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博士論文要旨

Evaluation of Industrial Plantation Forests and Rehabilitated Forests for Restoring Degraded Lands in the Tropics of Southeast Asia

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Introduction

This thesis focused on forest productivity in industrial plantation forests and rehabilitated forests to obtain biomass accumulation and growth characteristics of timber tree species in the tropics of Southeast Asia. The results might be practical information for sustainable forest management and use of forest resources

Biomass of industrial plantation forests

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 (γ^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.

In northern Thailand, trunk volume, tree biomasses, and soil carbon were evaluated in 17- and 22-year-old teak (*Tectona grandis* L.f.) stands using highly accurate allometric equations (γ^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.

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) (Figure 1). 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.

Biomass of rehabilitated forests

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.

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.

Long-term management of productive forests in the humid tropics

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).

In addition, 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.

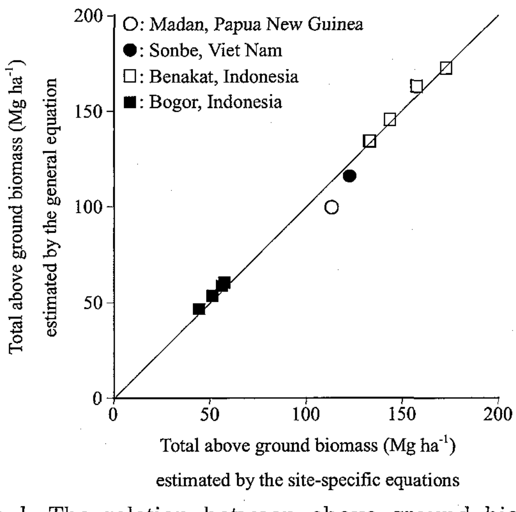

Figure 1. The relation between above ground biomass estimated by the site-specific and general equations at the four *A. mangium* plantation forests. The line shows $Y=X.$