha^{-1}	cm	m	m^2 ha^{-1}	m^3 ha^{-1}	Mg ha^{-1}	Mg ha^{-1} yr^{-1}
8	*Khaya anthotheca*	45	179	90.0	47.9	41.3	754.0	467.5	10.4
	Hopea mengarawan	29	16	20.5	23.4	0.3	3.7	2.6	0.1
	other		20	14.2	11.9	0.2	1.4	0.8	-
	total		215	-	-	41.9	759.1	470.9	-
9	*Azadirachta excelsa*	46	248	70.7	45.1	36.2	638.6	424.7	9.2
	other		12	13.0	12.8	0.1	0.9	0.4	-
	total		260	-	-	36.3	639.5	425.1	9.2
10	*Maranthes corymbosa*	44	165	61.6	38.8	26.3	468.2	449.5	10.2
	Hopea mengarawan	46	120	43.1	38.3	9.3	153.3	108.8	2.4
	total		285	-	-	35.6	621.5	558.3	-
11	*Pterygota alata*	45	336	66.7	32.4	35.3	589.5	424.4	9.4
	other		4	18.8	15.0	0.1	0.9	0.4	-
	total		340	-	-	35.4	590.4	424.8	9.4
12	*Shorea balangeran*	45	316	52.4	34.1	33.0	514.3	442.3	9.8
	Vatica pauciflora	35	20	39.0	26.9	1.6	19.6	14.8	0.4
	other		32	19.1	15.1	0.5	4.1	1.9	-
	total		368	-	-	35.2	538.0	459.0	-
13	*Pinus merkusii*	42	236	68.7	45.0	34.6	602.5	423.6	10.1
	other		8	12.9	8.1	0.1	0.3	0.2	-
	total		244	-	-	34.7	602.9	423.8	10.1
14	*Pinus merkusii*	45	240	70.0	45.3	34.0	613.8	431.5	9.6
	other		56	16.2	17.4	0.7	4.0	2.7	-
	total		296	-	-	34.7	617.7	434.2	9.6

Table III-2-1.
(*continued*)

Plot no.	Tree species	Age	Tree density	D^{*1}	H^{*1}	Basal area	TV with bark	TB	MAI of TB[*2]
		year	trees ha^{-1}	cm	m	m^2 ha^{-1}	m^3 ha^{-1}	Mg ha^{-1}	Mg ha^{-1} yr^{-1}
15	*Dipterocarpus retusus*	45	160	85.4	46.1	33.2	658.1	493.6	11.0
	other		12	18.9	20.1	0.3	2.7	1.6	-
	total		172	-	-	33.4	660.7	495.1	11.0
16	*Hopea mengarawan*	33	308	41.8	37.7	23.1	379.6	269.6	8.2
	Hopea odorata	46	64	65.0	41.6	8.9	162.3	125.8	2.7
	other		12	20.8	22.5	0.4	4.3	3.1	-
	total		384	-	-	32.4	546.2	398.4	-
17	*Hydnocarpus alpina*	45	280	60.0	44.4	32.0	425.3	348.8	7.8
	other		4	18.2	30.0	0.1	0.9	0.4	-
	total		284	-	-	32.1	426.2	349.2	7.8
18	*Shorea guiso*	44	170	63.7	47.2	30.6	587.6	487.7	11.1
	other		15	28.5	30.0	0.4	5.6	3.9	-
	total		185	-	-	31.0	593.2	491.6	11.2
19	*Vatica pauciflora*	40	276	46.2	29.9	26.3	338.5	255.6	6.4
	other		28	29.8	25.3	0.9	8.7	4.9	-
	total		304	-	-	27.2	347.2	260.5	6.5
20	*Hopea bancana*	44	289	41.5	32.5	24.5	357.2	262.6	6.0
	total		289	-	-	24.5	357.2	262.6	6.0

[*1]Maximum value.

[*2]MAI of TB was calculated for plots where one or same aged two tree species were planted.

Table III-2-2.

Tree density (trees ha^{-1}), trunk biomass (TB, Mg ha^{-1}), and mean annual increment (MAI) of TB (Mg ha^{-1} yr^{-1}) of some primary forests and some industrial plantation forests in the tropics of Southeast Asia

Forest type and location	Tree density (trees ha^{-1})	TB (Mg ha^{-1})	MAI of TB (Mg ha^{-1} yr^{-1})	Authors
Primary forests				
Lowland rain forest in Khao Chong, peninsular Thailand [a]	-	254.0	-	Ogawa et al. 1965
Lowland rain forest in Khao Chong, peninsular Thailand [a]	-	206.0	-	Ogawa et al. 1965
Lowland rain forest in Sebulu, East Kalimantan of Indonesia [b]	550	403.3	-	Yamakura et al. 1986a
Lowland rain forest in Pasoh, peninsular Malaysia [b]	-	522.2	-	Kato et al. 1978
Lowland rain forest in Pasoh, peninsular Malaysia [b]	-	367.5	-	Kato et al. 1978
Industrial tree plantations				
Acacia auriculiformis (6-year-old) in Sonbe, Vietnam	-	77.9	13.0	Yamada et al. 2004
Acacia mangium (6-year-old) in Benakat, South Sumatra of Indonesia	822	106.4	17.7	Hiratsuka et al. 2005
Acacia mangium (7-year-old) in Madang, Papua New Guinea	506	92.6	13.2	Morikawa et al. 2002
Acacia mangium (9-year-old) in Subanjeriji, South Sumatra of Indonesia	-	138.9	15.4	Yamada et al. 2004
Acacia mangium (9-year-old) in Subanjeriji, South Sumatra of Indonesia	-	118.0	13.1	Yamada et al. 2004

[*1]TB was for trees with over 4.5 cm trunk diameter at 1.3 m high above the ground.

[*2]Tree density and TB were for trees with over 10 cm trunk diameter at 1.3 m high above the ground.

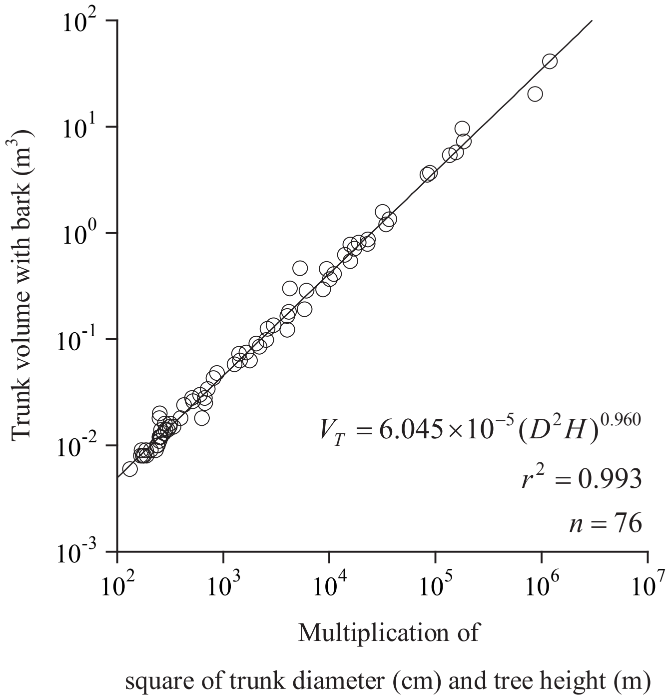

Figure III-2-1.

Relationship between multiplication of square of trunk diameter (*D*, cm) and tree height (*H*, m) and trunk volume with bark (T_V, m^3). Sample trees were from inventory data of Yamakura et al. (1986b).

IV. Long-term management of productive forests in the humid tropics

This chapter is divided into two sections, as follows;

IV-1. Trunk diameter and tree height growths of long-term productive forests in the humid tropics of West Java, Indonesia

This research was conducted by Motoshi Hiratsuka, Nina Mindawati, Ika Heriansyah, Takeshi Toma and Yasushi Morikawa.

IV-2. Trunk volume equations for commercial timber species in the humid tropics of West Java, Indonesia

This research was conducted by Motoshi Hiratsuka, Nina Mindawati, Hendromono, Takeshi Toma, Masahiro Amano and Yasushi Morikawa.

IV-1. Trunk diameter and tree height growths of long-term productive forests in the humid tropics of West Java, Indonesia

Keywords: Growth curve, Productive forest, timber tree species

IV-1-1. Introduction

Demand for the timber woods of the tropics has been increasing in the world. This tendency has hardly changed with the late 20th century. Production of tropical industrial logs as staple timber wood in producer countries (58 countries) of International Tropical Timber Organization (ITTO) were 136 million m^3 in 2003, and this value was equivalent to 12% of total industrial logs production from overall forests in all ITTO member countries in 2003 (ITTO 2004). It is clear that timber from primary forest could be exhaustion in the near future.

China's imports of log increased to 7.6 million m^3 (60% of all consumer country log imports) in 2003 (ITTO 2004). China also continued as the world's largest tropical sawnwood importer in 2003, despite a slight decline of 1% in imports to under 2.8 million m^3. China's economy continued its rapid growth in 2003 and 2004, expanding by over 9% in both years to lead all major economies. Other Asian developing countries (excluding China and India) continued to grow strongly, with output increasing by 5.1% in 2003, 5.6% in 2004. As economic growth increase, demand for wood products by Asian developing countries is obviously increased, and to fill such demands for wood products, illegal logging activities play an important role ironically now. Therefore, sustainable woods supply with legal from productive forests is strongly expected.

In order to halt the illegal flow of sawnwood, Indonesian government has proposed a ban on exports. Indonesia also decided in December 2004 to carry out government-to-government timber trade where only logs received through government designated ports would be considered as legal, collaborated with Malaysia. Other proposals of Indonesia include death penalty to stop illegal logging activities (ITTO 2004). The illegal logging activities are quite a big problem which need countermeasures. Other producer countries of wood products also have similar problem of illegal logging activities and took measures to meet the solution.

Indonesia is principal country of timber production in the world. Production of logs was 30 million m^3. In the case of plywood, production was 6.4 million m^3 (ITTO 2004). On the other hand, Indonesia has lost huge forest resources in last two decades of 20th century through terrible forest fires, especially 1997 to 1998 and 1997 to 1998 fires (Fatawi and Mori, 2000; Fuller and Fulk, 2001; Siegert and Hoffmann, 2000) and spread illegal logging activities (Casson and Obidzinski, 2002).

Restoring degraded land by planting timber tree species is required now from various viewpoints of environmental protections, carbon sequestration, and continuous wood products supply. In addition, artificial forests might decrease harvesting pressure on primary forests in the tropics (Fenning and Gershenzon, 2002) if they could supply timber instead of that from primary forest. Thus, production of tropical timber from artificial forests is important to satisfy the demand for the timber woods which is going on increase (Fredericksen and Putz, 2003; Sedjo 2001). Hence, we need to make up the scenario of silvicultural system using timber tree species. However, information on growth characteristics of timber tree species is still limited because long-term investigation in artificial forests has not been carried out in the humid tropics.

On Chapter III-2, we estimated trunk biomass of over 40 years artificial forest of timber tree species. This study is following to study cited in Chapter III-2 and aimed to present adequate information on growth characteristics of artificial forests with timber tree species in the humid tropics, as a measure of silvicultural system instead of supplying timber from primary rainforests.

IV-1-2. Material and methods

IV-1-2.1. Study sites

This study was carried out in five experimental forests, the Cikole, the Cikampek, the Carita, the Dramaga, and the Haurbentes experimental forests of the Forest Research and Development Agency, Ministry of Forestry of Indonesia (FORDA) in West Java, Indonesia. The annual rainfall and soil classification are shown in Table IV-1-1 and they were no remarkable differences in each site. These forests were established between 1937 and 1955 for evaluation of growth characteristics, fruiting pattern, and silvicultural potential of Dipterocarpaceae and exotic timber tree species on mainly grasslands affected by wildfires. When these forests were established, seeds and saplings were obtained from Sumatra and Kalimantan islands and Bogor botanical garden in West Java. First, seeds were planted into small pots with canopied nursery and hurdling operation were carried out under the net shades. When saplings grew up to about 40 cm height, they were planted on each experimental forest.

Each forest comprised trial plots with an area 0.25 ha (50 × 50 m). One to several tree species were planted in each plot at initial stage. Spacing of initial planting was 3 × 3 m (1,111 trees ha^{-1}) in most plots. Since supplementary trees were planted when originally planted trees died, therefore, each plot was composed of different-aged individuals. Selective cutting of planted trees had not been conducted in each experimental forest since establishment.

IV-1-2.2. Field investigation

Tree census, which is measurements of the trunk diameter of all trees equal to 10 cm or over at 1.3 m high above the ground (D, cm) and tree height (H, m) has been conducted continuously since establishment in each forest. For trees with high buttress over 1.3 m high, the diameter was measured above 20 cm from the upper ridge of the buttress. Interval of each tree census is differenced from each forest and each plot. Basically, tree census had been conducted three to five years intervals, and those were carried out from next year of establishment to our recent measurement in July to October 2003. One to sixteen times tree censuses were conducted in each plot in five experimental forests.

IV-1-2.3. Growth curves of *D* and *H*

The growth curves on *D* and *H* of each tree species were analyzed by the Gompertz growth function using continuous tree censuses data. We assumed that the mean *D* and *H* growths of each species follow the Gompertz growth function, expressed by the following equation:

$$Y = Ae^{-be^{-kt}} \qquad (1)$$

where *Y* is *D* or *H*, *A* is the carrying capacity, *b* is a coefficient depending on the initial *D* and *H*, *k* is the coefficient of growth, and *t* is age after planting. Values of *A* and *k* denote the asymptotic maximum *D* and *H* and the potential growth rate of each tree species, respectively. Therefore, *A* and *k* are used as indices for the mature size and the growth rate of each tree species, respectively, in this study.

IV-1-3. Results

IV-1-3.1. Forest condition in year 2003

Natural regenerated trees from planted trees were observed in many plots. In Dipterocarpaceae, *Shorea palembanica* Miq., *S. pinanga* R. Scheffer, and *S. leprosula* Miq. were markedly regenerated and pioneer tree species were also regenerated in most plots. Some of those trees had *D* over 10 cm in 2003.

From the result of supplemental planting since establishment, there were 229 plots (57%) where initial planted trees were dominated over 75% as basal area (BA, $m^2\ ha^{-1}$) base in 2003.

IV-1-3.2. *D* and *H* growths

Growth curves i.e., the relationship between age after planting and *D* or *H* at the age were constructed in 49 timber tree species (Appendix IV-1-1). All tree species showed high accuracy (r = 0.76 to 1.00 on *D* growth and r = 0.80 to 1.00 on *H* growth) in each growth curves. These relationships indicated that no marked increase was observed in almost all tree species when stand ages were over 30 to 40 years old. Some Dipterocarpaceae tree species mentioned high asymptotic maximum value *A* with low value of *k* on *D* and *H* growth curves.

The relationship between potential growth rate *k* and asymptotic maximum value *A* on *D* and *H* growth curves showed negative correlations, respectively ($p < 0.1$ on *D* and $p < 0.01$ on *H*) (Figure IV-1-1). Tree species belonging to Leguminosae, such as *Piptadenia peregrine* Benth. and *Enterolobium cyclocarpum* (Jacq.) Griseb. showed high asymptotic maximum value *A* on *D* growth curve. On the other hand, tree species belonging to Dipterocarpaceae, such as *S. selanica* (DC.) Blume, *S. stenoptera* Burck, and *Hopea mengarawan* Miq. showned high *A* on *H* growth curves. Tree species with high bulk density (kg m^{-3}) according to World Agroforestry Centre (2005), such as *Vatica pauciflora* (Korth.) Blume and *S. seminis* (de Vriese) Slooten showed low values of potential growth rate *k* ($p > 0.1$).

IV-1-4. Discussion

The growth curves on *D* and *H* of each tree species showed that growth characteristics of popular timber tree species were obviously differenced from each other (Appendix IV-1-1). Those were roughly separated into *A* type and *k* type growths from analysis of relationships between *A* and *k* values of *D* and *H* growths. Former type showed tendency of growth with large mature size *A* in spite of low *k* value and later type showed tendency of growth with high rate of *k* in spite of low *A*.

It is necessary to obtain tree growth patterns from the viewpoint of forest restoration, because we have to select trees correctly in suitable site. In this study, we got knowledge of growth potential of timber tree species such tree species in Depterocarpaceae of *S. stenoptera*, *S. selanica*, and so on (Figure IV-1-1). These tree species have high potential to supply timber wood in short-term rather than other Dipterocarpaceae species in the humid tropics, because these tree species grow faster with large maximum size of *D* and *H*.

In the humid tropics, growth characteristics of timber trees have not been evaluated, and such information gap make the efforts for establishment of forests difficult, because it is difficult to plan and manage established forests. We suggested that information on growth characteristics of each timber tree species is valuable for the preliminary selection of tree species for establishment and management of artificial forests, especially productive forests as timber sources in the humid tropics.

IV-1-5. References

Casson A., and Obidzinski K., 2002. From new order to regional autonomy: shifting dynamics of “illegal” logging in Kalimantan, Indonesia. World Development, 30: 2,133-2,151.

Fatawi M., and Mori T., 2000. Description of forest and forestry in East Kalimantan. In: Guhardja E., Fatawi M., Sutisna M., Mori T., and Ohta S., (eds.). Rainforest ecosystems of East Kalimantan. Ecological Study, Vol. 140, Springer Tokyo, 4-12.

Fenning T. M., and Gershenzon J., 2002. Where will the wood come from? Plantation forests and the role of biotechnology. Trends in Biotechnology, 20: 291-296.

Fredericksen T. S., and Putz F. E., 2003. Silvicultural intensification for tropical forest conservation. Biodiversity and Conservation, 12: 1445-1453.

Fuller D. D., and Fulk M., 2001. Burned area in Kalimantan, Indonesia mapped with

NOAA-AVHRR and Landsat TM imagery. International Journal of Remote Sensing, 22: 691-697.

ITTO, 2004. Annual review and assessment of the world timber situation 2004. ITTO. available at ITTO's web site, http://www.itto.or.jp/. Cited in October 25, 2005.

Sedjo R. A., 2001. From foraging to cropping: the transition to plantation forestry, and implications for wood supply and demand. Unasylva, 204: 24-32.

Siegert F., and Hoffmann A. A., 2000. The 1998 forest fire in East Kalimantan (Indonesia): a quantitative evaluation using high resolution, multitemporal ERS-2 SAR images and NOAA-AVHRR Hotspot Data. Remote Sens. Environ, 72: 64-77.

World Agroforestry Centre, 2005. Wood density database. available at World Agroforestry Centre's web site, http://www.worldagroforestrycentre.org/-sea/Products/AFDbases/WD/Index.htm. Cited in October 25, 2005.

Table IV-1-1.

General information on five experimental forests in West Java, Indonesia

Site	Carita	Cikampek	Cikole	Dramaga	Haurbentes
Latitude	06°18'	06°25'	06°46'	06°33'	06°33'
Longitude	105°50'	107°27'	107°39'	106°45'	106°26'
Altitude (m. asl)	50	50	1,500	220	250
Rainfall (mm yr^{-1})	2,102	1,796	2,996	3,552	4,276
Soil Classification	Alluvial	Latosol	Brown Alluvial	Brown Reddish Latosol	Red Yellow Podsolik
Established year	1955	1937	1954	1956	1940
Area (ha)	50	45	40	60	100
Number of plot	65	171	132	120	164
Main species	*Shorea* sp., *Hopea* sp.	*Hymenaea* sp.,	*Alnus* sp., *Eucalyptus* sp.	*Shorea* sp., *Hopea* sp.	*Shorea* sp., *Hopea* sp.
Number of investigated plots	47	149	107	20	101

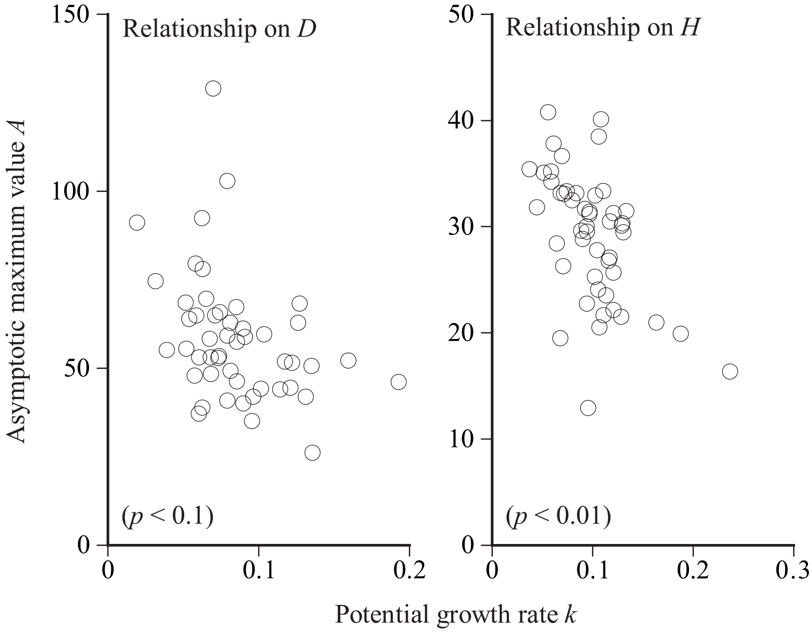

Figure IV-1-1.

The relationships between potential growth rate k and asymptotic maximum value A of growth equations on D and H by Gomperz function

Appendix IV-1-1.

Coefficients of growth equations on trunk diameter (D, cm) and tree height (H, m) by the Gomperz function in each species

Tree species	Family	Age[*1]	Coefficients of growth equation on D				Coefficients of growth equation on H				BD[*2]
		year	A	b	k	r	A	b	k	r	
Agathis borneensis	Araucariaceae	48	44.04	3.79	0.11	1.00	31.30	3.53	0.12	0.97	470
Agathis dammara	Araucariaceae	49	52.84	3.55	0.07	0.97	34.26	2.48	0.06	0.94	520
Durio zibethinus	Bombacacea	52	37.13	2.60	0.06	0.98	21.67	2.62	0.11	0.98	570
Canarium schweinfurthii	Burseraceae	65	57.50	2.93	0.09	1.00	22.76	1.82	0.09	0.98	360
Casuarina equisetifolia	Casuarinaceae	43	41.95	1.96	0.10	0.97	27.79	1.45	0.10	0.99	950
Maranthes corymbosa	Chrysobalanaceae	65	78.02	3.04	0.06	0.99	30.49	2.46	0.12	0.96	765
Terminalia arjuna	Combretaceae	48	52.19	5.28	0.16	1.00	22.16	2.66	0.12	0.99	817
Terminalia kaernbachii	Combretaceae	48	40.04	1.98	0.09	0.95	20.97	1.49	0.16	0.98	520
Widdringtonia nodiflora	Cupressaceae	48	47.88	1.96	0.06	0.99	19.49	1.31	0.07	0.95	545
Dipterocarpus tempehes	Dipterocarpaceae	63	55.10	2.78	0.04	0.99	28.41	3.35	0.06	0.99	668
Hopea mengarawan	Dipterocarpaceae	50	64.87	3.57	0.06	0.90	36.65	3.05	0.07	0.95	710
Hopea odorata	Dipterocarpaceae	49	46.25	3.02	0.09	0.94	26.29	2.06	0.07	0.91	775
Shorea hypochra	Dipterocarpaceae	63	67.29	4.87	0.09	0.97	31.48	7.21	0.13	0.90	690

Appendix IV-1-1.

(continued)

Tree species	Family	Age[*1]	Coefficients of growth equation on *D*				Coefficients of growth equation on *H*				BD[*2]
		year	*A*	*b*	*k*	*r*	*A*	*b*	*k*	*r*	
Shorea leprosula	Dipterocarpaceae	63	51.88	2.66	0.12	0.90	33.36	2.39	0.11	0.91	583
Shorea palembanica	Dipterocarpaceae	63	51.56	6.39	0.12	0.93	26.80	4.47	0.12	0.92	560
Shorea pinanga	Dipterocarpaceae	63	53.04	2.79	0.07	0.93	33.32	2.78	0.07	0.90	468
Shorea selanica	Dipterocarpaceae	49	58.36	2.26	0.07	0.95	40.77	2.09	0.06	0.97	485
Shorea seminis	Dipterocarpaceae	63	91.16	2.34	0.02	1.00	31.82	1.67	0.04	0.99	905
Shorea stenoptera	Dipterocarpaceae	63	68.32	6.01	0.13	0.88	38.50	3.13	0.11	0.91	575
Shorea virescens	Dipterocarpaceae	63	92.43	4.06	0.06	1.00	29.53	3.49	0.09	0.99	470
Vatica pauciflora	Dipterocarpaceae	42	38.88	2.39	0.06	0.94	35.41	2.21	0.04	0.96	520
Ricinodendron heudelotii	Euphorbiaceae	50	46.16	3.16	0.19	0.96	21.52	1.95	0.13	0.93	570
Calophyllum soulattri	Guttiferae	49	40.82	2.37	0.08	0.99	20.52	2.06	0.11	1.00	360
Cinnamomum porrectum	Lauraceae	48	55.49	2.06	0.05	0.99	35.08	1.88	0.05	0.93	950
Enterolobium cyclocarpum	Leguminosae	54	102.88	2.77	0.08	0.96	30.01	1.88	0.09	0.94	765
Hymenaea courbaril	Leguminosae	65	63.92	2.10	0.05	0.93	31.40	1.83	0.10	0.86	817

Appendix IV-1-1.
(continued)

Tree species	Family	Age[*1]	Coefficients of growth equation on *D*				Coefficients of growth equation on *H*				BD[*2]
		year	*A*	*b*	*k*	*r*	*A*	*b*	*k*	*r*	
Piptadenia peregrina	Leguminosae	54	129.02	3.59	0.07	0.97	30.31	2.53	0.13	0.94	520
Trachylobium verrucosum	Leguminosae	64	50.67	4.18	0.13	0.98	23.55	2.67	0.11	0.90	545
Azadirachta excelsa	Meliaceae	46	68.51	2.68	0.05	0.90	33.10	2.06	0.07	0.95	668
Azadirachta indica	Meliaceae	50	26.10	5.32	0.14	0.98	12.93	2.07	0.10	0.97	710
Cedrela odorata	Meliaceae	64	53.03	1.93	0.06	0.95	16.36	1.45	0.24	0.80	775
Chukrasia tabularis	Meliaceae	64	65.83	3.24	0.07	0.97	28.85	2.00	0.09	0.99	690
Khaya anthotheca	Meliaceae	53	79.53	2.69	0.06	0.88	32.96	2.29	0.10	0.93	583
Khaya grandifoliola	Meliaceae	54	62.89	3.31	0.08	0.98	32.51	2.12	0.08	0.95	560
Khaya senegalensis	Meliaceae	48	62.89	3.48	0.13	0.98	27.10	2.00	0.12	0.96	468
Swietenia macrophylla	Meliaceae	62	59.24	2.71	0.08	0.92	24.09	2.32	0.11	0.96	485
Eucalyptus deglupta	Myrtaceae	49	53.42	1.79	0.07	0.87	29.49	1.46	0.13	0.93	905
Eucalyptus maidenii	Myrtaceae	44	35.09	2.23	0.10	0.94	33.18	1.98	0.07	0.93	575
Eucalyptus platyphylla	Myrtaceae	45	41.97	2.95	0.13	0.96	19.93	1.52	0.19	0.91	955

Appendix IV-1-1.

(continued)

Tree species	Family	Age[*1]	Coefficients of growth equation on *D*				Coefficients of growth equation on *H*				BD[*2]
		year	*A*	*b*	*k*	*r*	*A*	*b*	*k*	*r*	
Eucalyptus saligna	Myrtaceae	49	48.33	1.64	0.07	0.98	35.22	1.00	0.06	0.96	900
Eucalyptus tereticornis	Myrtaceae	48	58.89	2.69	0.09	0.97	33.16	1.75	0.08	0.99	765
Eucalyptus torelliana	Myrtaceae	48	64.94	2.25	0.07	0.99	40.13	3.60	0.11	0.94	853
Melaleuca quinquenervia	Myrtaceae	40	74.63	1.95	0.03	0.99	37.83	2.05	0.06	0.99	725
Pinus caribaea	Pinaceae	57	44.48	3.04	0.12	0.76	25.68	2.88	0.12	0.80	410
Pinus kesiya	Pinaceae	63	59.57	3.14	0.10	0.97	30.12	2.97	0.13	0.98	560
Pinus merkusii	Pinaceae	64	49.24	2.07	0.08	0.85	29.61	2.33	0.09	0.87	505
Anthocephalus chinensis	Rubiaceae	45	61.17	2.04	0.09	0.99	31.69	1.63	0.09	0.92	465
Pterygota alata	Sterculiaceae	50	44.20	3.14	0.10	0.90	31.18	2.25	0.10	0.92	720
Vitex cofassus	Verbenaceae	65	69.64	2.69	0.07	0.93	25.30	1.84	0.10	0.94	735

[*1] Tree age in recent tree census

[*2] DB is quoted from the database of World Agroforestry Center (2005)

IV-2. Trunk volume equations for commercial timber species in the humid tropics of Southeast Asia

Keywords; Artificial forest, Commercial trunk volume, Timber supply

IV-2-1. Introduction

Trunk diameter and basal area are the main parameters generally used as proxies for the trunk volume or tree biomass and to investigate their growth in target forests when equations for estimating trunk volume are not available. Both parameters are relatively easy to measure with high accuracy. However, the most useful parameter, for both silviculturalists and timber suppliers, is the trunk volume because it is most strongly correlated with the primary commercial biomass of the living stand. For researchers, the mean annual increment of trunk volume can also be a useful parameter for evaluating the status of a forest site (Enggelina 1998).

However, the trunk volume is not easy to assess with high accuracy, because there is no direct relationship between it and the readily measured stand parameters of trunk diameter or basal area. Furthermore, developing trunk volume equations for every species used in commercial forestry in the humid tropics is time-consuming and laborious. For these reasons, there have been few systematic attempts to evaluate trunk biomass parameters in artificial tropical forests to date. Nevertheless, there are urgent needs to replace wood obtained from primary forests with timber from artificial forests to meet increasing demands for wood products in developing countries and to promote sustainable forest management. Indeed, Sedjo (2001) predicted that 75% of industrial wood will come from planted forests by the year 2050. Thus, convenient methods must be developed to estimate the trunk volumes of commercial species in artificial tropical forests.

In the study reported here, we focus on the twenty main timber tree species in the humid tropics and supply information that can be used to develop equations for estimating commercial trunk volumes based on convenient parameters. In this thesis, commercial trunk volume is considered synonymous with the merchantable trunk bole volume in the forest.

IV-2-2. Study Site

This study was carried out in the Dramaga and Haurbentes experimental forests owned and managed by Forest Research and Development Agency, Ministry of Forestry of Indonesia (FORDA), in West Java, Indonesia. Annual rainfall in these areas amounts to about 3,500 and 4,200 mm, and the soil types are brown-reddish latosolic and red-yellow podzolic, respectively (Subiakto et al., 2001). The condition of the stands in these experimental forests is similar. The forests were established in 1954 and 1940, respectively, to evaluate the growth characteristics, fruiting pattern, and silvicultural potential of various timber tree species (Masano and Alrasjid, 1991). The total areas of the Dramaga and Haurbentes experimental forests are 60 ha and 100 ha, divided into 120 and 164 plots of 0.25 ha (50 × 50 m) on flat land and gently undulating hills, respectively.

IV-2-3. Field measurements

We selected plots of timber tree species with closed canopies in each forest. Tree species were totally 20 and were mainly Dipterocarpaceae and some exotic tree species. In each plot, we selected sample trees to develop equations for estimating commercial trunk volume (*CTV*, m^3), defined as the part of the trunk from 0.3 m above the ground (low point) to the lowest living branch (high point) in each tree species. For trees with high buttresses, over 0.3 m high, the diameter at the top of the buttress (hereafter 'buttress height') was regarded as the low point. These trees had a wide range of sizes. For instance, the diameter at the low point of *Shorea selanica* (DC.) Blume ranged from 29.4 to 91.8 cm.' where *S. selanica* is one of the species investigated.

We then measured the trunk diameter at: heights of 0.3 cm ($D_{0.3}$, cm) and 1.3 m (D, cm); buttress height (D_B, cm), the lowest living branch height (D_{LAB}, cm), and each height at 2 to 4 m intervals between the low and high points. We also measured the tree height (H, m), buttress height (H_B, m), and the lowest living branch height (H_{LAB}, m) of all sample trees. These measurements were taken using a Tele-Relaskop (Relaskop-Technik Ltd.). For trees with a high buttress, over 1.3 m high, we measured the diameter at 20 cm above the upper ridge of the buttress, ant regarded them as D. We also measured bark thickness by scraping off a small part of the bark at 1.3 m height. Field investigations were carried out in August and September 2002.

IV-2-4. Equations for trunk volume

We first analyzed the trunk form of each tree species. Kajihara (1985) reported that the trunk form of trees in Japanese plantation stands of *Cryptomeria japonica* (L. f.) D. Don and *Chamaecyparis obtusa* Sieb et Zuee were similar because there were small coefficients of variation in their relative trunk diameters to relative heights, which he suggested could be conveniently used to provide reasonably accurate estimates of trunk volume and to generate trunk volume tables. In this study, we analyzed the variation of trunk form in each species to find out if the corresponding coefficients of variation were small, as in the Japanese plantation forests. We then calculated the relative trunk diameter at heights 30, 50, 70, and 90% of the H_{LAB} (RD_{30RH}, RD_{50RH}, RD_{70RH}, RD_{90RH} where $RD_{10RH} = 1$). The constancy of trunk form in each species was then analyzed by calculating the coefficients of variation of the relative diameters at relative H_{LAB}. The results confirmed that the coefficients of variation of these relative diameters in each species were small, suggesting that simple height and diameter parameters could be validly used to estimate the trunk volume of trees of these species with a large range of sizes.

To estimate the trunk volume of each sample tree, we used Smalian’s equation. We then developed equations for estimating commercial trunk volume based on the parameter RD_{10RH} and H_{LAB} for each tree species. The formula is based on same dimension (three-dimensions) in both side of equation, and we used this formula on an experimental basis:

$$CTV = a(RD_{10RH}{}^2 H_{LAB})^b \qquad (1)$$

where CTV is the commercial trunk volume (m^3), and a and b are coefficients of the regression function of each equation.

IV-2-5. Results and discussion

The variations in trunk form in each species were similar to those reported by Kajihara (1985), and the coefficient of variation of the relative trunk diameter at relative H_{LAB} was small for each species investigated (Table IV-2-1). Therefore, the parameters RD_{10RH} and H_{LAB} can be used to calculate adequate estimates of CTV of trees with a large range of sizes for the 20 timber species we investigated. For each tree species, equations developed from the multiple functions showed high accuracy (p < 0.001) (Table IV-2-2). Therefore, CTV can be estimated with high accuracy by measuring the parameters RD_{10RH} and H_{LAB}.

However, the parameter RD_{10RH} is sometimes difficult to measure in forests with high tree densities, because it can be difficult to distinguish clearly the D_{LAB} point from ground level. Therefore, quick estimates of CTV require equations based on a convenient parameter that is easy to measure. In such cases, we would recommend use simple parameter D:

$$CTV = aD^b \qquad (2)$$

For each tree species, allometric equation based on D also showed high accuracy (p < 0.001) (Table IV-2-2). Furthermore, there were no significant differences between the F values for the equation based on RD_{10RH} and H_{LAB} (1) and equation based on D (2) obtained for each species. Therefore, CTV can be quickly measured if we have tree census data including just D.

The timber from plantation forests is becoming increasingly important, due to the decline in primary forests, and the drive to conserve what is left of them, especially since large proportions of the increasing demands for wood products (notably in the developing economies of various Asian counties) have been met by illegal logging activities. Wood production from plantation forests must be strongly boosted to meet these demands and reduce the pressures promoting illegal logging. The information and equations for estimating *CTV* presented here should facilitate the management of artificial forests in the humid tropics, for instance when selecting stems for cutting.

IV-2-6. References

Enggelina A., 1998. Volume equation. In: Jean-Guy, Bertault, and Kadir K., (eds.), Silvicultural research in a lowland mixed dipterocarp forest of East Kalimantn, CIRD-forêt, FORDA, and P. T. INHUTANII, pp 250.

Kajihara M., 1985. Studies on the relative stem-form and its application for estimating stem volume (VII): variations of the relative stem-form and normal form-factors within a stand. Journal of Japanese Forestry Society, 67: 341-347.

Masano, and Alrasjid H., 1991. Planting trial of *Shorea platyclados* at Pasir Hantap experimental garden. BIOTROP Special Publication, 41: 471-477.

Sedjo R., 2001. From foraging to cropping: the transition to plantation forestry, and implications for wood supply and demand. Unasylva, 52: 24-32.

Subiakto A., Hendromono, and Sunaryo, 2001. *Ex-situ* conservation of dipterocarp species in West Java and Banten. In; Proc. Inter. Conference on *in-situ* and *ex-situ* conservation of commercial tropical trees. Thielges B. A., Sastrapradja S. D., and Rimbawanto A., (eds.), Faculty of Forestry, Gadjah Mada University, Yogyakarta, Indonesia, pp 183-191.

Table IV-2-1.

Number of sample trees for each of 20 investigated species and the coefficients of variation (%) of relative trunk diameter at heights 30, 50, 70 and 90% of the lowest living branch height (RD_{30RH}, RD_{50RH}, RD_{70RH} and RD_{90RH}, respectively)

Tree species	Sample tree number at each site	Coefficient of variation (%)							
		RD_{30RH}		RD_{50RH}		RD_{70RH}		RD_{90RH}	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Anisoptera costata	Haurbentes (20)	5.1	4.3	5.7	4.2	6.1	4.1	9.8	5.9
Dipterocurpus retusus	Dramaga (20)	4.6	4.1	6.2	5.0	7.2	5.3	11.3	7.5
Hopea bancana	Dramaga (26)	7.5	6.4	6.4	5.0	6.8	5.0	7.2	5.1
Hymenaea courbaril	Dramaga (20)	6.8	6.0	9.2	7.8	12.9	10.2	14.4	10.7
Hopea mengarawan	Dramaga (9), Haurbentes (11)	9.7	8.7	10.5	8.4	12.3	8.8	13.2	8.3
Hopea odorata	Dramaga (14), Haurbentes (6)	6.2	5.7	7.2	5.9	10.6	7.9	14.3	9.4
Khaya anthotheca	Dramaga (20)	4.7	4.1	6.4	5.2	7.3	5.6	8.0	5.7
Khaya grandifoliola	Dramaga (18)	3.9	3.4	4.5	3.7	6.4	4.9	8.7	6.2
Khaya senegalensis	Dramaga (17)	4.8	4.3	8.2	6.7	9.3	7.2	13.3	9.5
Shorea balangeran	Dramaga (20)	4.5	4.0	5.6	4.5	6.1	4.5	10.8	6.9

Table IV-2-1.
(continued)

Tree species	Sample tree number at each site	Coefficient of variation (%)							
		RD_{30RH}		RD_{50RH}		RD_{70RH}		RD_{90RH}	
		Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Shorea guiso	Dramaga (17), Haurbentes (4)	6.4	5.7	9.1	7.3	14.0	10.0	17.2	11.1
Shorea leprosula	Dramaga (12), Haurbentes (11)	5.8	5.3	7.7	6.4	11.4	8.5	17.0	11.2
Shorea mecisropteryx	Haurbentes (18)	3.8	3.3	6.8	5.3	10.5	7.1	16.7	9.3
Shorea ovalis	Haurbentes (20)	5.5	5.1	6.2	5.1	7.9	5.8	13.4	8.4
Shorea palembanica	Haurbentes (19)	6.7	5.9	6.7	5.4	9.3	6.9	13.2	8.8
Shorea pinanga	Haurbentes (20)	5.5	4.9	6.3	5.0	7.3	5.0	11.1	6.6
Shorea selanica	Dramaga (14), Haurbentes (5)	4.9	4.5	6.3	5.3	7.5	5.7	10.9	6.9
Shorea seminis	Haurbentes (21)	5.2	4.6	4.8	3.8	7.9	5.7	11.8	7.7
Shorea stenoptera	Haurbentes (21)	5.0	4.5	6.4	5.2	7.4	5.5	13.6	8.8
Vatica pauciflora	Dramaga (12), Haurbentes (8)	6.2	5.5	7.3	5.9	10.7	7.8	8.4	5.4

Table IV-2-2.

Coefficients of allometric equations based on parameter RD_{10RH} (cm) and H_{LAB}, (m) and parameter D (cm) for estimating commercial trunk volume (CTV, m^3) with and without bark in each tree species

Tree species	Estimated volume	No.	Coefficients of allometric equation based on RD_{10RH} and H_{LAB}				Coefficients of allometric equation based on D			
			a	b	r^2	p	a	b	r^2	p
Anisoptera costata	With bark	20	1.21×10^4	9.02×10^1	0.97	< 0.001	1.11×10^3	1.86	0.93	< 0.001
	Without bark	20	1.02×10^4	9.14×10^1	0.97	< 0.001	9.53×10^4	1.88	0.93	< 0.001
Dipterocurpus retusus	With bark	21	9.26×10^5	9.48×10^1	0.99	< 0.001	5.66×10^4	2.17	0.95	< 0.001
	Without bark	21	7.98×10^5	9.58×10^1	0.99	< 0.001	4.87×10^4	2.20	0.95	< 0.001
Hopea bancana	With bark	26	3.53×10^5	1.03	0.90	< 0.001	3.60×10^4	2.18	0.79	< 0.001
	Without bark	26	3.43×10^5	1.02	0.90	< 0.001	3.41×10^4	2.19	0.79	< 0.001
Hymenaea courbaril	With bark	20	1.46×10^5	1.13	0.99	< 0.001	1.68×10^4	2.50	0.94	< 0.001
	Without bark	20	1.29×10^5	1.13	0.99	< 0.001	1.49×10^4	2.52	0.94	< 0.001
Hopea mengarawan	With bark	20	1.09×10^4	9.22×10^1	0.97	< 0.001	6.79×10^4	2.10	0.95	< 0.001
	Without bark	20	1.10×10^4	9.17×10^1	0.97	< 0.001	7.06×10^4	2.07	0.94	< 0.001
Hopea odorata	With bark	20	5.76×10^5	9.94×10^1	0.98	< 0.001	9.40×10^4	2.01	0.89	< 0.001
	Without bark	20	4.73×10^5	1.00	0.98	< 0.001	8.07×10^4	2.03	0.88	< 0.001
Khaya anthotheca	With bark	20	8.55×10^5	9.49×10^1	0.98	< 0.001	3.70×10^4	2.23	0.93	< 0.001
	Without bark	20	7.03×10^5	9.62×10^1	0.98	< 0.001	3.07×10^4	2.26	0.93	< 0.001

Table IV-2-2.

(continued)

Tree species	Estimated volume	No.	Coefficients of allometric equation based on RD_{10RH} and H_{LAB}				Coefficients of allometric equation based on D			
			a	b	r^2	p	a	b	r^2	p
Khaya grandifoliola	With bark	18	6.10×10^5	9.79×10^1	0.99	< 0.001	2.31×10^4	2.33	0.97	< 0.001
	Without bark	18	4.67×10^5	9.98×10^1	0.99	< 0.001	1.81×10^4	2.37	0.97	< 0.001
Khaya senegalensis	With bark	17	4.86×10^5	1.01	0.96	< 0.001	4.75×10^4	2.17	0.85	< 0.001
	Without bark	17	4.00×10^5	1.02	0.96	< 0.001	3.85×10^4	2.21	0.86	< 0.001
Shorea balangeran	With bark	20	6.30×10^5	9.78×10^1	0.99	< 0.001	2.75×10^4	2.33	0.95	< 0.001
	Without bark	20	4.51×10^5	1.00	0.98	< 0.001	2.02×10^4	2.39	0.96	< 0.001
Shorea guiso	With bark	21	8.54×10^5	9.47×10^1	0.97	< 0.001	1.02×10^4	2.60	0.89	< 0.001
	Without bark	21	7.43×10^5	9.56×10^1	0.97	< 0.001	8.93×10^5	2.62	0.89	< 0.001
Shorea leprosula	With bark	23	6.83×10^5	9.71×10^1	0.98	< 0.001	6.27×10^4	2.14	0.97	< 0.001
	Without bark	23	5.64×10^5	9.83×10^1	0.98	< 0.001	5.29×10^4	2.17	0.97	< 0.001
Shorea mecisropteryx	With bark	18	2.52×10^5	1.06	0.99	< 0.001	7.06×10^4	2.11	0.98	< 0.001
	Without bark	18	1.70×10^5	1.09	0.99	< 0.001	5.17×10^4	2.17	0.98	< 0.001
Shorea ovalis	With bark	20	4.40×10^5	1.02	0.99	< 0.001	3.66×10^4	2.25	0.97	< 0.001
	Without bark	20	3.69×10^5	1.03	0.98	< 0.001	3.12×10^4	2.27	0.97	< 0.001

Table IV-2-2.

(continued)

Tree species	Estimated volume	No.	Coefficients of allometric equation based on RD_{10RH} and H_{LAB}				Coefficients of allometric equation based on D			
			a	b	r^2	p	a	b	r^2	p
Shorea palembanica	With bark	19	6.18×10^5	9.70×10^1	0.98	< 0.001	6.42×10^4	2.02	0.97	< 0.001
	Without bark	19	4.79×10^5	9.88×10^1	0.98	< 0.001	5.19×10^4	2.05	0.97	< 0.001
Shorea pinanga	With bark	20	4.72×10^5	1.00	0.99	< 0.001	8.32×10^4	1.99	0.95	< 0.001
	Without bark	20	3.84×10^5	1.02	0.99	< 0.001	7.09×10^4	2.02	0.95	< 0.001
Shorea selanica	With bark	19	9.88×10^5	9.46×10^1	0.99	< 0.001	8.57×10^4	2.10	0.95	< 0.001
	Without bark	19	8.33×10^5	9.57×10^1	0.99	< 0.001	7.39×10^4	2.13	0.95	< 0.001
Shorea seminis	With bark	21	5.03×10^5	9.95×10^1	0.98	< 0.001	5.01×10^4	2.10	0.93	< 0.001
	Without bark	21	4.57×10^5	1.00	0.98	< 0.001	4.59×10^4	2.12	0.93	< 0.001
Shorea stenoptera	With bark	21	6.93×10^5	9.72×10^1	0.99	< 0.001	1.43×10^3	1.92	0.97	< 0.001
	Without bark	21	5.34×10^5	9.90×10^1	0.99	< 0.001	1.16×10^3	1.95	0.97	< 0.001
Vatica pauciflora	With bark	20	6.34×10^5	9.78×10^1	0.92	< 0.001	5.77×10^4	2.05	0.86	< 0.001
	Without bark	20	5.77×10^5	9.83×10^1	0.91	< 0.001	5.12×10^4	2.07	0.86	< 0.001

V. Conclusions and discussion

This chapter is divided into four sections, as followes:

V-1. Industrial plantation forests in the tropics of Southeast Asia

V-2. Rehabilitated forests in the tropics of Southeast Asia

V-3. Timber supply from artificial forest in the tropics of Southeast Asia

V-4. Sustainability of forest resources in the tropics

V-1. Industrial plantation forests in the tropics of Southeast Asia

V-1-1. Biomass evaluation in industrial plantation forests in South Sumatra and East Java, Indonesia

In Indonesia, biomasses were evaluated in plantation forests of 6-year-old *Acacia mangium* Willd. and 20-year-old *Swietenia macrophylla* King in South Sumatra, and 14-year-old *S. macrophylla* and 16-year-old *Pinus merkusii* Jungh. & de Vriese in East Java using highly accurate allometric equations (r^2 = 0.228 to 0.997) that we developed in each forest. The above and below ground biomasses of the trees were 162.4 Mg ha^{-1} in 6-year-old *A. mangium*, 342.5 Mg ha^{-1} in 20-year-old *S. macrophylla*, 257.7 Mg ha^{-1} in 16-year-old *P. merkusii*, and 139.1 Mg ha^{-1} in 14-year-old *S. macrophylla* stands. The mean annual increments (MAI) of total tree biomass were 27.1, 17.1, 18.4, and 8.7 Mg ha^{-1} yr^{-1}, while the ratios of below to above ground biomass were 15.3, 27.2, 13.5, and 38.2%, respectively. Biomass accumulation in the investigated forests indicated that industrial plantation forests in Indonesia have high potential if suitable tree species for the respective sites are planted and they are intensively managed.

V-1-2. Tree biomass and soil carbon in 17- and 22-year-old stands of teak (*Tectona grandis* L.f.) in northern Thailand

Trunk volume, tree biomasses, and soil carbon were evaluated in 17- and 22-year-old teak (*Tectona grandis* L.f.) stands in northern Thailand using highly accurate allometric equations (r^2 = 0.841 to 0.999) that we developed in each forest. The trunk volumes, total above and below ground biomasses and ratios of below to above ground biomass of the trees were 116.9 and 139.6 m^3 ha^{-1}, 89.3 and 98.8 Mg ha^{-1}, and 25.5% and 20.0% in the 17- and 22-year-old stands, respectively. The mean annual increment (MAI) of the trunk volume and the total biomass of the trees were 6.9 and

6.3 $m^3 ha^{-1} yr^{-1}$, and 5.3 and 4.5 Mg $ha^{-1} yr^{-1}$, respectively. The average carbon stock in the soil was 211.4 MgC ha^{-1} (ranging from 153.2 to 251.8 MgC ha^{-1}) in the 17-year-old stand and 137.2 MgC ha^{-1} (ranging from 122.7 to 157.9 MgC ha^{-1}) in the 22-year-old stand. These values are about three times higher than the carbon stock of the trees themselves (44.6 and 49.4 MgC ha^{-1}; assuming 50% carbon content of tree biomass), highlighting the importance of estimating the below ground carbon pool.

V-1-3. A general allometric equation for estimating the above ground biomass of *Acacia mangium* Willd. plantation forests

Based on a census of trunk diameter at 1.3 m above the ground in *Acacia mangium* Willd. plantation forests, we developed a general allometric equation for estimating the above ground biomass (AGB) of *A. mangium* plantations at harvest age.

To construct the general allometric equation, destructive sampling was carried out at plantations in Papua New Guinea (PNG), Vietnam, and Indonesia (two sites). At each site, four to twelve trees were felled and site-specific allometric equations were determined for each site. General allometric equations for estimating the biomass of each organ and above ground dry matter were developed from the overall total of 26 sample trees felled. AGB values for each of the plots were estimated using the site-specific equations and general allometric equation, and compared. There was no significant difference between the two sets of estimates (p <0.001: X^2 test for goodness of fit). The general allometric equation may enable the AGB of *A. mangium* plantations at harvest age throughout Southeast Asia to be estimated from trunk diameter data alone, without destructive sampling at the respective sites.

V-2. Rehabilitated forests in the tropics of Southeast Asia

V-2-1. Biomass recovery of naturally regenerated vegetation after the 1998 forest fire in East Kalimantan, Indonesia

In East Kalimantan, we established research plots in naturally regenerated vegetation that included pioneer tree species, and were dominated by pioneer species of *Homalanthus populneus* (Geiseler) Pax, *Macaranga gigantea* (Reichb. F. & Zoll.) Muell Arg and *M. hypoleuca* (Rchb.f. & Zoll.) Mull. Arg., *Mallotus paniculatus* Muell Arg, *Melastoma malabathricum* L., *Piper aduncum* L., and *Trema cannabina* Lour. and *T. orietalis* (L.) Blume. Annual tree censuses over four years (from 2000 to 2003) showed that on plots where the initially dominant tree species were *M. malabathricum*, *T. cannabina* and *T. orietalis*, they tended to disappear, and were replaced with *M. gigantea* and *M. hypoleuca*. In contrast, on plots where the initially dominant species were *M. gigantea* and *M. hypoleuca*, *M. paniculatus*, or *P. aduncum*, they continued to dominate five years after the fire. We classified tree species that were initially dominant but disappeared within five years after the fire as extremely short-lived tree species. The above ground biomass (AGB) averaged 12.3 Mg ha^{-1} (ranging from 9.2 to 17.0 Mg ha^{-1}) in 2000 and 15.9 Mg ha^{-1} (ranging from 7.4 to 25.0 Mg ha^{-1}) in 2003. Between 2000 and 2003, some plots exhibited an increase in AGB and some a decrease in AGB. In the plots dominated by *M. gigantea* and *M. hypoleuca*, the AGB increased to over 20 Mg ha^{-1}, but other plots accumulated significantly less AGB in the five years following the fire. These results suggest that the pattern of AGB accumulation in secondary forests is strongly dependent on the dominant pioneer tree species.

V-2-2. Biomass of an artificial forest of timber tree species in the humid tropics of West Java, Indonesia

In West Java, the trunk biomass of an artificial forest was estimated from trunk diameter, tree height and bulk density data. The largest trunk diameter (121.5 cm) was observed in a 46-year-old *Khaya grandifoliola* C. DC tree, and the tallest tree (50.6 m) was a 46-year-old *Shorea selanica* (DC.) Blume. The Largest trunk biomass (911.1 Mg ha^{-1}) was achieved in a plot composed of two *Khaya* spp.. Among the plots composed of indigeneous Dipterocarpaceae species, the largest trunk biomass was 635.0 Mg ha^{-1}. These trunk biomasses were larger than those reported from primary rainforests in Southeast Asia; 403.3 Mg ha^{-1} in East Kalimantan, and 522.2 and 367.5 Mg ha^{-1} in Peninsular Malaysia. The large biomass in this forest suggests that, given favorable conditions, artificial forests can accumulate the quantities of atmospheric carbon that have been lost through logging of the primary forests in the humid tropics.

V-3. Timber supply from artificial forest in the tropics of Southeast Asia

V-3-1. Trunk diameter and tree height growth of long-term artificial forests in the humid tropics of West Java, Indonesia

In the work underlying this thesis, the trunk diameter and tree height growth curves of popular 49 timber tree species were evaluated in East Java, Indonesia. The trunk diameter (*D*, cm) and tree height (*H*, m) of all trees were measured and growth curves of *D* and *H* were defined by the Gompertz growth functions ($Y = Ae^{-be^{-kt}}$, where *Y* is *D* or *H*, *A* is the carrying capacity and denotes the asymptotic maximum value, *b* is a coefficient depending on the initial *D* and *H*, *k* is the coefficient of growth and denotes the potential growth rate, and *t* is age after planting) in each tree species. The timber tree species were then classified on the basis of the relationship between their potential growth rate *k*, and asymptotic maximum carrying capacity *A*. Some of the Dipterocarpaceae tree species examined gave high values of *A* with low values of *k* for growth of both *D* and *H*. These growth performance data for specific timber tree species may facilitate the establishment of silvicultural systems with long-term rotations (30 to 50 years).

V-3-2. Trunk volume equations of main timber tree species in the humid tropics of West Java, Indonesia

We developed equations for estimating commercial trunk volume (m^3), i.e., merchantable trunk bole volume up to the lowest living branch, of twenty timber tree species in the humid tropics of West Java, Indonesia. The commercial trunk volume of 17 to 26 sample tree representing each tree species was calculated using Smalian's equation. Equations based on the relative trunk diameter at height 30% of the lowest living branch height (RD_{10RH}, cm) and the lowest living branch height (H_{LAB}, m) gave significant correlations ($p < 0.001$), and also equations based on the single parameter of trunk diameter at 1.3 m height above the ground (*D*, cm) gave significant correlations ($p < 0.001$) for each tree species. These equations gave similar estimates of commercial trunk volume. Therefore, commercial trunk volume of timber tree species can be estimated quickly using the readily measurable parameter *D* with high accuracy.

V-4. Sustainability of forest resources in the tropics

V-4-1. Evaluation of prospects for industrial plantations in the tropics

New industrial plantation forests are being established globally. About 48% of these plantation forests are intended to produce material for the wood processing industries, 26% of the others are for non-industrial uses (fuelwood, soil, water protection, etc.) and the rest are for unspecified purposes (Food and Agriculture Organization, FAO 2001). Apart from the rapid growth of industrial plantation forests, which is a notable feature of many tropical plantation forests, all industrial plantation forests that have been successfully established to date have several other management advantages which should promote high productivity per unit area.

In Japanese plantation forests of *Cryptomeria japonica* (L. f.) D. Don and *Chamaecyparis obtusa* Sieb et Zuee, the rate of biomass accumulation (Fukuda et al., 2003) is quite slow compared to corresponding rates for plantation forests in the tropics, and the rapid growth of industrial plantation forests in the tropics compared with plantation forests in temperate or boreal areas is a major reason for the interest in them. In plantation forests of fast-growing tree species in Southeast Asia, 150 to 200 Mg ha^{-1} can be accumulated in six to eight years, as described in Chapter II or published papers (Hiratsuka et al., 2005; Morikawa et al., 2001; Morikawa et al., 2002; Yamada et al., 2004); equivalent to about 50% of rates found in primary forests, which range from 350 to 500 Mg ha^{-1} (Kato et al., 1978; Yamakura et al., 1986). Thus, the data presented in this thesis and various cited studies show that relatively high biomass accumulation rates can be obtained from plantation forests on suitable sites with appropriate management strategies.

Forest fires and illegal logging are reportedly problems for establishing and managing such forests in remote areas with high human impact. Therefore, it is necessary to develop management strategies that are appropriate for each site by identifying features of successful cases. However, the potential effects of management systems with short rotations on industrial plantation forests have to be considered, for instance nutrient removal through intensive and repeated harvesting may cause long-term reductions in productivity (Yamada et al., 2004).

Social and environmental objectives remain crucial issues to consider when developing forestry strategies for most tropical countries in Southeast Asia. However, information on social and environmental effects (non-industrial uses) of plantation forests cannot be gathered simply by accumulating biomass data. Such information is an essential element of project design documents (PDDs) for projects of afforestation or reforestation Clean Development Mechanism (AR-CDM) under the Kyoto Protocol (United Nations Framework Convention on Climate Change, UNFCCC 1997). Therefore, we need to acquire relevant information on environmental and social benefits of AR-CDM projects to Annex I and III countries of UNFCCC.

V-4-2. Evaluation of prospects for rehabilitated forests in the tropics

Recent deforestation and/or forest degradation in Southeast Asia has been spurred by commercial logging, large-scale agricultural exploitation, illegal logging, and forest fire. Deforestation and/or forest degradation have resulted in losses of forest productivity in terms of both products (wood and non-wood) and environmental services (Evans and Turnbull, 2004).

Recently, there has been increasing recognition of the potential importance of secondary effects of rehabilitated forests in terms of both the wood and non-wood forest products they can provide, and many researchers and governments have concluded that meaningful assessments of rehabilitation efforts must consider their effects on the income of local people. In Chapter III, it was shown that rehabilitated forests can have high potential, because biomasses of ca. 40-year-old rehabilitated forests reached over 500 Mg ha^{-1}, comparable to those of primary forests in the humid tropics. Furthermore, forests can have considerable social, cultural, environmental, and economic value. A key environmental issue related to rehabilitated forests is, therefore, maintenance of the long-term production potential and environmental values of the sites they occupy.

Several benefits of establishing forests on degraded sites were considered in the studies underlying this thesis, timber supply being one of the most important. The studies described in chapters III and VI demonstrated the high potential timber production of established forests with indigenous tree species. If established forests can supply timber or other forest products instead of primary forests, they can reduce the heavy pressures on primary forests. In addition, other indirect benefits should also be considered. Notably, establishing forests in degraded lands might bring environmental services not only to local people but also to the global population. Therefore, we need to apply suitable long-term and intensive measures to rehabilitated forests throughout multiple rotations.

The data sets presented in this thesis should facilitate the establishment and management of productive forests in the tropics. A final conclusion is that there is an urgent need for human intervention to rehabilitate forests that have been degraded by human activities in such a way as to maximize the sustainability of their resources.

V-2-2. References

Evans J., and Turnbull J., 2004. Plantation forestry in the tropics. Third Edition. Oxford University Press, pp 467.

FAO, 2001. State of the world’s forests 2001. Available at FAO’s web site, http://www.fao.org/forestry/index.jsp. Cited in October 25, 2005.

Fukuda M., Iehara T., and Matsumoto M., 2003. Carbon stock estimates for sugi and hinoki forests in Japan. Forest Ecology and Management, 184: 1-16.

Hiratsuka M., Morikawa Y., Nagatsuka Y., and Osumi Y., 2005. Biomass accumulation on rehabilitating forest in South Sumatra, Indonesia. The Tropical Forestry, 62: 58-64 (in Japanese).

Kato R., Tadaki Y., and Ogawa H., 1978. Plant biomass and growth increment studies in Pasoh forest. Malayan Nature Journal, 30: 211-224.

Morikawa Y., Inoue H., Yamada M., Hadriyanto D., Diana R., Marjenah, Fatawi M., JIFPRO, and JOPP, 2001. Carbon accumulation of man-made forests in Monsoon Asia in relation to CDM. In: Ishii K., Masumori M., and Suzuki K., (eds.), Proceedings of International Workshop on BIO-REFOR. Tokyo, Japan, pp 43-51.

Morikawa Y., Ohta S., Hiratsuka M., and Toma T., 2002. Carbon sequestration of man-made forests: sequestration estimate and its bearings on CDM. In: Lin K-C., Lin J-C., and Taiwan Forestry Research Institute, (eds.), Proceedings of International Symposium on forest carbon sequestration and monitoring, Taipei, Taiwan. Taiwan Forestry Research Institute, pp 171-180.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. available at UNFCCC’s web site, http://unfccc.int. Cited in October 25, 2005.

Yamada M., Toma T., Hiratsuka M., and Morikawa Y., 2004. Biomass and potential nutrient removal by harvesting in short-rotation plantations. In: Nambiar E. K. S., Ranger J., Tiarks A., and Toma T., (eds.), Proceedings of International Workshop in Congo July 2001 and China February 2003 on site management and productivity in tropical plantation forests. Center for International Forestry Research, Bogor, Indonesia, pp 213-226.

Yamakura T., Hagihara A., Sukardjo S., and Ogawa H., 1986a. Aboveground biomass of tropical rain forest stands in Indonesian Borneo. Vegetatio, 68: 71-82.