Environmental Conservation and Land Use Management of Wetland Ecosystem in Southeast Asia

Annual Report
for
April 2001 - March 2002

Core University Program
between
Hokkaido University, Japan and Research Center for Biology, LIPI, Indonesia
Sponsored by
Japan Society for the Promotion of Science

March 2002

Content

1. Outline of the project

Objective

Researches with collaboration by Japanese and Indonesian scientists into the environmental conservation, management and regional utilization of wetland ecosystems including peat land in Southeast Asia from the view point of environmental earth science.

Organization

List of cooperative universities

	Japan	*Indonesia*
Core university	Graduate School of Environmental Earth Science, Hokkaido University	Research Center for Biology, Indonesian Institute of Science
Coordinator	Dean, Prof. Norio Nishi	Head, Dr. Arie Budiman
Cooperative Universities	Kyoto University Kagosima University Tottori University Kanazawa University University of Shiga Prefecture Kwansei University Tokyo University of Agriculture and Technology Hokkaido University of Education Hokkaido Institute of Technology Hokusei Gakuen University	Research Center for Geotechnology, Indonesian Institute of Science Research Center for Limnology, Indonesian Institute of Science Bogor Agricultural University Institute of Technology Bandung University of Palangka Raya

Number of cooperative scientists

(Name of all members are listed on the end of this report)

	Japan	*Indonesia*
Staffs	88	85
Graduate students	15	0

2. Activity in 2001th fiscal year

2-1. Scientist exchange program

Invited/sent scientist	*Host scientist*	*Period*
Napa Johanes Awat	Norio Nishi	1-10 October, 2001
Arie Budiman	Norio Nishi	11-21 March, 2002
Herwint Simbolon	Norio Nishi	11-21 March, 2002
Norio Nishi	Arie Budiman	16-22 February, 2002
Hidenori Takahashi	Arie Budiman	16-22 February, 2002

2-2. Cooperative study

Group 1. Ecosystem function and genetic diversity in wetland forest of Kalimantan

	Japan	*Indonesia*
Leader	Seigo Higashi	Herwint Simbolon
Number of scientists	18	19
Sent or invited scientists	9	1

Group 2. Rehabilitation of peatlands and establishment of sustainable agro-system in Central Kalimantan

	Japan	*Indonesia*
Leader	Mitsuru Osaki	Hanny Wijaya
Number of scientists	26	30
Sent or invited scientists	14	2

Group 3. Hydrology and peatland technology in Central Kalimantan

	Japan	*Indonesia*
Leader	Harukuni Tachibana	Mr. Nyoman Sumawijaya
Number of scientists	16	10
Sent or invited scientists	9	2

Group 4. Function of Aquatic Ecosystem in Kalimantan

	Japan	*Indonesia*
Leader	Toshio Iwakuma	Dr. Hery Harjono
Number of scientists	16	24
Sent or invited scientists	6	2

3. Collaborative study

(1)

Ecosystem function and genetic diversity in wetland forests of Kalimantan

Group leaders

Seigo Higashi Herwint Simbolon

Members

Takasi Kohyama
Masahito Kimura
Hitoshi Suzuki
Masashi Ohara
Ryuichi Masuda
Kunihide Takahashi
Masatugu Suzuki
Kazuo Yabe
Toshiki Aoi
Eiji Suzuki
Kunio Watanabe
Shigeo Kobayashi
Kazuki Miyamoto
Hajime Hirosawa
Joeni Setijo Rahajoe
Noriko Azuma
Takahide Ishida
Hari Sutrisno

Elizabeth A. Widjaja
Rugayah
Edi Mirmanto
Soedarsono Riswan
Tukirin Partomihardjo
Beth Paul Naiola
Siti Nuramaliati Prijono
Agustinus Suyanto
Ibnu Maryanto
Sri Sulandari
Maharadatunkamsi
Syamsul Arifin Zein
Dedy Darnaedi
Patricia Erosa Putir
Cakrabirawa
Dessy Natalia
Ronny Ratchman Noor
Toto Tohamat

Annual report

In 2001, Japanese members continued the survey of structure and biodiversity in wetland forests of central Kalimantan and its vicinity under the collaboration with Indonesian members of this project. The researchers of LIPI further made an effort for constructing DNA Bank in Zoological Division, Research Center for Biology- LIPI, and we introduce their research in this report.

Indonesia is rich in biodiversity, e.g. with 1539 species of birds (17% of all birds in the world, Andrew, 1992) and 681 species of mammals (12% of all mammals in the world, Suyanto *et al.*, 1998), and these biological resources become an international concern since they may include some unknown important genetic materials but many of them are threatened to extinction (2000 IUCN Red List of Threatened Species). Major efforts to preserve biological diversity in Indonesia are underway through *in-situ* conservation, collection of living organisms as maintained in zoological parks and the amassing and documentation of museum specimen. However, relatively little effort has been made to collect and document DNA materials as genetic resources.

The establishment of DNA bank for Indonesian wildlife has been started in Zoological Division, Research Center for Biology- LIPI since 1999 as one of the research topics in the Core University Program of JSPS. In 1999 and 2000, 4.9% of the total mammals and 5.8% of the total birds in Indonesia were collected in the form of DNA at the genetic laboratory. Further efforts were made in 2001, especially focusing on the endangered- and/or endemic-species.

Samples were collected from Bird Park (TMII, Jakarta), Hartono's Bird Trader (Jakarta), Hardi's Bird Trader (Jakarta), Monkey Trader (Jakarta), Tarsier Trader (Sawangan, Depok), and deer captive breeder (Jonggol, West Java), as well as from natural habitats Cibodas Botanical Garden (Cibodas, West Java) and Pangandaran Nature Reserve (Pangandaran, West Java), in the form of blood, tissue, liver, shed feathers, hair-root, saliva or dry skin specimen. Each sample was preserved with 96% ethanol in a 1.5 cc eppendorf tube and kept in freezer.

Extraction and concentration of DNA were made in genetic laboratory of zoological division, Research Center for Biology - LIPI, Cibinong - Indonesia. Total genomic DNA was extracted from blood, tissue, liver or saliva using a standard protocol (Sambrook *et al.*, 1989) and from shed feathers and hair roots using ISO Hair Kit (Nippon Gene, Made in Japan). DNA concentration was measured using a spectrophotometer (Beckman DU 650, Made in USA).

A total of 125 DNA samples of 36 bird species was deposited in the DNA Bank, including 11 endemic species (*Stachyris melanothorax*, *Aethopyga eximia*, *Pycnonotus bimaculatus*, *Cinclidium diana*, *Enicurus velatus*, *Otus brooki*, *Eos borneo*, *Lorius garrulus*, *Eos squamata*, *Cacatua sulphure*, *Chalcopsitta ater*) and 3 protected species (*Arachnothera longirostra*, *Stachyris melanothorax*, *Aethopyga eximia*). At this moment, our collection increased up to 109 species corresponding to 7.08% of Indonesian bird fauna. Out of the 125 DNA samples, 50 samples of 18 species were collected from Cibodas Botanical Garden and 75 DNA samples of 18 species were from Hartono's bird trader. Furthermore, 16 of the 18 species obtained from Hartono's bird trader were parrots, reflecting that the parrot birds constitute the largest number of bird species exported abroad from Indonesia which is the second after Argentina (WCMC, 1992) among the countries exporting a large number of parrots, with 12% of the world's parrots being available in Indonesia. Indonesian government protects the parrots by classifying most of them into CITES Appendix 2(exporting the birds of this class must be based on annual quota).

Also, tissues for extracting DNA were collected from 183 individuals of 30 mammal species, including one protected species (*Lariscus insignis*) and one species listed in CITES Appendix 3 (*Herpestes javanicus*), and our collection increased up to 42 species corresponding to 6.02% of total Indonesian mammal fauna. Main mammals collected in this term were 3 rat species (*Maxomys bartelsii*, *Rattus tiomanicus*, *Leopoldamys sabanus*), 4 bat species (*Aethalops alecto*, *Chironax melanocephalus*, *Cynopterus brachyotis*, *Macroglossus minimus*), 1 species of Sciuridae family (*Lariscus insignis*) and 1 species from carnivora group (*Herpestes javanicus*).

In conclusion, the activities under this project enhanced the DNA collection from various animals available in Indonesia and accelerated the establishment of Indonesian DNA Database. This project has made significant contribution to the development of molecular genetic research in Indonesia.

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Dynamic steady state of patch-mosaic tree size structure of a mixed dipterocarp forest regulated by local crowding

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A patch age- and tree size-structured simulator was applied to demonstrate the landscape dynamics of a lowland mixed dipterocarp forest, using census data over a 3 year interval from two 1 ha plots in northern West Kalimantan, Indonesia (Western Borneo). Tree growth rate and recruitment rate were estimated as functions of tree size and local crowding. The effect of local crowding was assumed to be one-sided through light competition, where the basal area for all trees larger than a target tree inside the circle of 10 m radius around the target was employed as the index of crowding. Estimated parameters were similar between the two plots. Tree mortality was expressed by descending function of tree size with asymptotic mortality for large trees corresponding to the gap formation rate. One parameter specifying the survival of trees at gap formation, which was required for the landscape-level simulation of a shifting-gap mosaic, was left undetermined from plot census data. Through simulation, this parameter was estimated so as to best fit the observed among-patch variation in terms of local basal area. The overall time course of simulation and tree size structure were not sensitive to this parameter, suggesting that one-sided competition along the vertical forest profile is a stronger determinant of average forest structure than among-patch horizontal heterogeneity in this forest. Simulated dynamic steady state successfully reproduced the observed forest architecture in the gap-dynamic landscape. It took about 400 years for a vacant landscape to be replaced by a steady-state architecture of forest. Sensitivity analysis suggests that steady-state basal area and biomass are most sensitive to changing gap formation rate and intrinsic size growth rate.

Key words: advanced regeneration; gap mosaic; landscape; model; patch age; tropical rainforest.

INTRODUCTION

Since Botkin *et al.* (1972) constructed a simulator JABOWA to predict the patch-scale development of a mixed forest in North America, many individual tree-based simulators of forest structural development have been presented (Shugart 1984; Botkin 1993). Simulators gather available information to synthesize functional (quasi-physiological) response of individual trees to environmental factors. They are now beyond mere site-specific description and projection, enabling the prediction of forest ecosystem response to climate change (Bugmann *et al.* 1996; Bugmann 2001). Although most models keep the spatial scale of interest at a crown size of 100–400 m^2, some models deal with landscape-level, patch-mosaic forest dynamics (Smith & Urban 1988; Pacala *et al.* 1996; Liu & Ashton 1998).

There is another contrasting idea of simulating the dynamics of forest architecture. A simplified frequency–distribution base, partial differentiation model of Kohyama (1993) combines the patch-scale vertical forest profile (via tree size distribution) and horizontal distribution of

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Received 15 March 2000.

Accepted 6 September 2000.

patches (via patch age distribution). Kohyama (1993) successfully applied this model to reproduce the dynamics of a warm–temperate rainforest in southern Japan. He also shows that stationary coexistence among species is possible via architecture-mediated light resource heterogeneity in space. Hurtt *et al.* (1998) report that simulated dynamics of a mixed forest in North America with this type of partial differentiation model agrees with that of the individual tree-based simulator SORTIE (Pacala *et al.* 1996). The present study aims to reconstruct the landscape-level architecture of a tropical rainforest by applying the model of Kohyama (1993).

Many inventory data from repeated censuses in permanent forest plots are available for reconstructing the dynamics of natural forests, so that simulations based upon these data enable us to characterize the dynamic capacity of each forest plot. These data are basically obtained with the same census protocol; namely, the measurement of trunk girth using a measuring tape at a fixed height, recording the location, species identity, mortality and recruitment at the census-defined minimum size in trunk girth or diameter. Therefore, the same procedures of data examination can be applied across sets of data to extract parameters of demographic processes determining size–structure dynamics. It is worthwhile to examine whether these parameters aptly reconstruct the observed forest structure specific to research plots.

Tropical rainforests consist of many tree species, and species-explicit approaches of simulation require the estimation of species-specific demographic parameters (Vanclay 1994, 1995; Alder 1995; Liu & Ashton 1995). Such estimation is not always possible, because data from limited plot areas do not cover a sufficient number of individual trees of each species for the estimation. Grouping of species into functional types has been applied in some simulations (Vanclay 1991; Köhler & Huth 1998). A simple alternative is to ignore species difference in demographic behavior of tree populations, and to deal with the whole tree populations irrespective of species. This kind of approach can successfully reproduce the overall population dynamics (Kohyama 1991), and enables the comparison of forest dynamics among permanent plots with limited area. Through among-plot comparison, species-averaged parameters that quantitatively characterize forest structure and dynamics can be related to environmental parameters.

The present paper examines the dynamics of forest landscape at species-averaged level, based exclusively upon census data over a 3 year period in two 1 ha plots set in a primary mixed dipterocarp forest in Western Borneo. The principle assumption in the present study is that local crowding of trees irrespective of species regulates the demographic rates. Considering competition for light, foliage density above a target tree is likely to suppress its growth and affect the probability of survival. We examined whether empirical demographic functions that were derived from short-term re-census data sufficiently explained the dynamics and the present state of forest architecture. A simplified version of this model, which ignores patch age distribution, or a patch-mosaic averaged model, was first applied to Sumatran tropical rainforest data as well as Japanese warm–temperate rainforest data (Kohyama 1991, 1992). It was then successfully applied to a wide variety of forests (Nakashizuka & Kohyama 1995; Takahashi & Kohyama 1999). We also examined the contribution of a shifting patch mosaic to the overall tree size structure by comparing simulation with a patch-mosaic model and with a patch-mosaic ignored model. The model parameters for the two nearby plots were determined independently so that the reliability of results could be shown by a comparison of these duplicate data/parameter sets.

METHODS

Study site

Two permanent plots were established at 0°45′N 110°06′E in a lowland mixed dipterocarp forest on Gunung Berui, Desa Serimbu, Kachamatan Air Besar, Kabupaten Pontianak, West Kalimantan, Indonesia. Continuously humid conditions characterized the local climate; annual precipitation at Serimbu town, which was 2 km east from the forest, was 4300 mm with >250 mm every month (Yamada & Suzuki 1996). Two plots, S-1 and S-2, were located in early middle November 1992 on gentle ridge plateaus about 500 m distant from each other. Each was exactly 100 m × 100 m in horizontal area. All trees ≥15 cm in girth (thus 4.8 cm in diameter) at breast height or just above the buttress were marked by aluminum tags (5 cm above the height of measurement) and the horizontal location recorded to the nearest 10 cm at the two coordinates. Trunk girth was measured to the nearest millimeter by a steel measure of 1 cm width with official approval. Re-census of trunk girth was made in early November 1995.

The first census recorded 1280 trees, 270 species and 42.2 $\mathrm{cm^2 m^{-2}}$ basal area in S-1, and 1356 trees, 314 species and 44.6 $\mathrm{cm^2 m^{-2}}$ basal area for trees ≥ 5 cm trunk diameter at breast height (hereafter to be designated d.b.h.). The total number of species recorded in the two plots above 5 cm d.b.h. was 410 in 1992. These plots were similar in tree species composition; the percentage similarity of species composition was 50.4% in terms of tree number and 42.9% in terms of basal area. The dominant emergent-tree species in the two plots was *Dryobalanops beccarii* Dyer, sharing 13% and 25% of total basal area in S-1 and S-2, respectively.

Demographic equations

We need to derive empirical equations of tree size growth, recruitment and mortality for reconstructing forest structure dynamics. Growth and mortality are functions of tree size, and all three rates can also be functions of local crowding. The basic idea of the size–structure-based simulators (Kohyama 1989, 1991, 1992, 1993) is to introduce basal area of forest stands at different stages of development to infer the degree of crowding. Further, taking into account the importance of competition for light resources, one-sided competition is assumed *a priori*, and the local basal area of trees larger than the target tree is employed as the index of crowding. The upper basal area, or the basal area for larger trees, has also been applied to evaluate the intensity of shading on tree growth rate for various types of forests (Wykoff 1990; Vanclay 1991, 1994, 1995).

Kohyama (1989, 1991, 1992, 1993) describes crowding dependence by comparing these two landscape categories in stands with different tree size structure; namely, gaps (or secondary stands) and non-gaps (or closed primary stands). A more objective procedure is applied in other trials, where fixed square subplots of 10 m × 10 m or 20 m × 20 m (Nakashizuka & Kohyama 1995; Kubo & Ida 1998; Takahashi & Kohyama 1999) are employed.

The dependence of tree demography on local crowding can, however, be properly demonstrated more by a target tree-centered circle with a particular radius as the area of interference, than by such *a priori* land area division as stated earlier (J. Liu *et al.* unpubl. data, 1996). Calculation of individual-based local basal area is possible if the position of plot trees is precisely recorded, as in the present data set. This local upper basal area above d.b.h. x (cm), denoted $B(x)$ ($\mathrm{cm^2 m^{-2}}$) in the present paper, was thus defined for the circle with a certain radius around the target tree. By preliminary trial of changing radius, we chose the radius of 10 m, around which the determination coefficient as well as the estimated parameter of susceptibility to local crowding of growth rate in equation 1 were largest. The area of 10 m radius corresponded to the crown area of emergent trees: crowns of trees larger than 100 cm in d.b.h. had 10.7 ± 3.7 m radius (mean ± SD of 13 trees; crown radius was calculated as half of the geometric average of two perpendicular crown diameters). To avoid the margin effect in the plots, we only used trees that were located where the distance from the nearest plot margin was more than 10 m. We compared tree-centered upper basal area with subquadrat-based upper basal area at the similar spatial scale of 20 m × 20 m.

The same growth function as Kohyama (1991, 1992, 1993) was used here,

$$\begin{aligned} G &= bx[1 - b_1 \ln x - b_2 B(x)] \\ &= bx[1 - \ln(x/x^*) - b_2 B(x)] \qquad (1) \end{aligned}$$

where $G = \mathrm{d}x/\mathrm{d}t$ (cm $\mathrm{year^{-1}}$) is growth rate of tree at d.b.h. x (cm) and local crowding $B(x)$. The asymptotic d.b.h. where average growth rate becomes zero is denoted to be $x^* = \exp(1/b_1)$ (cm). Trees were classified in terms of x ($2^n - 2^{n+1}$ octave class; n as integer) and $B(x)$ (class at intervals of 10 $\mathrm{cm^2 m^{-2}}$). We used equation 1 to demonstrate average relative growth rates of these classes. Parameters were estimated by multiple linear regression between x, $B(x)$ and the relative growth rate during the 3 year period as $G/x = (dx/dt)/x = [\ln (x \text{ in } 1995) - \ln (x \text{ in } 1992)]/3$. Growth rate was largely variable among trees with similar d.b.h. and at similar local crowding. Therefore, the analysis of class-divided data enabled us to calculate average trends as well as the extent of within-class variation.

Observed recruitment events across the 6 cm d.b.h. as lower boundary size x_0 during 1992–1995 were 62 in S-1 and 53 in S-2 per ha, and thus were too small to detect the local density dependence of recruitment rate. Therefore, we employed the technique of Gf estimation (Kohyama & Takada 1998). The Gf estimate of recruitment rate is the density of trees at the lowest size class multiplied by the average growth rate of this class. The Gf estimate was calculated for 1681 points set on 2 m × 2 m grid in each plot, leaving a 10 m margin from the plot edge. For the circle with a 10 m radius from each point, we calculated the Gf recruitment rate at 6 cm d.b.h. using the density of trees at 5–7 cm d.b.h. in 1992 and the average annual growth rate of this size class during 1992 and 1995 for the fraction that survived, and subdivided by the class width of 2 cm. The total basal area above 6 cm d.b.h., $B(x_0)$, was used to project the local density dependence of Gf estimates of recruitment, R ($\mathrm{m^{-2}\ year^{-1}}$). A linear model:

$$R = d[1 - d_1 B(x_0)] \tag{2}$$

was used here, because the previous exponential model in Kohyama (1991, 1992, 1993), $R = d' \exp[-d'_1\, B(x_0)]$, was slightly less fitted. As in the growth equation estimation, we classified 1681 points into $B(x_0)$ classes at intervals of $10\ \mathrm{cm^2\ m^{-2}}$.

The probability of instantaneous mortality of trees is likely to be an increasing function of local crowding $B(x)$ (cf. Kohyama 1993). However, we could not detect this local crowding dependence of mortality from census data. The mortality was then described simply as the function of tree size. We estimated tree mortality $D = D(x)$ ($\mathrm{year^{-1}}$) at size classes of 5–6, 6–8, 8–12 cm, and with a further increasing class width of 2^n cm, as the subtraction of logarithmic density at the second census from that at the first census divided by the period of 3 years. We employed a simple size-dependent function to fit the observed data:

$$D = c + c_1/x. \tag{3}$$

The parameter c ($\mathrm{year^{-1}}$) is the asymptotic mortality for large x, thus it is used here to give the gap formation rate. The other parameter c_1 ($\mathrm{cm\ year^{-1}}$) describes the degree of additional mortality for smaller-sized trees.

For the modeling of gap-mosaic dynamics, we need to separate total mortality into gap formation-dependent mortality (death of gap makers and that of non-gap makers involved in gap formation) and gap formation-independent mortality (mainly by thinning of understory trees) (Kohyama 1993). However, we did not have sufficient census data to distinguish between these two types of tree death. In new gap formation, smaller trees are less likely to die thus total mortality is an increasing function of tree size with asymptotic mortality of large-sized gap makers, c. Therefore, we introduce another function that expresses the size-specific increasing ratio of gap formation-dependent mortality $\delta(x)$ ($\mathrm{year^{-1}}$):

$$\delta(x) = kcx/(c + kx), \tag{4}$$

where the parameter k ($\mathrm{cm^{-1}\ year^{-1}}$) describes the size-dependent probability of tree mortality at gap formation. As c defines the gap formation rate at patch scale, equation 4 assumes that the probability of survival through the gap formation event as advanced regeneration is $1 - \delta(x)/c$. The residual of the total mortality, $D(x) - \delta(x)$ ($\mathrm{year^{-1}}$), corresponds to non-gap mortality by thinning so that the total mortality M is kept constant irrespective of the parameter k.

Equation 4 has a convenient characteristic; that is, that changing k covers all possible cases of the gap formation dependence in mortality. When $k = 0$, $\delta(x)$ is also zero and no mortality is linked to gap formation, which resets patch age at zero. All patches are thus equivalent irrespective of operational 'patch age' notation in simulation. When k is infinite (or practically $k > 1000$), $\delta(x) = c$ and all trees in a local patch of interaction are killed by a gap formation event. Actual rainforests have conditions between these two extremes. We carried out simulation with a changing value for k, and evaluated k-value by comparing observed and simulated distributions of the local basal area.

Above-ground biomass can be estimated from d.b.h. by allometric relationships between d.b.h., tree height, and partial mass. We demonstrate biomass dynamics by using allometric relationships between d.b.h. x and partial mass. The following reciprocal equation represents the asymptotic relationship between x (cm) and tree height h (m):

$$1/h = 1/(Ax) + 1/H^* \qquad (5)$$

where two parameters A and H^* (i.e. asymptotic height for infinite x) are estimated as 1.51 m cm^{-1} and 80.8 m for S-1, and 1.79 m cm^{-1} and 72.0 m for S-2, respectively, by minimizing the residual of sum of squares in terms of logarithmic h (Kohyama *et al.* 1999). We used leaf/branch/trunk mass allometry from x^2h, reported previously by Yamakura *et al.* (1986) for a mixed dipterocarp forest in Seburu, East Kalimantan. It is known that the diameter–height relationship is forest stand-specific and that allometric relationship between x^2h and mass is common across similar forest types. Note that the present dynamic simulation exclusively uses census data of d.b.h., thus the simulated dynamics of tree density and d.b.h. distribution is not influenced by parameters of these mass allometric relationships between d.b.h. and biomass.

The simulation model

The simulator employed here (Kohyama 1993) consists of two submodels describing the dynamics of patch age distribution and that of tree size distributions at patches of each age. Figure 1 illustrates the model structure. The first submodel of patch age structure is described by the Von-Forester equation 6 and the boundary condition equation of new patch formation (7) (Vance *et al.* 1988):

$$\partial s(t, a)/\partial t = -\partial s(t, a)/\partial a - \gamma(a)s(t, a), \qquad (6)$$

$$s(t, 0) = \int_0^\infty \gamma(a)s(t, a)\mathrm{d}a, \qquad (7)$$

where $s(t, a)$ (year^{-1}) is the frequency of patches of age a (year) since gap formation at time t (year), $\gamma(a)$ (year^{-1}) is the patch age-specific probability of gap formation, or transition from a patch of age a to that of age 0. The present simulation assumes a constant rate of gap formation independent of patch age as in equation 3; that is, $\gamma(a) = c$. The age of a patch does not represent the age of trees inside; advance regeneration, or survived portion of trees beyond gap formation exists (except in the case of infinite k) at patches of age zero, and continuous regeneration from sapling pool occurs at patches of any age (Fig. 1).

The second submodel of tree size structure in Kohyama (1993) consists of the two-dimensional continuity equation 8 (Sinko & Streifer 1967), which is the boundary condition equation with respect to the initial tree size structure as advance regeneration of new-born gap patches (9), and that with respect to the recruitment to the minimum tree size at variously aged patches (10):

$$\begin{aligned}\partial f(t, a, x)/\partial t = &-\partial f(t, a, x)/\partial a \\ &-\partial[G(t, a, x)f(t, a, x)]/\partial x \\ &-[\gamma(a) + \mu(t, a, x)]f(t, a, x), \qquad (8)\end{aligned}$$

$$f(t, 0, x) = n(x)\int_0^\infty \gamma(a)f(t, a, x)\mathrm{d}a, \qquad (9)$$

$$G(t, a, x_0)f(t, a, x_0) = R(t, a, x_0)s(t, a), \qquad (10)$$

where $f(t, a, x)$ (cm^{-1}m^{-2}year^{-1}) is the distribution density of trees of d.b.h. x (cm) at patch of age a (year) at time t (year); $G(t, a, x)$ (cm year^{-1}) is mean size growth rate of a tree of size x in a patch of age a at time t; $\gamma(a)$ (year^{-1}) is the probability of patch mortality or gap formation; $\mu(t, a, x)$ (year^{-1}) is mortality of trees of size x in a patch of age a at time t by thinning independent of gap formation; $n(x)$ is the size-specific probability of survival of trees during new gap formation; and $R(t, a, x_0)$ (m^{-2} year^{-1}) gives the local recruitment rate of trees to the minimum size x_0 in a unit area of a patch of age a at time t. In the present simulation, we define that $G(t, a, x) = G$ of equation 1, $R(t, a, x_0) = R$ of equation 2. The local crowding index $B(x)$ of equation 1, and $B(x_0)$ of equation 2 as well, is defined in the present model specific to patch age a as

$$\left.\begin{aligned} B(x) &= \frac{\pi}{4s(t, a)}\int_x^\infty x'^2 f(t, a, x')\mathrm{d}x', & s(t, a) > 0, \\ B(x) &= 0, & s(t, a) = 0. \end{aligned}\right\} \qquad (11)$$

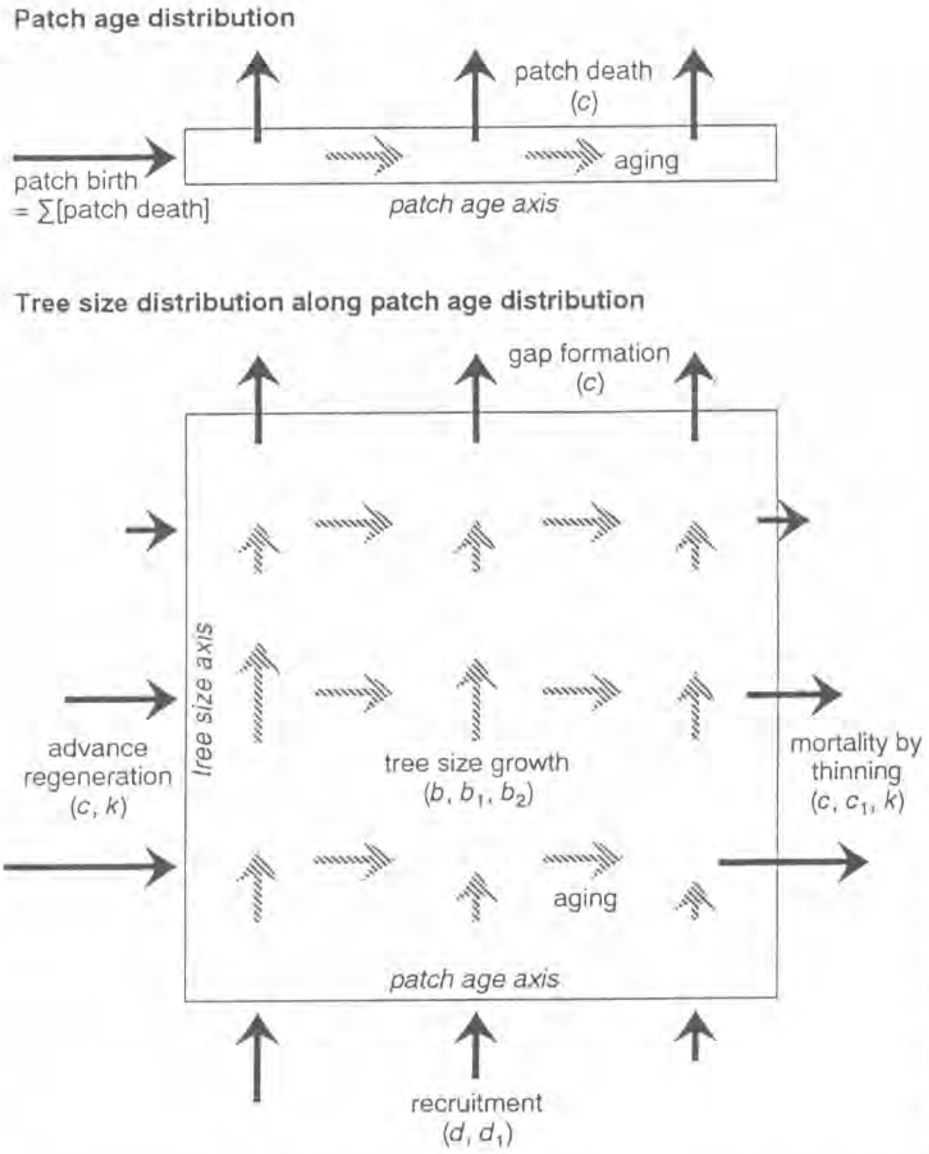

Fig. 1. Diagram showing the framework of the simulation model of gap-dynamic, size-structured model of forest dynamics. The dynamics of patch age distribution is described by equations 6–7, and that of tree size distribution by equations 8–10. Corresponding parameters of the processes, shown in parentheses, are from equations (1)–(4).

From equations 3 and 4, we derive that $\gamma(a)=c$, $\mu(t, a, x)=D(x)-\delta(x)=c_1/x+c^2/(c+kx)$, and $\pi(x)=1-\delta(x)/c=c/(c+kx)$.

As mentioned earlier, the present model with the condition of $k=0$ of equation 4 is collapsed into the patch mosaic-ignored model of Kohyama (1991, 1992) and Pacala and Deutschman (1995), so that we can evaluate the effect of patch mosaic by changing the parameter k.

The first submodel of patch demography is easily solved under the present assumption of age-independent gap formation rate, $\gamma(a)=c$, where the stationary patch age distribution $s(a)$ (year^{-1}) converges to an exponential distribution: $s(a)=c\ \exp(-ca)$. However, the other submodel of tree size structure dynamics across patch age is non-linear due to the effect of local crowding that is a function of instantaneous tree size structure of a patch, as in equation 11. Therefore, we needed to simulate the system only numerically with finite difference approximation. Sufficient resolution of simulation to compare with field data was 20 years for interval for patch age a, and 4 cm for tree size x. The time interval should be set small enough not to allow skipping classes (Takada & Hara 1994). In the present case, 5 years was a sufficient time interval of simulation, and a finer time interval hardly affected the time course as well as steady-state forest structure.

Table 1 Estimated parameters of tree growth equation 1

Plot	S-1 Tree centered	 Subplot	S-2 Tree centered	 Subplot
No. classes	40	95	38	106
b (cm year^{-1})	0.0217	0.0247	0.0221	0.0258
b_1 ([ln cm]$^{-1}$)	0.183	0.200	0.181	0.185
b_2 (m^2 cm^{-2})	0.00259	0.00081	0.00342	0.00403
r^2	0.57	0.37	0.44	0.27
P	<0.001	<0.001	<0.001	<0.01

The simulator, written by C++, which is also applicable to explicit multiple-species systems, is capable of being compiled in various computing platforms. Unlike simulators for individual-based stochastic processes that require iterative runs, the simulation of the present model returns a unique steady-state solution and the time course is dependent only on the initial condition at time zero. One simulation run for 2000 year dynamics typically took a couple of seconds on a personal computer. The sample code is available on request.

RESULTS

Demographic parameters

Equation 1 explained approximately 50% of the average tree growth rate in class divided data (Table 1). The within-class variance of tree growth rate was proportional to the average growth rate in the two plots (Fig. 2), which is commonly observed in rainforest data (Kohyama 1989). We also carried out the regression using the local crowding index calculated for 20 m × 20 m subplots. For each subplot, trees were classified into octave size classes. The coefficients of determination with subplot-based data was smaller than those with individually centered data (Table 1). Estimated parameters of b and b_1 were similar between the two plots and between the individual tree-centered regression and subplot-based regression. However for the parameter b_2, there was a large discrepancy between the two plots in subplot-based regression (Table 1). We thus concluded that the individual tree-centered index of local crowding was better than the subplot-based index, and used estimated parameters with the tree-centered index in the simulation discussed later.

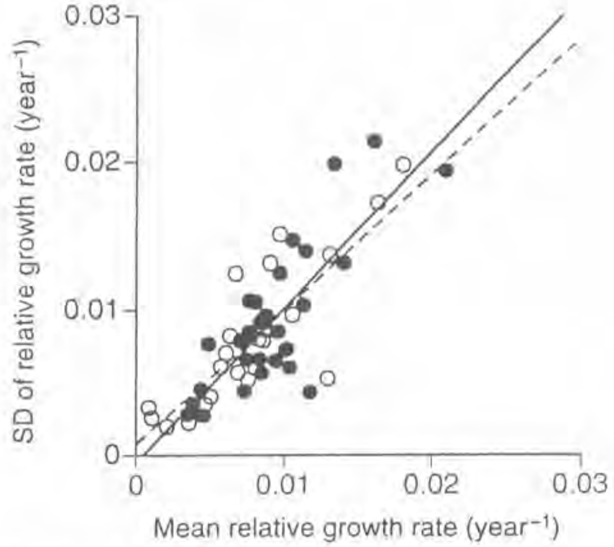

Fig. 2. Correlation between mean relative growth rate and SD of growth rate in each size-crowding class. (●), with full line for plot S-1; (○), with broken line for S-2.

Negative correlation existed between recruitment rate and crowding. By dividing local patches into basal area classes at 10 cm^2 m^{-2} interval, we found the class-average recruitment rate was sufficiently explained by equation 2 (Fig. 3a). The estimated parameters of equation 2 regression in Fig. 3a were $d=0.00196$ m^{-2} year^{-1} and $d_1=0.00520$ m^2 cm^{-2} for S-1 ($n=11$, $r^2=0.89$) and $d=0.00223$ m^{-2} year^{-1} and $d_1=0.00726$ m^2 cm^{-2} for S-2 ($n=10$, $r^2=0.88$). Within-class variation of recruitment rate was again readily related to the class average of recruitment rate (Fig. 3b), which is expected from the variation pattern of growth

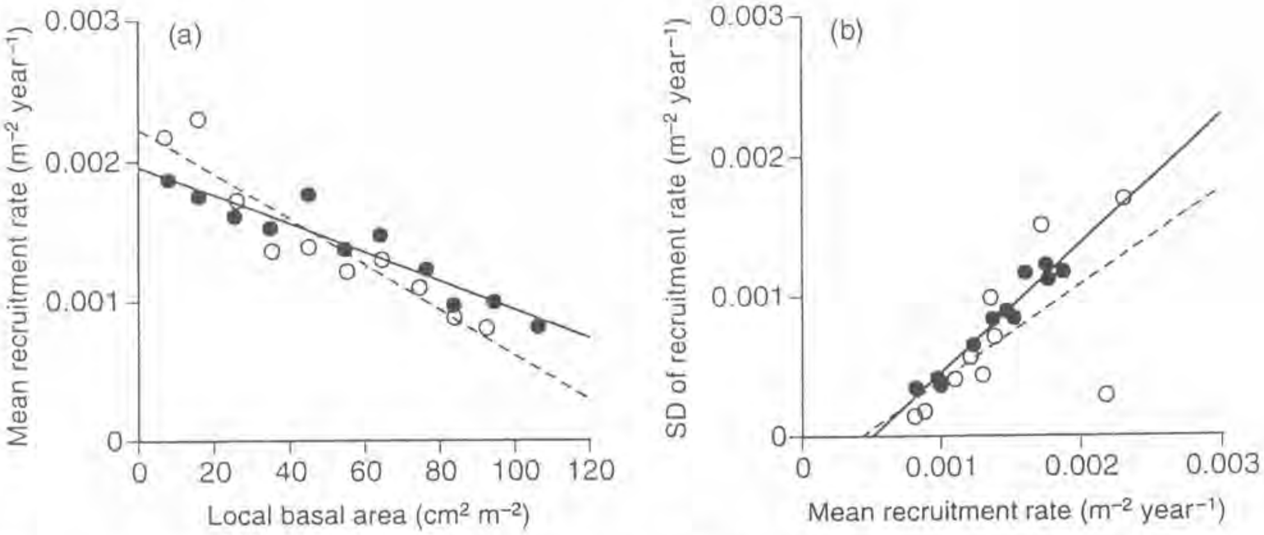

Fig. 3. (a) Dependence of mean recruitment rate (at each class of local basal area) on local basal area; (b) correlation between mean recruitment rate and SD of recruitment rate. (●), with full line for plot S-1; (○), with broken line for S-2.

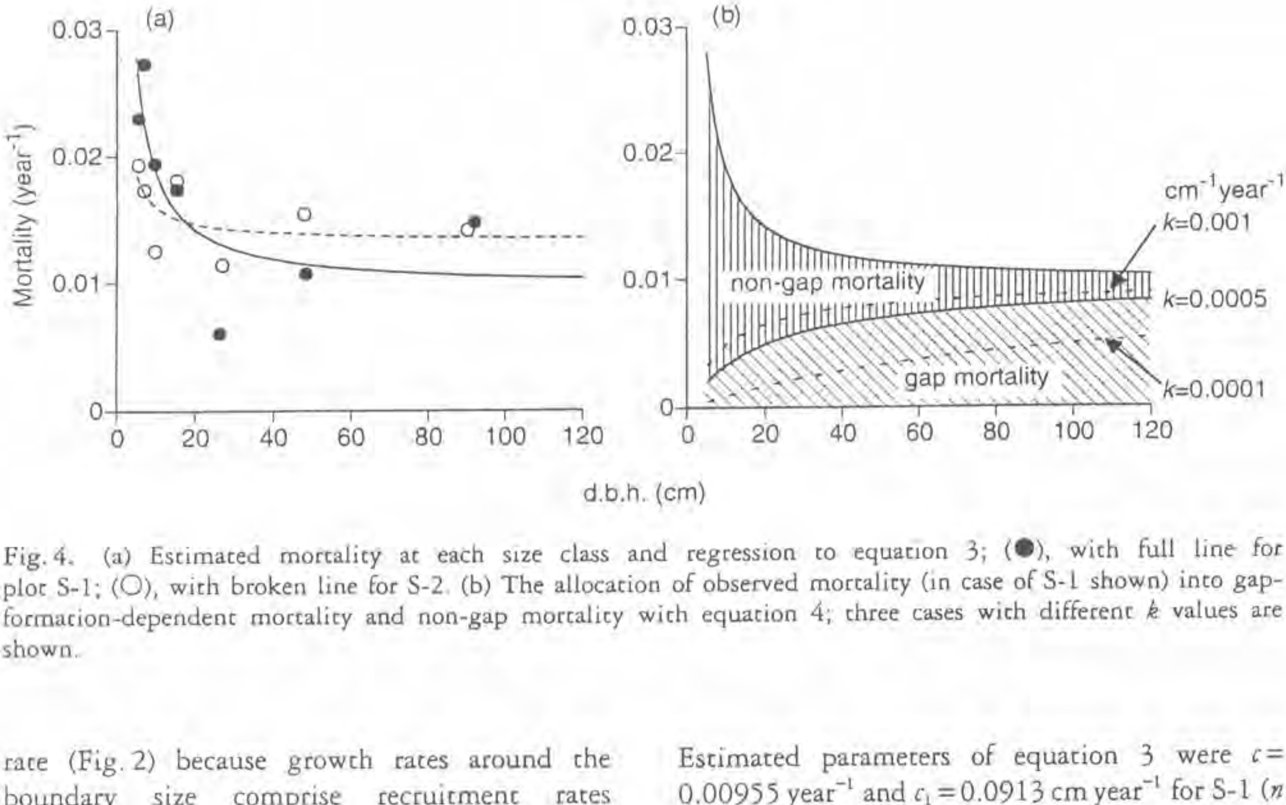

Fig. 4. (a) Estimated mortality at each size class and regression to equation 3; (●), with full line for plot S-1; (○), with broken line for S-2. (b) The allocation of observed mortality (in case of S-1 shown) into gap-formation-dependent mortality and non-gap mortality with equation 4; three cases with different *k* values are shown.

rate (Fig. 2) because growth rates around the boundary size comprise recruitment rates (Kohyama & Takada 1998).

We estimated the size-dependent mortality with equation 3 as in Fig. 4a. Data suggested that trees of intermediate size classes around 20–30 cm d.b.h. were likely to suffer the smallest mortality, while we employed the model of equation 3. Estimated parameters of equation 3 were $c = 0.00955$ year^{-1} and $c_1 = 0.0913$ cm year^{-1} for S-1 ($n = 7$, $r^2 = 0.68$) and $c = 0.0133$ year^{-1} and $c_1 = 0.0266$ cm year^{-1} for S-2 ($n = 7$, $r^2 = 0.35$). Figure 4b illustrates the allocation of observed mortality into gap formation-independent mortality and gap formation-dependent mortality, by equation 4 with changing parameter k.

Simulation

We carried out a simulation using the equations for empirical growth, recruitment, and mortality with the two independent parameter sets corresponding to the two plots. As long as the term of potential population increase (recruitment rate) surpasses the term of mortality, the system converges to a unique steady state, where the realized increase in population density and biomass (through local density dependence on growth and recruitment rates) is counterbalanced with their loss by mortality.

The initial condition for every simulation was no tree existed over the landscape and every patch was set at the youngest patch-age class. (It is necessary, however, to seed a small number of founder trees when closed system recruitment is assumed for species-explicit simulations in closed systems (Kohyama 1992, 1993)). Tree density, basal area and biomass at the landscape scale showed a similar time course between the two parameter sets, with more or less obvious overshoots (Fig. 5). The simulated steady-state tree density, basal area, biomass and biomass turnover rate were compared to those observed in the two plots (Table 2). The biomass turnover rate is defined here as the annual increment of biomass by growth of surviving trees and recruitment, which is counterbalanced with annual loss of biomass by mortality. Simulated attributes fit well to those observed in S-1. For S-2, basal area and biomass were smaller, and turnover rate was larger in the simulated steady-state forest than in the observed forest. The difference between observation and simulation in S-2 can be caused by the sampling (plot-setting) bias of the plot. S-2 looked more closed in canopy than S-1, so that it is possible that the plot covered aged patches more than young patches. The steady-state

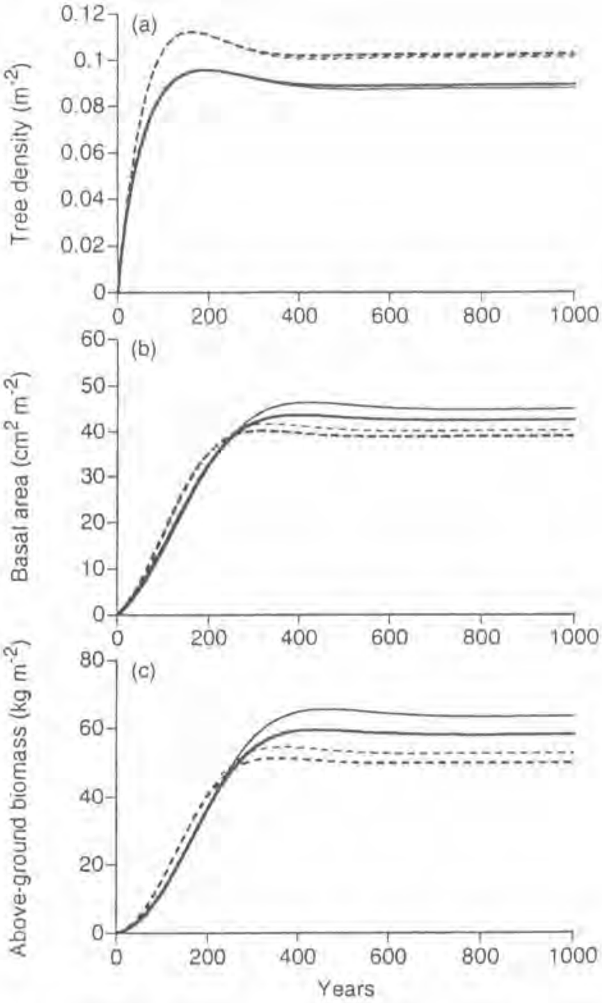

Fig. 5. Time course of simulation of tree populations (above 6 cm d.b.h.) shown by (a) tree density, (b) total basal area, and (c) aboveground biomass in dry weight. (——) for S-1 and (----) for S-2; (——), for gap-dynamic simulation with $k=0.0005\ \mathrm{cm}^{-1}\ \mathrm{year}^{-1}$ in equation 4; (——), for gap-averaged simulation in case of $k=10^4\ \mathrm{cm}^{-1}\ \mathrm{year}^{-1}$

Table 2 Comparison of observed forest attributes and simulated steady-state attributes at $k=0{,}0005\ \mathrm{cm}^{-1}\ \mathrm{yr}^{-1}$

	S-1		S-2	
Plot	Observed	Simulated	Observed	Simulated
Tree density (ha^{-1})	983	892	1074	1027
Basal area ($\mathrm{cm}^2\ \mathrm{m}^{-2}$)	41.5	42.6	43.9	39.1
Biomass ($\mathrm{kg\ m}^{-2}$)	57.3	58.1	59.6	50.1
Biomass turnover rate ($\mathrm{kg\ m}^{-2}\ \mathrm{year}^{-1}$)	0.618	0.667	0.538	0.700

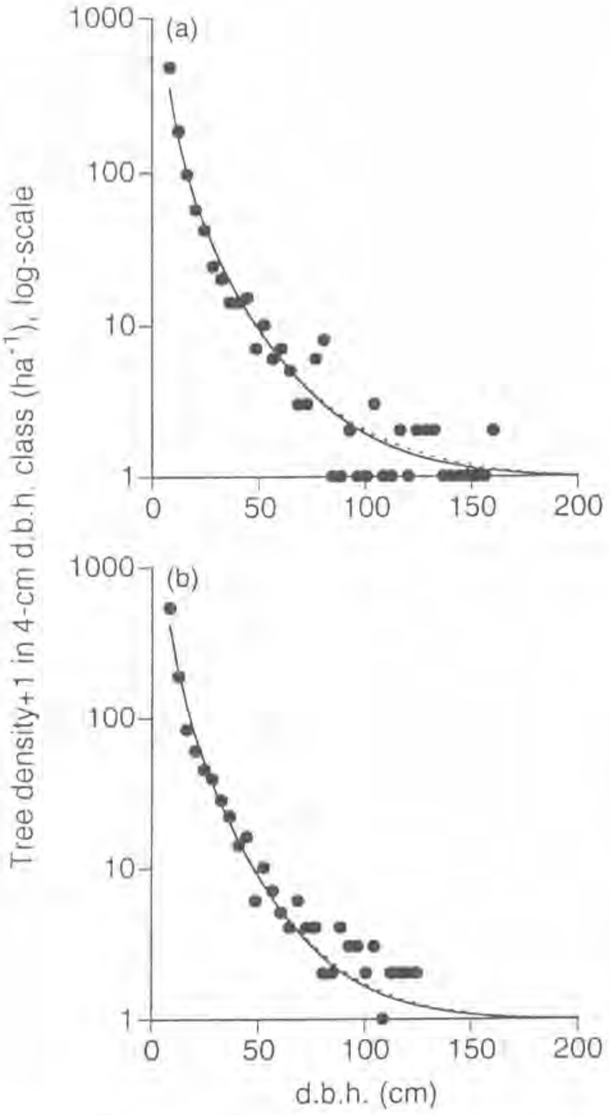

Fig. 6. Frequency distribution of d.b.h. in two permanent plots; (a) for S-1 (b) for S-2. (•••), show observed distribution at 1992 at 4-cm intervals. (——), steady-state distribution by gap-dynamic model with $k=0.0005\ \mathrm{cm^{-1}\ year^{-1}}$ in equation 4; (----), (almost overlapped with full line), steady-state distribution by gap-averaged model with $k=10^4\ \mathrm{cm^{-1}\ year^{-1}}$.

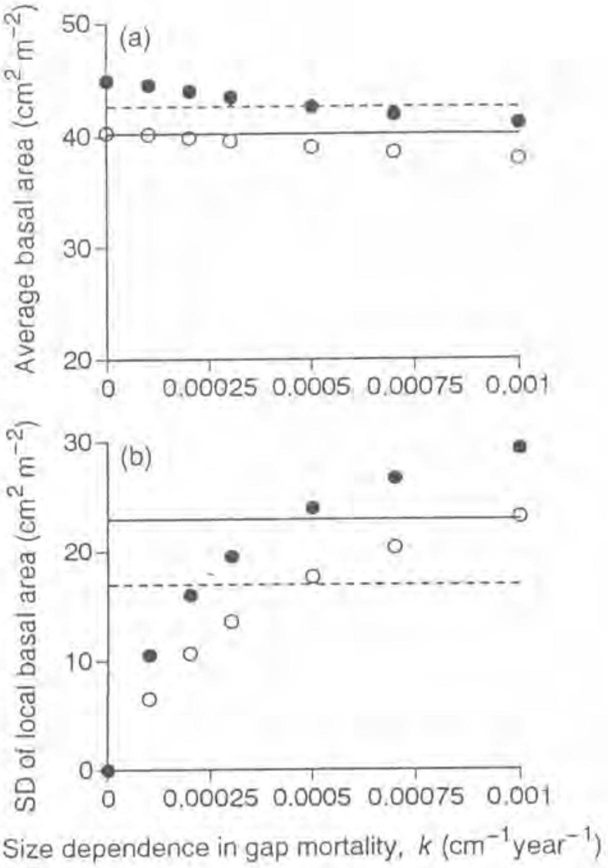

Fig. 7. Dependence of (a) steady-state average basal area, and (b) SD of steady-state distribution of local basal area on the parameter k of equation (4), in simulation. Simulation results for (●) S-1 and (○) S-2; 1992 observed values for (——) S-1 and (-----) S-2.

d.b.h. distribution fit fairly well to the observed distribution (Fig. 6).

These time courses were hardly changed with parameter k of equation 4 at landscape average (Figs 5,7a). Steady-state d.b.h. distribution was similar at landscape level between the patch-mosaic model ($k=0.0005\ \mathrm{cm^{-1}\ year^{-1}}$) and the patch-averaged model ($k=10^4\ \mathrm{cm^{-1}\ year^{-1}}$) (Fig. 6). These results were a result of the fixed size-specific tree mortality over simulations with variable k as in equations 3 and 4. However, the change in k remarkably affected the among-patch heterogeneity. The observed standard deviation among patches in terms of local basal area was closest to simulated standard deviation around $k=0.0005\ \mathrm{cm^{-1}\ year^{-1}}$ (Fig. 7b), thus we employed this value as the default k. The simulated frequency distribution of local basal area drew a positively skewed distribution as was observed in plot data. It was particularly close to the observed distribution in plot S-1, while it was higher in the lower basal area than the one observed in plot S-2 (Fig. 8). This disagreement between simulation and observation in S-2 supports the argument presented earlier that S-2 was set in sites biased toward aged patches. Reflecting the differential

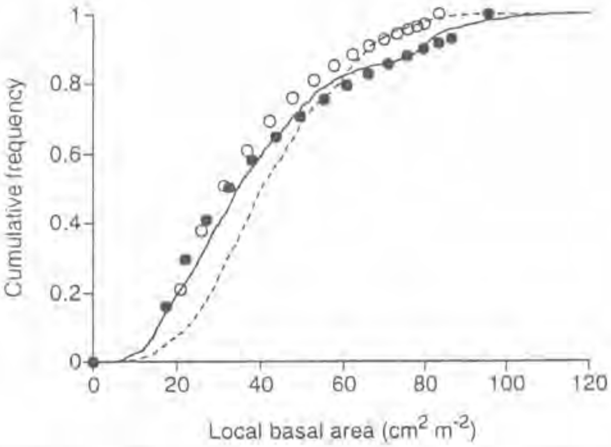

Fig. 8. Observed frequency distribution and simulated steady-state distribution of local basal area with $k = 0.0005$ cm^{-1} year^{-1} in equation 4. Simulation results for (●) S-1 and (○) S-2; 1992 observed distribution for (——) S-1 and (-----) S-2.

time course between them, tree density and basal area with time drew eddy time trajectories, separated between simulations for two plots. The relationship between basal area and above-ground biomass, however, fit well to an allometry:

$$\ln[\text{biomass, t ha}^{-1}] = -1.01 + 1.34 \ln[\text{basal area, cm}^2\text{m}^{-2}] \qquad (12)$$

($n = 120$ for every 10 years recorded up to 600 years in the two plots, $r^2 = 0.997$) without any obvious separation between the two simulation trajectories. Therefore, it can be used as a universal empirical relationship in this forest type, irrespective of small differences in parameters of d.b.h. versus tree height allometry of equation 5 between the two plots.

The effects of doubling and halving parameter values are summarized in Fig. 9. The steady-state density was sensitive to potential recruitment rate *d*, and the steady-state basal area was sensitive to potential growth rate *b*, baseline mortality *c*, and potential recruitment rate *d*, as compared to other parameters (Fig. 9a,b). The time required for system convergence, which is expressed by the time from initial condition to attain the overshoot, was robust and only sensitive to potential growth rate *b* (Fig. 9c).

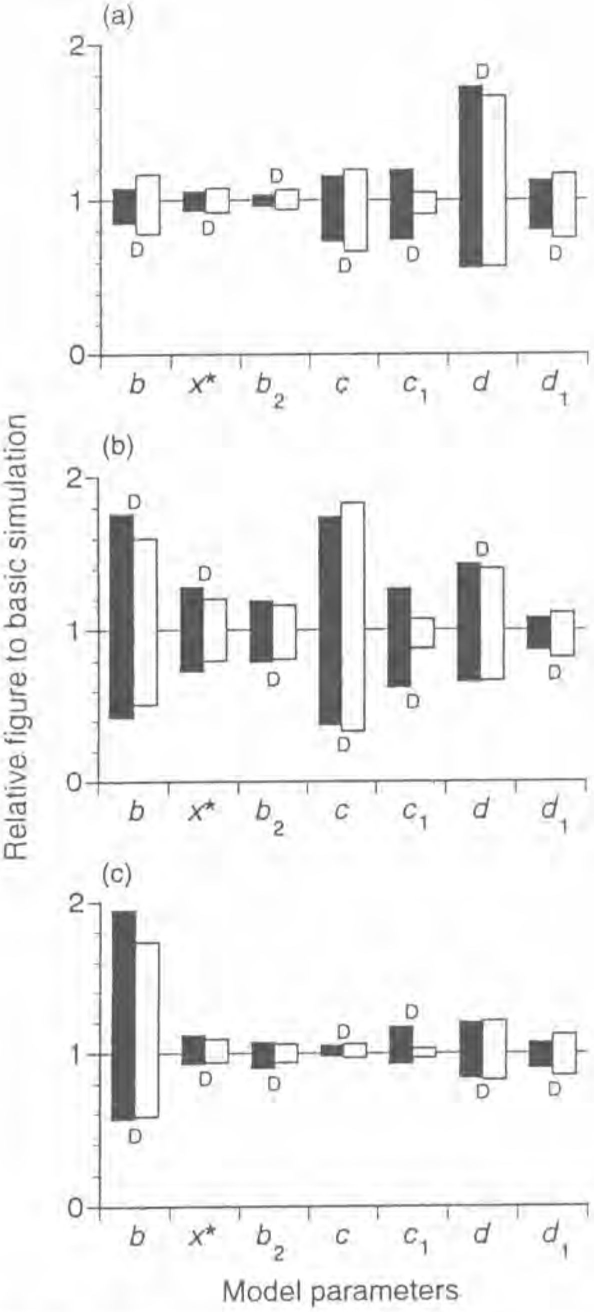

Fig. 9. Sensitivity of simulation results upon doubling and halving each of seven parameters in (a) steady-state tree density, (b) steady-state basal area, and (c) the time from no-tree initial condition to attain the maximum basal area. Relative difference from basic simulation is shown; column edge toward the letter 'D' shows the case for doubling parameter values, the opposite edge for halving values. (■), S-1; (□), S-2.

DISCUSSION

The present results suggest that repeated census data from permanent plots with limited plot size provide sufficient estimates of parameters describing the dynamics of the gap-mosaic tree size structure of a forest landscape. The similarity in estimated parameters between the two nearby plots suggests the efficiency of the estimation. The present parameter sets that were estimated from repeated censuses at 3 year intervals sufficiently reconstructed the forest architectural dynamics and stability. It suggests that a long-term series of repeated censuses from permanent plots offer an opportunity to detect a changing response of forests to, for instance, undergoing climate change. Besides constructing functionally integrated forest ecosystem models (Bugmann *et al.* 1996; Bugmann 2001), such a descriptive approach of modeling based only on inventory data provides compensatory significance for the prediction of forest response to environmental change.

A time course over 1000 years has no power of prediction. Substantial shifts in tree community composition and soil fertility accompany forest development, and the climatic condition may also change. These simulations took a longer time to approach asymptotes, approximately 400 years in basal area (Fig. 5), compared to those presented by Kohyama (1991) who simulates the time to asymptotic basal area to be approximately 100 years for a foothill rainforest in West Sumatra and approximately 200 years for a warm–temperate rainforest in southern Japan. The shorter time intervals proposed by Kohyama (1991) resulted because data from secondary forest stands after clear-felling, which are composed of abundant pioneers, were used to detect the local crowding dependence. In contrast, the projected time course of the present study reflects the capacity of the present tree community at around dynamic equilibrium to respond to disturbance.

The simulator with gap-dynamic landscape (Kohyama 1993) reconstructed not only the average structure but also the spatial pattern of crowding as illustrated in Figs 7 and 8. The landscape-level pattern of density, basal area and biomass was, however, similar between the gap-dynamic model and the gap-averaged model, and the present study reconfirms the conclusion of Kohyama (1991) that gap-averaged models sufficiently describe the horizontally averaged forest structure and dynamics. Our results showed that total basal area was slightly higher in the gap-averaged model than in the gap-dynamic model (Fig. 5).

By contrast, Stephen Pacala and colleagues find that gap-averaged models substantially underestimate the total basal area compared to gap-dynamic models as well as individual tree-based models, for cool–temperate forests in north-eastern North America (Pacala & Deutschman 1995; Hurtt *et al.* 1998) and a cool–temperate beech forest in western Japan (T. Kubo *et al.*, unpubl. data, 1997). Their results suggest that horizontal heterogeneity is necessary to reconstruct the overall forest stock and structure from demographic parameters. The discrepancy between the results of the present study and those from cool–temperate forests reflects the relatively low contribution of suppression terms in both growth (b_2) and recruitment (c_1) in the present model. A larger c_1 simulation generated the increasing steady-state basal area with increasing k and patch heterogeneity. Therefore, increasing basal area is not the universal consequence of the inclusion of patch-mosaic landscape. It is likely that suppression terms do not strongly regulate forest architecture in the present Kalimantan plots, because the present model estimates parameters only from the present plot inventory data and it does not take into account the earlier stage of succession. Difficulty also exists in estimating size-independent suppression susceptibility from census data, because upper canopy trees are always less covered by foliage than understory trees in any real forest. Therefore, we must be careful about the efficiency of detecting the degree of regulation only from inventory data. The present approach is still useful for answering to what extent demographic rates observed from repeated censuses explain the observed three-dimensional architecture of the forest landscape.

ACKNOWLEDGEMENTS

We thank Soedarsono Riswan, Herwint Simbolon, Naohiko Noma, Koichi Takahashi for field collaboration, and Peter Ashton, Fakhri Bazzaz, Stuart Davies, Takuya Kubo, Helene Muller-Landau, Matthew Potts and Cambell Webb and anonymous reviewers for valuable suggestions on earlier drafts. The Research and Development Center for Biology, Indonesian Institute of Sciences, kindly supported our field research. Financial support was provided by the International Scientific Research Program of the Ministry of Education, Science, Sports and Culture of Japan and by the Scientist Exchange Program of the Japan Society for the Promotion of Science. TK acknowledges the support from the Bullard Fellowship of Harvard University for providing the opportunity to compile this paper.

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Functional Ecology 2001
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Optimal leaf display and biomass partitioning for efficient light capture in an understorey palm, *Licuala arbuscula*

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Summary

1. The effects of leaf display and biomass partitioning on light capture efficiency were examined in a non-branching understorey palm, *Licuala arbuscula*, by using a three-dimensional geometric simulation model. This species has several fan-shaped laminae, attached on long petioles at a mostly constant deflection angle (D_P). The petiole of the youngest leaf was almost vertical, and slanted downwards as it aged.

2. The combination of large D_P and small Z_{max} (zenith angle of the oldest leaf's petiole) maximized light capture for a plant with few leaves; this combination kept the lamina facing in the approximate direction of the zenith with high light intensity. For a plant with many leaves, the combination of large Z_{max} and small D_P increased light capture because it reduced self-shading.

3. For a given total leaf biomass, the plant increased its total leaf area by producing many small leaves. This occurred because the leaf area per unit biomass decreased with increasing biomass per individual leaf. This effect was most pronounced in larger plants. However, an increasing number of leaves intensified self-shading among leaves. Allocation of biomass to the petioles reduced self-shading, but decreased leaf area.

4. There was an optimal allocation of biomass to petioles and an optimal number of leaves that maximized the crown's light capture. Greater investment in petioles as the number of leaves increased was the favoured strategy for larger plants.

5. In most cases, the leaf geometry and biomass partitioning in the plants were close to the optima predicted by a simulation model developed in this study. There were noticeable differences in a few cases, but the reduction in the crown's light capture due to these differences was small.

Key-words: Allocation, crown architecture, geometry, petiole, self-shading

Functional Ecology (2001) 15, 660–668

Introduction

The environment of the forest understorey is characterized by a shortage of light. This reduces the production of photosynthate and limits plant growth and survival; there must have been strong selection pressure on understorey plants to construct crowns that capture light efficiently with the least possible investment of carbon. Light capture by a plant depends on its total leaf area, which is determined by the allocation of photosynthate to leaf production. Whole-plant light capture also depends of the amount of light captured per unit of leaf area; it is determined by the orientation of the leaves with respect to incoming light (Chazdon 1985; Ackerly & Bazzaz 1995; Muraoka *et al.* 1998; Pearcy & Yang 1998) and the degree of self-shading among the leaves (Warren Wilson 1981; Niklas 1988; Takenaka 1994).

One possible strategy to minimize the amount of self-shading is to make fewer leaves. In the extreme case – the production of only one flat leaf – no self-shading would occur. However, the specific leaf area (leaf area per unit of dry biomass) would decrease with increasing lamina area, because correspondingly greater biomass must be invested to provide sufficient mechanical stability (Chazdon 1986; Niinemets 1996). Therefore, total leaf area is likely to be smaller in a plant that makes few large leaves than in one with many small leaves. Another way to reduce self-shading is to distribute leaves in a larger volume of canopy

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space. However, this requires more investment in support tissues such as stems, petioles and rachises. Again, there is a trade-off between the total leaf area and the degree of self-shading.

As a result of these trade-offs, it is reasonable to expect that an optimal crown architecture exists for any given light environment and amount of biomass available to construct the crown. Unfortunately, determination of this optimal structure is not straightforward, because light capture by a crown is a non-linear function of the many mutually dependent morphological features of the crown (Pearcy & Yang 1998). Moreover, the complex branching architecture of plants makes it hard to infer the optimal structure under a given set of conditions.

Takahashi & Kohyama (1997) studied the crown architecture of *Licuala arbuscula* Becc. (Palmae), a small, non-branching understorey palm that grows in lowland rain forests in south-east Asia (Whitmore 1985). The palm has a stagnant vertical stem less than 40 cm high with several fan-shaped, palmately compound laminae on long petioles. The simplicity of the crown structure of *L. arbuscula* facilitates analysis of the structural dependency of light capture by its crown. Takahashi & Kohyama (1997) discussed the possible advantages of the various morphological characteristics of this species in terms of receiving light efficiently. These characteristics include the deflection angle between the lamina and its petiole, the range of petiole zenith angles and the biomass investment in petioles.

The purpose of the present study was to examine quantitatively the effects of changes in leaf display pattern and in biomass partitioning on whole-plant light capture in *L. arbuscula*. We tested the hypotheses that *L. arbuscula* adjusts the maximum zenith angle of the petiole, the deflection angle between the lamina and its petiole, the size and number of leaves and the relative biomass allocation to the laminae and petioles so as to maximize whole-plant light capture.

Materials and methods

PLANT MATERIAL

Licuala arbuscula has palmately compound leaves that clump near the top of the stem (< 40 cm high). The leaf has a thin petiole and wedge-shaped leaflets (≈ 25 or more). The proximal leaflets are shorter than the distal ones, and the petioles do not elongate after the full expansion of laminae. The leaf size and number of leaves within a crown increase in the later stage of plant growth, while the ratio of petiole length to lamina diameter also increases as the plant grows. The leaf lamina deflects ≈ 40° from the horizontal to the inside of the crown when the petiole stands vertically (i.e. the deflection angle between a lamina and its petiole is ≈ 50°). The petiole of the youngest leaf is almost vertical, but slants increasingly downwards with age; consequently, the petiole of the oldest leaf within the crown has the maximum zenith angle. The deflection angle of the lamina to the petiole does not change with age, but the maximum zenith angle within a crown increases as the plant grows. In the juvenile stage, this angle amounts to ≈ 50° and all laminae cluster at the top of the crown. In older plants, the zenith angle increases to ≈ 110°, and the leaves form a hemispherical crown.

THE MODEL PLANT

A computer model of the crown of *L. arbuscula* was developed based on geometrical measurements of 24 plants growing on the forest floor of a primary lowland dipterocarp forest on the slope of Mount Berui (West Kalimantan, Indonesia). In addition to these non-destructive measurements, we harvested 38 leaves to measure the biomass of the leaf laminae and petioles. Unless otherwise stated, the values of the parameters reported below are based on these measurements. Details of the study area and the sampling procedures are described by Takahashi & Kohyama (1997).

An example of the plant simulated with the computer model is shown in Fig. 1. The petiole of the youngest leaf was vertical, and those of older leaves slanted downwards. In the present study, the zenith angle of the n^{th} leaf [with the youngest leaf in the crown assigned a value of 1 in a plant with N leaves $(N > 1)$] is defined as $Z_n = Z_{max}(n - 1)/(N - 1)$, where Z_{max} is the maximum zenith angle of the petioles within

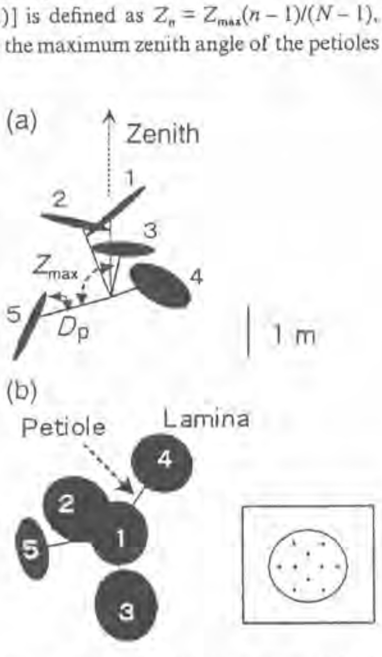

Fig. 1. An illustration of the computer model of *Licuala arbuscula*. The dry biomass of each of the five leaves was set at 33·7 g, the relative allocation to the lamina was set at 0·583, Z_{max} (zenith angle of the oldest leaf) was set at 90° and D_p (the angle between the lamina and petiole) was set at 49·6°. Leaves are numbered from 1 to 5 with the increasing zenith angle of the petioles. (a): Side view of the model plant; (b): vertical view. The inset in (b) shows the distribution of sampling points (●) on each lamina for the determination of photon flux density.

the crown. The leaves were arranged in a spiral phyllotaxis, with a divergence angle between successive leaves of 135°.

The lamina of the fan-shaped, palmately compound leaf was approximated as an ellipse. The ratio of lamina area to the area of the enclosing ellipse was 0·535. The major axis of the ellipse ran from the basal end to the tip of the leaf, and the ratio of the minor axis to the major axis was set at 0·84. From the leaves sampled, it was found that the specific leaf area (SLA, $m^2 g^{-1}$) of the lamina depended on leaf size. A regression equation for SLA was developed as a function of the area of the ellipse that enclosed the leaf's lamina (E, m^2) as follows:

$$\mathrm{SLA} = -0{\cdot}00847E + 0{\cdot}0217 \qquad \text{eqn 1}$$

($R^2 = 0{\cdot}360$, $P < 0{\cdot}01$). The area of the ellipse represented by a given biomass of leaf lamina of the model plant was calculated from this relationship. Generally, SLA is affected by various factors other than leaf size, such as light and water conditions. In the present study, such environmental factors were not taken into account because they did not vary much under the closed forest canopy where the sample plants were located.

The shape of a petiole was approximated as a truncated cone. The diameter at the distal end of the cone was 66% of that at the basal end. The petiole was considered to attach to the major axis of the ellipse that represented the lamina at a point 40% of the distance along the axis from the proximal end of the lamina.

Given the biomass of a petiole and the attached leaf lamina, we determined the length of the petiole by assuming that it could be simulated as a cantilever fixed to the stem and loaded with its own weight plus that of its lamina. In the calculations, the cantilever was assumed horizontal because the bending moment working on a petiole is greatest in this case. The maximum bending stress of the leaves sampled did not show any significant correlation with leaf size. Thus, the maximum stress at the base of a petiole was assumed to be constant at $2{\cdot}08 \times 10^7$ N m^{-2}, which is the mean moment calculated from all the leaves sampled. Based on this assumption, the size of a petiole was calculated for a given biomass of leaf lamina plus petiole. The details of this calculation are shown in the Appendix. The petiole geometry was not determined using an empirical relationship between its mass and the length of leaves sampled because we intended to show explicitly that the mechanical stability is the constraint to which the petiole should conform.

BIOMASS ALLOCATION IN REAL PLANTS

The relationships between total leaf biomass and both the number of leaves and the relative allocation of biomass to the lamina were derived using data from the plants sampled. These relationships were used to compare the optimal crown structure predicted by the computer simulation with the structure of real plants.

Equations 2 and 3 were obtained from the 38 leaves harvested by using a reduced-major-axis regression (Niklas 1994):

$$\log_{10} m_p = 2{\cdot}502 \log_{10} L + 0{\cdot}859 \qquad \text{eqn 2}$$

($r^2 = 0{\cdot}893$, $P < 0{\cdot}01$) and

$$\log_{10} m_l = 1{\cdot}483 \log_{10} A + 1{\cdot}665 \qquad \text{eqn 3}$$

($r^2 = 0{\cdot}952$, $P < 0{\cdot}01$), where m_p and m_l are the dry biomasses (g) of a leaf's petiole and lamina, respectively, L is the length (m) of the petiole and A is the area (m^2) of the ellipse that encloses the leaf's lamina. The total leaf biomass was calculated for each of the 24 non-destructively sampled palms with these equations. From the number of leaves and the estimated total leaf biomass for each of the 24 sample palms, equation 4 was obtained; this was used to estimate the number of leaves (N) as a function of the total leaf biomass (W):

$$\log_{10} N = 0{\cdot}287 \log_{10} W + 0{\cdot}277 \qquad \text{eqn 4}$$

($r^2 = 0{\cdot}695$, $P < 0{\cdot}01$). The allometric relationship between lamina and petiole was derived from their respective estimated biomasses:

$$\log_{10} M_l = 0{\cdot}795 \log_{10} M_p + 0{\cdot}543 \qquad \text{eqn 5}$$

($r^2 = 0{\cdot}914$, $P < 0{\cdot}01$), where M_l and M_p are the total dry biomasses of all laminae and petioles, respectively. The number of leaves per plant and the relative allocation of biomass to the laminae and petioles were calculated for a given total leaf biomass using equations 4 and 5.

CALCULATION OF LIGHT CAPTURE

Light capture by the model plant was calculated by following the method described by Takenaka *et al.* (1998) and Muraoka *et al.* (1998). Firstly, the three-dimensional structure of the model plant was simulated on the computer. Light capture was estimated by incorporating the directionality of the light source, the self-shading among the leaves of the crown and the incidence angles of light striking the leaves.

The sky hemisphere above the horizon was divided into a 200-cell 'web' (Anderson 1964). Unlike Anderson's web, all the cells represented the same solid angle (Fig. 2). Ten sampling points, each representing 10% of the leaf area, were spread uniformly over the surface of each model leaf, as shown in Fig. 1. Obstruction of these sample points by other leaves was assessed for light from each of the 200 cells over the sky hemisphere by using three-dimensional analytical geometry. If leaves did not obstruct the light source at a point, the full quantity of light from that cell was considered to

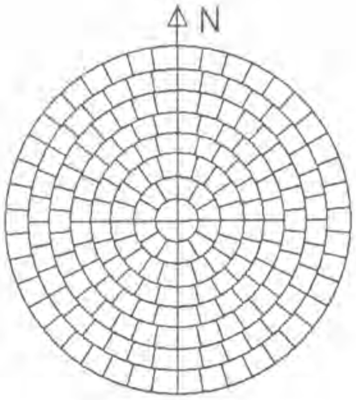

Fig. 2. The web dividing the hemisphere above the horizon into 200 cells of identical solid angle. The web is drawn on a circular image of the polar projection of the hemisphere. The arrow indicates the direction of north.

reach the point. Conversely, if the light was obstructed, the photon flux density (PFD) from that cell was reduced by the light absorptance of the obstructing leaf. Here, the light transmissivity was assumed to be 1 – (leaf area)/(ellipse area), i.e. 0·465. After calculating the quantity of incoming light from all cells at a sampling point on the leaf, the PFDs were cosine-corrected using the angle of incidence of the light, and the values from all cells were summed to give the total PFD at the sampling point.

Determining the angular distribution of the incoming light that reaches a plant on the forest floor requires estimates of the distribution of both irradiance across the sky and openings in the forest canopy. The distribution of irradiance was modelled using the standard overcast sky (SOC) model of diffuse light distribution (Moon & Spencer 1942). Here, irradiance at the zenith is considered to be three times greater than that at the horizon. In the present study, the light intensity at the zenith was chosen so that the PFD measured on a horizontal surface above the forest canopy equalled 1000 μmol m^{-2} s^{-1}. The solar beam coming directly from the solar disk was not taken into account for the sake of simplicity: doing so would not greatly alter the angular altitude dependency of the relative light source intensity averaged over a year.

Information on the distribution of openings in the forest canopy where the palms were sampled was not available. Instead, hemispherical photographs of the canopy of a tropical forest in Peninsular Malaysia with a similar floristic composition were analysed. Sixty-nine photographs taken under the closed forest canopy were provided courtesy of Dr T. Okuda (National Institute of Environmental Studies, Japan). Details of the forest are provided by Okuda *et al.* (1997). Images of the forest canopy with distinct canopy gaps were not used, because the present study focused on the adaptive geometry of the palms under light-limited conditions, not those in open gaps with abundant illumination.

Table 1. Relationship between zenith angle and canopy openness, determined from hemispherical photographs taken under the canopy of a tropical rain forest

Zenith angle (°)	Canopy openness (%)
0·0–11·5	8·5
–23·1	6·7
–35·0	5·5
–45·6	4·2
–55·9	2·4
–67·1	1·3
–77·9	0·34
–90·0	0·04

The photographs, which were taken with a fisheye lens, were scanned into a computer. The images of the hemisphere were divided into 200 cells as described above and the proportion of open canopy was determined for each cell, checking the proportion of bright pixels. Analysis of the photographs provided a measure of how the canopy openness depended on the zenith angle (Table 1). Superimposing the zenith angle dependency of the canopy openness on the SOC model of diffuse light generated the directionality of the diffuse light over the sky.

SIMULATION OF LIGHT CAPTURE

Two simulations of light capture by the model plant were performed. The first analysed the effect of the deflection angle between the leaf lamina and its petiole (D_P) and the effect of the range of zenith angles of the petioles within the crown. In the simulations, D_P varied from 0 to 90° at 10° intervals. The range of zenith angles for the petiole was represented by the maximum zenith angle (Z_{max}), i.e. the zenith angle of the oldest leaf. This angle varied from 30 to 135° at 15° intervals. These two ranges included the observed range for real plants. Among the sample plants, D_P was constant at around 50° and Z_{max} ranged between 50 and 110° (Takahashi & Kohyama 1997). All combinations of D_P and Z_{max} were tested to determine the interaction of their effects on light capture by the crown. The biomass of the lamina and petiole of an individual leaf were kept constant at 23·4 and 10·3 g, respectively (the mean values for the sampled leaves). The simulation was carried out for model plants with four different numbers of leaves (5, 10, 15 and 20). To estimate the effects of the angle of incident light and self-shading on whole-plant light capture separately, hypothetical values for light capture (I_{ns}) were calculated without consideration of the effects of self-shading within a crown. As an index of the relative contribution of self-shading to reducing light capture, the ratio $(I_{ns} - I)/I_{ns}$ was calculated, where I is the light capture when self-shading is considered (calculated as before).

The second simulation studied the effect of changes in the allocation pattern of leaf biomass. The number of individual leaves and their biomasses were varied, with the total leaf biomass per plant held constant. In the simulation, the number of leaves was varied from 1 to 30. The effects of the allocation of biomass on the lamina and petiole were also analysed. The relative allocation of biomass to the leaf lamina [lamina biomass/(lamina biomass + petiole biomass), R_l] was varied from 0·1 to 0·9 at intervals of 0·1. The total leaf dry biomass of the model plant was varied from 20 to 640 g (six values, each double the previous one). The ranges of these parameters included the observed ranges of the plants in the forest. The largest total dry biomass of leaves per plant among the 24 sample palms was 469 g, and the minimum and maximum numbers of leaves per plant were 2 and 13, respectively. The minimum and maximum R_l values for the sampled leaves were 0·44 and 0·73. In the simulations, the deflection angle between the petiole and the leaf lamina was kept constant at 49·6°, which is the mean value for the sample data. Z_{max} was fixed at 90° in all simulations. Thus, the most slanted leaf within a crown had a horizontal petiole. All combinations of total biomass, number of leaves and relative allocation of biomass to the lamina were tested.

Results

EFFECTS OF THE GEOMETRY OF LEAF DISPLAY ON LIGHT CAPTURE

For every Z_{max} and number of leaves tested, the curve of the relationship between D_P and whole-plant light capture per unit of leaf area was concave, with an optimal value of D_P that maximized light capture (Fig. 3). The optimal value of D_P decreased as Z_{max} increased. The optimal combination of D_P and Z_{max} depended on the number of leaves. As leaf number increased, the optimal value of D_P decreased and that of Z_{max} increased (Table 2). The dependency of light capture on D_P was weak near the optimal value of D_P. Light capture at $D_P = 50°$, the value that was observed in real plants irrespective of the number of leaves within a crown, was less than that at the optimal D_P by 2% or less for each number of leaves.

Table 2. The optimal combinations of D_P (angle between lamina and petiole) and Z_{max} (zenith angle of the oldest leaf) for plants that maximized light capture

Number of leaves	D_P	Z_{max}
5	60	60
10	55	75
15	45	90
20	40	105

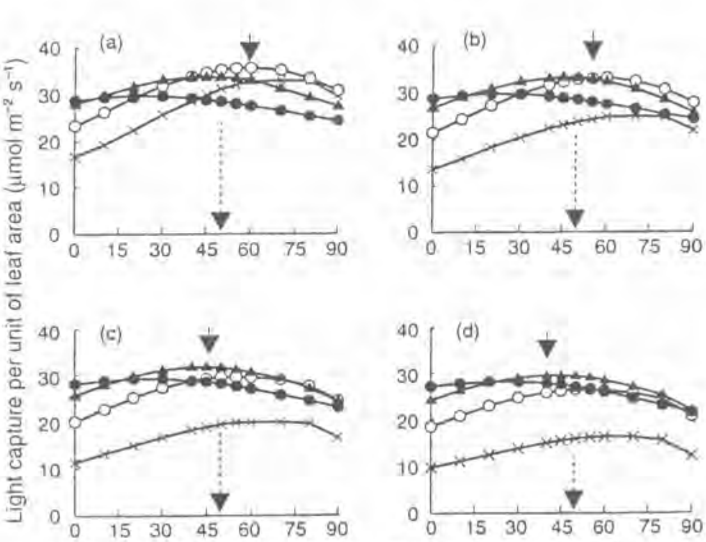

Fig. 3. The relationship between whole-plant light capture per unit of leaf area (μmol m^{-2} s^{-1}) and the deflection angle between the lamina and the petiole (D_P). The maximum zenith angle of the leaf petiole (Z_{max}) was set at 30 (×), 60 (○), 90 (▲) and 135° (●). Results are shown for plants with 5 (a), 10 (b), 15 (c) and 20 (d) leaves. The dry biomass of individual leaves and R_l (relative allocation to lamina) were set at 33·7 g and 0·583, respectively. Upper arrows indicate the deflection angle at which light absorption is maximal for each plant. Lower arrows with a broken line indicate the mean D_P observed in the field for *L. arbuscula*.

Figure 4 shows the ratio $(I_{ns} - I)/I_{ns}$, an index of the relative contribution of self-shading to reducing light capture. In a simulated plant with five leaves, this ratio was consistently < 0·1, except when Z_{max} was 30° (with leaves being packed into a very small space, this ratio ranged from 0·1 to 0·2) (Fig. 4a). The ratio was generally much larger in plants with 20 leaves, although the ratios for plants with high Z_{max} values were closer to those for the simulated plant with five leaves (Fig. 4b). This indicates that self-shading becomes more severe as the number of leaves increases, and that larger Z_{max} values reduce this effect.

EFFECTS OF BIOMASS PARTITIONING ON LIGHT ABSORPTION

In the present model, leaf area does not increase proportionally with lamina biomass. This is because of the decrease in SLA for larger leaves, as described in equation 1. Thus, the total whole-plant leaf area increases if the available biomass is divided into many small leaves (Fig. 5). The increase in total leaf area with an increasing number of leaves was more pronounced for large total leaf biomasses than for small total biomasses. Decreasing the biomass allocated to each leaf's lamina reduced the total lamina biomass, and diminished the effects of leaf number on total leaf area. When the total leaf biomass was small, increasing the allocation of biomass to the lamina resulted in a proportional increase in total leaf area (e.g. doubling the allocation to the lamina doubled the total leaf area), irrespective of the number of leaves. However, as total leaf biomass increased, increasing the allocation to the lamina had diminishing returns in terms of increasing the total leaf area, particularly with fewer leaves.

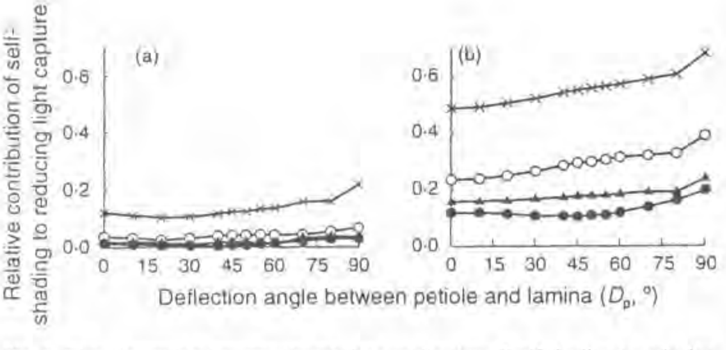

Fig. 4. The relationship between the relative contribution of self-shading to reducing light capture and D_P in plants with 5 (a) or 20 (b) leaves. The maximum zenith angle of the leaf petiole (Z_{max}) was set at 30 (×), 60 (○), 90 (▲) and 135° (●).

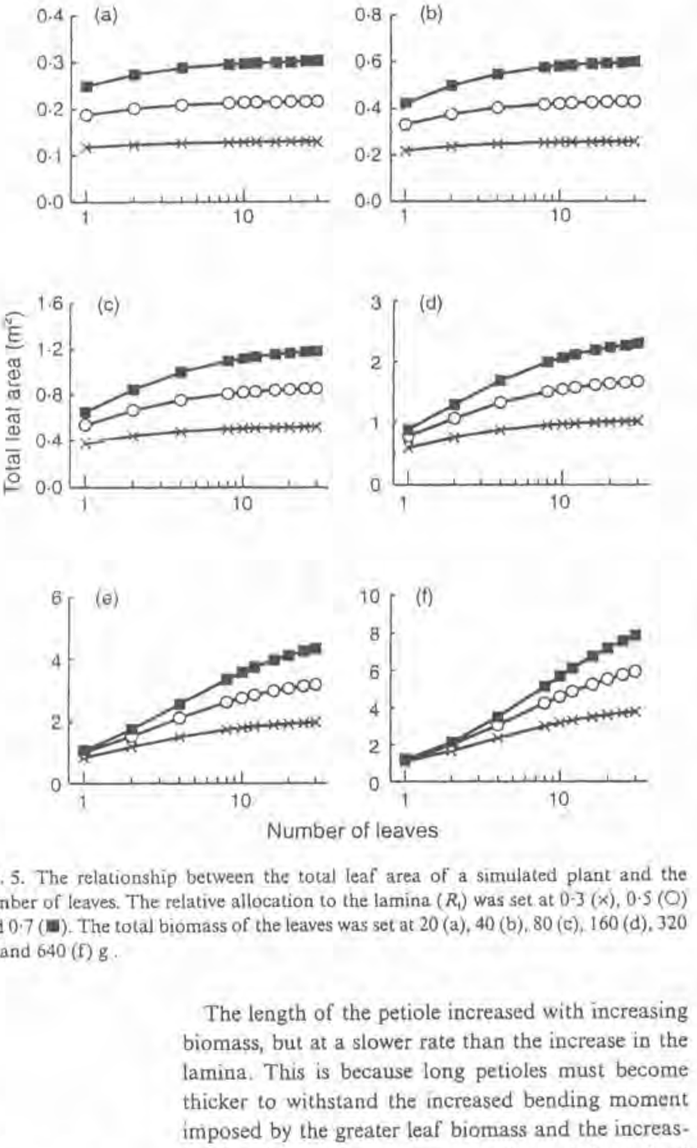

Fig. 5. The relationship between the total leaf area of a simulated plant and the number of leaves. The relative allocation to the lamina (R_l) was set at 0·3 (×), 0·5 (○) and 0·7 (■). The total biomass of the leaves was set at 20 (a), 40 (b), 80 (c), 160 (d), 320 (e) and 640 (f) g.

The length of the petiole increased with increasing biomass, but at a slower rate than the increase in the lamina. This is because long petioles must become thicker to withstand the increased bending moment imposed by the greater leaf biomass and the increasing length of the petiole as a cantilever. With a fixed relative allocation to the lamina (R_l), increasing leaf biomass produced leaves with disproportionately short petioles (Fig. 6).

Table 3. The number of leaves and relative allocation to the lamina (R_l) estimated for given total leaf biomasses in real plants. The optimal leaf number and R_l estimated for the model plant are also shown for each total leaf biomass

	Total leaf biomass (g)					
	20	40	80	160	320	640
Number of leaves						
Real plant	5·1	5·5	6·2	7·7	10·6	16·4
Model plant	3	4	4	6	12	16
R_l						
Real plant	0·69	0·66	0·63	0·60	0·57	0·54
Model plant	0·9	0·8	0·8	0·7	0·6	0·6

For these reasons, large plants should improve their light capture by increasing the number of leaves, thereby keeping SLA high and lowering R_l so that petioles can grow longer and reduce self-shading. The results of our simulation supported this expectation. For each given total leaf biomass, there was a combination of leaf number and R_l that maximized light capture (Fig. 7). The optimal number of leaves increased and the optimal R_l decreased with increasing total leaf biomass.

The numbers of leaves and R_l values for *L. arbuscula* plants were estimated for each total leaf dry mass from 20 to 640 g by using equations 4 and 5 (Table 3). The estimated numbers of leaves and R_l increased with increasing biomass as in the optimal model plants. The estimated numbers of leaves and values of R_l compared well with the optima for plants with total leaf biomasses of 160 g or more. In smaller plants, however, the estimated numbers of leaves were larger and R_l was smaller than the predicted optima.

Discussion

GEOMETRY OF LEAF DISPLAY

The results of the simulation supported Takahashi & Kohyama's (1997) hypothesis that the geometry of leaf display in *L. arbuscula* contributes to efficient light capture. The increasing value of Z_{max} with increasing numbers of leaves in a crown was advantageous in terms of light capture under the following constraints: all leaves are identical in shape, D_P is fixed and the zenith angle of the petiole increases gradually with increasing leaf age until it reaches Z_{max}. With few leaves, a small Z_{max}, combined with little variation in the zenith angle of the plant's petioles, lets all laminae face the brightest part of the hemisphere near the zenith. Then, a D_P larger than the observed value (50°) is favoured. However, the difference between the amount of light captured at the optimal and the observed D_P was small. As the plant grows in size, the number of leaves increases. With many leaves, self-shading becomes severe. A large Z_{max} then reduces self-shading by distributing the leaf laminae throughout a

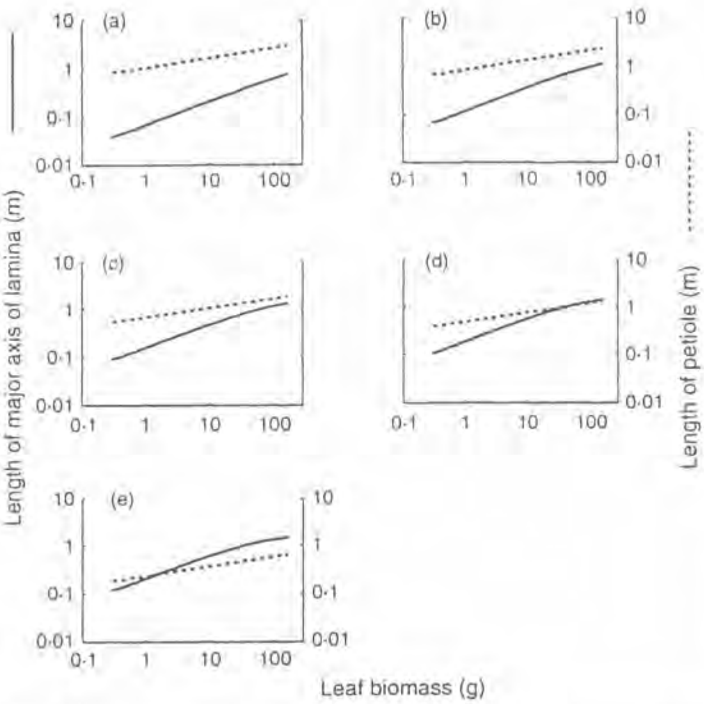

Fig. 6. The relationships between the leaf dry biomass and the length of the major axis of the ellipse that encloses the leaf's lamina (solid line) and the length of the petiole (broken line). The relative allocation to the lamina (R_l) was 0·1 (a), 0·3 (b), 0·5 (c), 0·7 (d) and 0·9 (e).

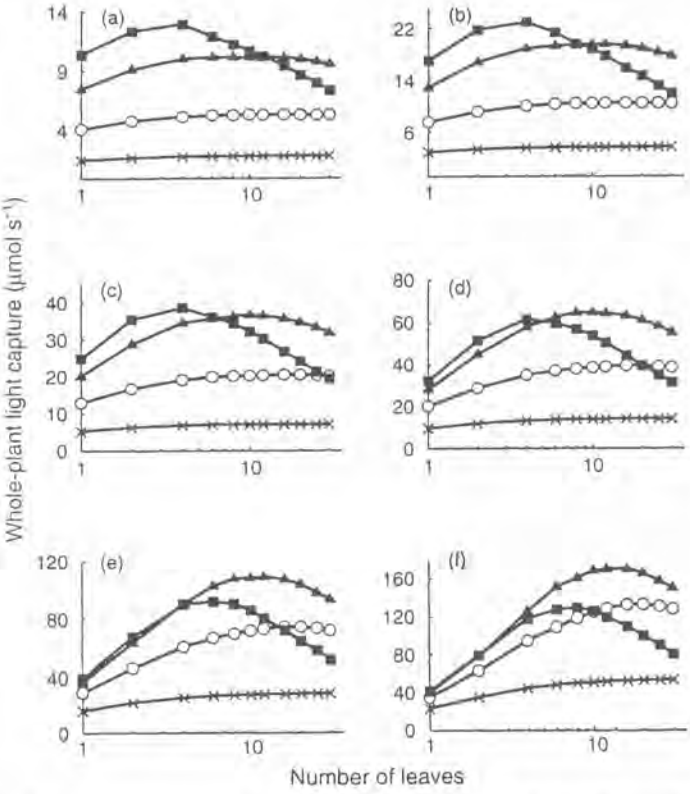

Fig. 7. Relationship between the number of leaves and the whole-plant light capture for plants with total leaf biomasses of 20 (a), 40 (b), 80 (c), 160 (d), 320 (e) and 640 (f) g. R_l was set at 0·1 (×), 0·3 (○), 0·6 (▲) and 0·9 (■).

larger volume. The negative effect of small Z_{max} on the light capture of plants with many leaves cannot be reduced much by adjusting D_P (Fig. 3). When Z_{max} is large, greater variation in the orientations of the leaf laminae becomes unavoidable. We found that a D_P of 50° represents a good compromise for plants with large Z_{max} values. These results support the conclusion that a D_P of around 50°, as measured in *L. arbuscula*, is a good solution for the palms in which Z_{max} changes during growth.

Chazdon (1985) pointed out that angular efficiency (the ratio of a leaf's projected area, as viewed from directly above, to leaf area) decreased with increasing plant size and increasing numbers of leaves in two understorey palm species [*Geonoma cuneata* (H. Wendl) ex Spruce and *Asterogyne martiana* (H. Wendl) H. Wendl]. This occurred because more of the leaf laminae deflected away from the horizontal. However, the magnitude of the reduction in light capture caused by the slanting of the leaf laminae is overestimated when the light is assumed to come exclusively from the zenith. Under such a light regime, a leaf lamina slanted by 60, 75 and 90° receives 50, 26 and 0%, respectively, of the light received by a horizontal one. In the present study, the assumed light regime took light from the entire hemisphere into consideration. Under these conditions, the leaf laminae slanted by 60, 75 and 90° receives 58, 46 and 42%, respectively, of light received by a horizontal one. By assuming the more realistic light regime, we showed that wide variations in petiole orientation contribute strongly to the avoidance of self-shading, especially in plants with many leaves. In a study of the adaptive geometry of plants, care should be taken in modelling the directionality of light source because it may influence the results substantially.

BIOMASS PARTITIONING

Many woody plants develop branching structures when they expand their crown. In these plants, self-shading can be reduced by distributing leaves throughout a large space by allocating biomass to branches (Kohyama 1987; Kohyama & Hotta 1990). *Licuala arbuscula* does not expand its crown by branching. All leaves sprout from the top of a single stem. In this case, increasing only the number of leaves results in severe self-shading. In contrast, increasing leaf size without increasing the number of leaves results in small SLA values because of the need to increase the mechanical stiffness of the laminae. More investment to the petioles required to support large laminae is also disadvantageous to light capture. The present study demonstrates that increasing both the size and number of leaves is a reasonable strategy for maintaining a high light capture efficiency as the single-stemmed palm grows, as Takahashi & Kohyama (1997) hypothesized.

Increasing the number of leaves inevitably intensifies self-shading, but elongation of the petiole can effectively reduce self-shading among the leaves on a vertical non-branching shoot (Takenaka 1994). Takahashi & Kohyama (1997) suggested that *L. arbuscula* reduces self-shading during crown development by investing more biomass in petioles. Our simulation study demonstrated quantitatively the advantage of increasing the investment in petioles as plant size increases. Optimization of petiole length was also reported in another understorey plant, *Adenocaulon bicolor* Hook (Pearcy & Yang 1998). The latter study showed that the petiole length of this species maximizes whole-plant light capture given the trade-off between petiole length and lamina area. The increase in allocation of biomass to the petiole has been reported in other understorey palm species (Chazdon 1986) and in non-branching single-stem trees (Yamada & Suzuki 1996).

In small *L. arbuscula* plants, the observed allocation of biomass to the petiole was considerably larger than the predicted optimum. One possible reason for this is that the palm has adapted to vertical gradients in light availability. More investment in long petioles enables a small palm with a stagnant stem to raise the lamina. If a vertical gradient of light exists near the ground in the natural habitat of this species, positioning leaf lamina higher above the ground is advantageous to light capture. If that is true, there must have been selection pressure in favour of more investment in petioles in *L. arbuscula* in the early stages of development.

Acknowledgements

We thank T. Okuda of Japan's National Institute for Environmental Studies for providing the hemispherical photographs taken in the forest in Malaysia, which we used to determine the spatial distribution of canopy openings in our model.

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Received 29 January 2001; revised 24 May 2001; accepted 24 May 2001

Appendix

In the simulation, the petiole was approximated as a truncated cone. The length and radii of the basal and distal ends of the truncated cone for a given dry biomass (m_p) were calculated as follows.

The volume of a petiole V is given as:

$$V = \frac{m_p}{\rho}, \qquad \text{eqn A1}$$

where ρ is the density of the petiole. Let the ratio of the radius at the distal end to that at the basal end be represented by α. Then, V can be calculated as:

$$V = \frac{\pi L}{3} r^2 B, \qquad \text{eqn A2}$$

where r is the radius of the basal end and B is $(1 + \alpha + \alpha^2)$. Thus,

$$L = \frac{3V}{\pi r^2 B}, \qquad \text{eqn A3}$$

where L is the length of the petiole. Consider the petiole as a horizontal cantilever, with the basal end fixed to the plant's stem. The lamina attached to the petiole acts as a load at the distal end. The case of a horizontal petiole is considered. The bending moment at the basal end of the petiole was divided into two components.

The first, I_l, is that caused by gravity acting on the lamina and the other, I_p, is that caused by gravity acting on the petiole itself. I_l is given by:

$$I_l = Lm_lk_lg, \qquad \text{eqn A4}$$

where m_l is the dry biomass of the lamina, k_l is the ratio of fresh to dry biomass for the lamina, and g is the gravitational constant. The other component, I_p, is given by:

$$\begin{aligned} I_p &= \pi g\rho k_p\int_0^L x\left(r - \frac{r-\alpha r}{L}x\right)^2 dx \qquad \text{eqn A5} \\ &= \frac{\pi g\rho k_g L^2}{12} r^2 C, \end{aligned}$$

where k_p is the fresh mass to dry mass ratio of a petiole, and C is $(1 + 2\alpha + 3\alpha^2)$. The section modulus of the petiole at the base (Y) is a function of r:

$$Y = \frac{\pi}{4}r^3. \qquad \text{eqn A6}$$

The maximum stress at the basal end of the petiole (σ) is calculated as

$$\sigma = \frac{(I_p + I_l)}{Y}. \qquad \text{eqn A7}$$

Thus, for given a value of σ,

$$r^3 = \frac{4(I_p + I_l)}{\pi\sigma}. \qquad \text{eqn A8}$$

Then, r is given as:

$$r = \left(\frac{3k_pm_pg(k_pm_pC + 4Bk_lm_l)}{\pi^2\sigma\rho C^2}\right)^{\frac{1}{3}}. \qquad \text{eqn A9}$$

We determined the values of these parameters from the sampled leaves of *L. arbuscula* as follows: $\alpha = 0{\cdot}66$, $\rho = 1450$ kg m^{-3}, $k_g = 2{\cdot}67$, $k_l = 2{\cdot}08$ and $\sigma = 20{\cdot}8$ MPa. From these parameters and equations A1, A3 and A9, the radii and length of a petiole were determined for a given petiole and lamina biomass.

3. Collaborative study

(2)

Rehabilitation of peatlands and establishment of sustainable agro-systems in Central Kalimantan

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Report of the Agricultural Sciences Group in FY2001

"Rehabilitation of peatlands and establishment of sustainable agro-system in Central Kalimantan"

in relation to

LIPI – JSPS Core University Program:
"Environmental Conservation and Land Use Management of Wetland Ecosystems in Southeast Asia"

Rehabilitation of peatlands and establishment of sustainable agro-system in Central Kalimantan

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Contents

I. Outline of the research activities in FY2001

Rationale and objectives of the research

Nowadays, the peat swamp and wetland in tropical area facing a crisis of disappearance due to human perturbations, which is accelerated by recent abnormal and unusual global climate changes. Since the tropical peatlands have been considered as the key ecosystem for not only reserving bio-resources and biodiversity, but also stocking of carbon in forests and peat, or controlling water resource, it is urgently required to protect this ecosystem from further destructions. In this regard, Agricultural Sciences Research Group under the umbrella of LIPI-JSPS Core University Program, proposes a study on the sustainability of ecological system of bio-production with putting into consideration of the susceptibility that inherent with peatland ecosystems in Central Kalimantan.

There are two main objectives of the research project directed by Agricultural Science Group: (1) to conserve peat forest lands and rehabilitates the destroyed, abandoned, and fire-damaged areas in peatlands; and (2) to establish the sustainable agro-systems including cultivated areas.

Research activities of Agricultural Science Group in FY2001

In order to achieve the main objectives as highlighted above, many scientists both from Japan and Indonesia have been carried out a series of field investigation and research activities in accordance with their specific field under the umbrella of Agricultural Sciences. The followings are detail research activities of each group in FY2001:

1. Soil research group

Soil research group is mostly working with the basic knowledge related to the biogeochemical element cycling in natural forest, regenerating forest, burnt forest, and farmlands. Many issues attributed to the soils in tropical peatlands have been studied in FY2001, such as (1) water quality in precipitation, soil and stream; (2) greenhouse gas emission from soil; (3) nitrogen and carbon cycling; (4) trace element in soil; and (5) acidification in soil.

2. Forestry research group

Research activities of forestry group in FY2001 have been focused in efforts to examine and evaluate the natural process of peat swamp forest after disturbance and the reforestation systems on cleared and intensively disturbed sites. Therefore, the research activities of forestry group can be summarized below:

1) Setting a planting trial using seedlings nursed in UNPAR by Mycorrhizal Group for the selection of suitable tree species to the rehabilitation of intensively disturbed sites in peat swamp forest
2) Checking the survival of planted seedlings
3) Checking the dynamics of seedlings and saplings in fixed plots in Kalampangan
4) Checking the dynamics of seedlings naturally regenerated on the canal bank for the selection of fast-growing tree species tolerant to intensively disturbed sites

3. Agronomy research group

This research group is interested in finding out information on growth and yield performance as well as various stress tolerances of local rice varieties. To this end, a study on local rice productivity under different ecosystems in South Kalimantan has been initiated. An understanding toward the growth yield performance in relation to soil environmental conditions in this area will provide important information for the sustainable rice production in Kalimantan. Therefore, in FY2001 the agronomy group has conducted a yield survey of 60 paddocks in "Gambut" and adjacent "Aluh-aluh" districts to see more closely the yield performance in this region. At the same time, soil properties are being analyzed to examine their relationship with grain yield. This research also consider that N balance in the paddocks is of paramount importance, so that crop growth, N uptake and indigenous N supply were monitored in a paddock that had relatively high yield without fertilizers. Yield, crop and soil analyses are underway.

4. Animal science research group

The main objective of research that carried out by animal science group was to verifying effectiveness and benefit of introducing livestock into reforestation process, and also in agroforestry farming system. Therefore, many aspects related to the vegetation change in fire-damaged area of peat swamp forest with grazing of goats, grazing behavior of goats, and performance of goats in the fire-damaged area have been reported. In FY2001, activities of animal science research group were focused into two main aspects, such as (1) effect of organic fertilization on growth of *Brachiaria humidicola* and *Stylosantes guyanensis* in fire-damaged area of the peat swamp forest, and (2) vegetation collection.

5. Mycorrhizal research group

Mycorrhizal symbiosis plays many important roles in plant growth. Mycorrhizal colonization increases phosphorus uptake and growth of plant. Mycorrhizal colonization also increases tolerances to drought stress and plant disease. However little is known about role of mycorrhizal in plants grown in tropical peat soils. In FY2001, therefore, the activities of mycorrhizal research group were directed to (1) clarify, composition and diversity of fungal species, mycorrhizal colonization of crops, trees and native pasture grown in peat soils, and (2) utilize mycorrhizal symbiosis in sustainable crop production, reforestation and reclamation of devastated areas in tropical peatlands of Central Kalimantan.

5. Micrometeorological research group

The aim of research activity of micrometeorological research group in FY2001 was to estimate the effect of deforestation and drainage on the CO_2 budget of the peatlands through the decomposition of organic matter. As the first step, it has been started a continuous measurement of micrometeorological aspects on a tower constructed in a tropical peat swamp forest located in Central Kalimantan, Indonesia. The vertical profile of short-wave radiation was also measured.

II. Soils survey on tropical peatlands in Central Kalimantan

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Purposes

The main purposes of "The study on the sustainability of ecological system of Bio-Production in Central Kalimantan" by Agricultural Sciences Group under Japan-Indonesia collaborative project are 1) to rehabilitate destroyed damaged peat land by forest fire or deforestation and 2) to establish sustainable agricultural system. In order to support the purposes, soil research group will present the basic knowledge about following items related to biogeochemical element cycling in natural forest, regenerating forest, burnt forest and farmlands:

1) Water quality in precipitation, soil and stream
2) Greenhouse gas emission from soil
3) Nitrogen and carbon cycling
4) Trace element in soil
5) Acidification in soil

Sampling

Soil, water and gas samples were taken at Kalampangan zone including natural forest (S2°20'40", E114°2'15"), regenerating forest after 1997 fire (S2°20'31", E114°2'16") and completely burnt forest by 1997 fire (S2°19'23", E114°1'0") and farmlands in the village from 23 November to 3 December, 2001 and from 18 to 21 March 2002. These periods were in wet season. Previous sampling was conducted in October 2000 in dry season. Ground water depth was measured at all sites.

Concentration and fluxes of greenhouse gasses of CO_2, CH_4 and N_2O, which are produced and consumed in soils, were also measured at all sites.

Cylindrical chamber 30 cm height and 30 cm in diameter was used for the measurement of the gas flux at the soil surface. The air inside the chamber was sampled by syringe at just after covering the soil surface with the chamber and after certain time (6 minutes for CO_2 and 40 minutes for CH_4 and N_2O). The air was sampled in 500mL Toddler bag for CO_2 and 10mL bile bottle for CH_4 and N_2O. The measurement was conducted in triplicate. CO_2 concentration was measured by Infrared CO_2 analyzer within a day. CH_4 and N_2O will be measured in the laboratory using FID gas chromatography and ECD gas chromatography, respectively.

Rainfall water was taken in the March investigation. Ground water was taken in December and March.

Soils

Soils in all sites were Histosols, which are woody well-decomposed peat soils. In natural forest where about 10-30m height trees stood densely and the peat color was the bright brown, rooting depth was 40cm. Water table depth was 1 m in October, 35 cm in December, 23 cm in March. In regenerating forest where a few tall trees remained and trees below 4 m height were densely growing, the rooting depth was 20cm and the peat color was the dark brown and water table depth was 85 cm in October, 33 cm in December and 20 cm in March. In completely burnt forest where ferns grew but no trees, topsoil was composed of almost charcoals, so peat color was black. Rooting depth was less than 10cm and water table depth was 80 cm in October, 54 cm in December and 32 cm in March. And we found a layer with past charcoals at a depth of 75cm in natural forest, 60cm in regenerating forest and 30cm in burnt forest. As accumulating rate of peat is 1 cm per 100 year, the charcoal layers indicate that big forest fire might be occurred from 3000 to 7500 years ago.

Greenhouse gas flux

CO_2 emission (mgC m^{-2} h^{-1}) was significantly low in burnt forest compared to other ecosystems. This is due to lack of root respiration in burnt forest. Burnt forest showed significantly higher CO_2 emission in dry season (October, 83-344) than in wet season (December, 47-123). Regenerating forest had a similar tendency to burnt forest (October, 283-525; December, 156-297), but natural forest had a contrary tendency to burnt and regenerating forest (October, 122-307; December, 291-526). This may be related to the differences of microbial activity and plant root activity among the sites. Probably plant root activity is higher in wet season than in dry season, and microbial activity is contrary tendency. There was no significant difference among CO_2 emission in crop fields in December wet season. The range of the value was 290-358 in grassland, 141-546 in cassava, 165-318 in long-bean, 394-437 in maize. Those values were similar with natural forest.

CH_4 fluxes (μ gC m^{-2} h^{-1}) in all forests showed CH_4 was absorbed by soil and the CH_4 absorption was greater in October dry season (negative value shows CH_4 absorption, -50 to -24 in natural; -93 to -36 in regenerating; -30 to -40 in burnt) than December wet season (-34 to –45 in natural; -36 to –32 in regenerating; -30 to –11 in burnt). On the other hand, CH_4 was emitted from all crop fields in Kalampangan village, especially Cassava fields showed higher emission. The range of the value was –3 to 40 in grassland, -11 to 215 in cassava, -2 to 10 in long-bean, -2 to 9 in maize.

N_2O fluxes (μ gN m^{-2} h^{-1}) in all fields showed N_2O was emitted from all forests and crop fields. However, N_2O emission was significantly higher in crop fields than in forests. Burnt forest showed relatively high N_2O emission of 5.1 to 11.5 in October, although that was small in December which was similar to that in natural and generating forests. Long-bean field showed considerably high N_2O emission of 1614 to 2973 compared to 1301 to 489 in maize field, 69 to 136 in cassava field and 4 to 18 in grassland.

Agricultural activities of farmers

Some characteristics investigated on 7 farmers are presented in Table 1. Population ranged from 2 to 9 person/family. Area of cropland ranged from 0.25 to 2.47 ha/family and area per person ranged from 0.1 to 0.5ha/person. Main crop was maize. However long-bean and many other kind of vegetables were also cultivated. Nitrogen application rate ranged from 4 to 228 kg N/ha, including chemical N fertilizer from 10 to 93 % which increased with increase of application rate. Income ranged from Rp. 6,380,000 to Rp. 46,835,000, which was obtained by sale of crop and animal products. Income from animal products accounted for 0 to 65%, which was higher in farmer with higher income. Richer farmer applied phosphorous and potassium fertilizer and ash made by burning peat.

Table 1. Some characteristic values of agricultural activity in 7 farms investigated

No.	Nane	Address	human	Livestock				
				Cattle	Goat	Horse	Broiler	Duck
			person	head				
1	Lamidi	Bagong Sidomolyo	3			10		
2	Sugiyanto	Desa Kalampangan RW 1	7	5	3			
3	Cipto Wiharjo	Desa Kalampangan RW 5	9	5			50	
4	Ediyanto	Desa Kalampangan RW 5	8		1			
5	Hidayat	Desa Kalampangan RW 4 RT2	4	6				
6	Marzuki	Transbangdep Tumbang Tahai	5	1	10		10	25
7	Kasman	Transbangdep Tumbang Tahai	2				3	

Table 1. (*continued*)

No	Crop land		Annual fertilization application										
			NPK	liming	urea	Manure	TSP	KCl	ash	N	P	K	Ca
	ha	ha/person	kg/ year							kg/ha			
1	0.7	0.2	36	3000	250	1800	0	0	0	228	55	58	1757
2	2.5	0.4	147	1000	347	1925	337	347	0	91	48	96	166
3	1.8	0.2	0	0	183	300	198	344	1200	52	33	128	10
4	2.4	0.3	0	0	60	350	275	265	250	15	28	64	2
5	2.1	0.5	5	0	4	250	2	2	60	4	3	4	0
6	0.5	0.1	0	0	8	1838	25	17	0	81	84	91	0
7	0.3	0.1	25	0	75	1140	25	25	0	248	119	156	0

No	Annual income (Rp)		
	total	Crop	Animal
	Rp		
1	8,910,000	8,910,000	0
2	36,820,000	32,570,000	4,250,000
3	46,835,000	39,272,500	7,562,500
4	12,575,000	4,375,000	8,200,000
5	8,060,000	4,560,000	3,500,000
6	6,600,000	4,275,000	75,000
7	6,380,000	5,180,000	0

Future works

We will carry out the following works in FY2002:

1) Seasonal change in greenhouse emission
2) Water quality in precipitation, soil solution, ground water and stream water
3) Organic matter decomposition
4) Biomass production
5) Availability of micro-nutrients
6) Nutrient budgets
7) Description of agricultural activities

III. Rehabilitation of intensively disturbed sites in peat swamp forest area in Central Kalimantan

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Research outlines in FY2001

1) Setting a planting trial using seedlings nursed in UNPAR by Mycorrhizal Group for the selection of suitable tree species to the rehabilitation of intensively disturbed sites in peat swamp forest
2) Checking the survival of planted seedlings
3) Checking the dynamics of seedlings and saplings in fixed plots in Kalampangan
4) Checking the dynamics of seedlings naturally regenerated on the canal bank for the selection of fast-growing tree species tolerant to intensively disturbed sites

Results achieved in FY2001

A. Setting a planting trial and monitoring the survival of planted seedlings

1) A planting trial of 0.75 ha in area has been carried out in an intensively disturbed site dominated by ferns located near the border between Kalampangan and Kapuas regions in the last November. Planting specification, tree species and mycorrhizas employed for the planting shown in Table 1.
2) The survival rate of seedlings was checked in the last January at 2 months after the planting. Results are summarized as follows:

***Planting trial under cleared-site preparation*:**

i) Survival rate of *Shorea pinanga* seedlings ranged from 6 to 20 % with a mean of 14 %. The difference between survival rates of seedlings with mycorrhizas *Pithoritus* and *Scroderma* was not apparent.

ii) Survival rate of *Shorea seminis* seedlings was larger than that of *S. pinanga* and ranged from 60 to 68 % with a mean of 64 %. The effect of two mycorrhizas *Pithoritus* and *Scroderma* on seedlings' survival was not also apparent for *S. seminis*.

iii) Sungkai (*Peronema canescens*) seedlings nursed for 2 weeks in a nursery at UNPAR showed very high survival rate (64 %) compared to the seedlings nursed for 2 months (15-23 %).

iv) Survival rate of hangkang (*Palaquium* sp.) was about 65-70 %, and *Shorea balangeran* was about 100 %, which is considerably high in this site preparation.

Planting trial under mounded-site preparation

(Seedlings have been planted on an artificially-made small mound of 50-60 cm in diameter and 30 cm in height):

i) Survival rate of *S. pinanga* was 35-55 % and was larger than in cleared-site preparation.

ii) Survival rate of *S. seminis* was 60-65 % and was similar to that in cleared-site preparation.

iii) No mortality occurred for sungkai (*Peronema canescens*) nursed for 2 weeks, although survival rate of *P. canescens* nursed for 2 months was 30 %.

iv) *Palaquium* sp. and *S. balangeran* showed considerably large survival rates again in this site preparation.

Planting trial on the site without preparation:

i) Survival rate of *S. pinanga* was 34-38 % and was similar to that in mounded-site preparation.

ii) Survival rate of *S. seminis* was 48-62 %. It was larger than that of *S. pinanga* and was similar to mounded-site preparation.

iii) Survival rate of sungkai seedlings was apparently smaller than those in cleared- and mounded-site preparations. This is because of the characteristic of sungkai as a fast growing species.

iv) Hangkang and *S. balangeran* showed considerably large survival rates again in this site preparation.

Conclusions and suggestions on the initial survival of seedlings:

1) Hangkang and *S. balangeran* can survive in planting on a disturbed site at a considerably high probability irrespective of site-preparation

methods. Probably they are suitable to the planting and rehabilitation of intensively disturbed peat swamp forest by repetitive wild fires and burnings. They also need not to be inoculated with mycorrhizal fungi before their planting on the site.

2) Survival rate of *S. seminis* was also large and seemed not to be affected by site-preparation methods. This species is expected to be suitable to the planting and rehabilitation of disturbed peat swamp site. However, we should remind that this species is not representative to Central Kalimantan.

3) Sungkai is considered to be available to the planting and rehabilitation, but it is recommended that the nursing period of the seedlings is limited less than a few weeks. This species need a clearing (weeding) before the planting. We need to try the direct planting of sungkai cuttings.

4) Survival rate of *S. pinanga* was less than the other species and increased slightly in mounded-site and in the site without preparation. *S. pinanga* may not suitable to the rehabilitation of disturbed sites.

5) The difference in effect of mycorrhizas *Pithoritus* and *Scroderma* on seedling survival was not apparent.

B. Dynamics of seedlings and saplings in fixed plots in Kalampangan

Two fixed plots have been set up in 2000 in Kalampangan region to examine the recovery process of tree stand after an intensive disturbance by wildfire. One plot is located in a non-disturbed stand (ND plot: 100 m^2), and the other is in a disturbed stand by a wildfire in 1997/1998 (WF plot: 50 m^2). In WF plot, tree seedlings occurred naturally from 1999. We are examining the recovery process of a disturbed stand (cf. species composition, growth and mortality of regenerated seedlings, etc.) comparing with the dynamics of seedlings and saplings in a non-disturbed stand. All saplings (2 m<height and DBH<10 cm) were tagged, and all seedlings (height<2 m) were checked for species and height in 4 m^2-sub plot in 2000. In ND plot, we made the same measurement to 2000 in November 2001. But in WF plot, we re-measured a part of sample trees because of the attack of poisonous ants.

1) ND plot

In 2000, 158 saplings occurred in the plot (15800 saplings·ha^{-1}). Thirteen saplings (1300 saplings·ha^{-1}) died until the re-measurement in 2001. Mortality rate was 0.086·$year^{-1}$ (8.2 %). Seven *Calophyllum* saplings died in this period. Mean relative growth rate of DBH (RDGR) was 0.054 (±0.068 SD). The number of seedlings decreased from 49 (12.3 seedlings·m^{-2}) to 35 (8.8 seedlings·m^{-2}). Species composition of seedlings in 2001 was similar to that in 2000.

Table 1. Survival rate of seedlings at 2 months after plantings

Line	Tree species	Mycorrhizae	Treatment	Number of seedlings	Survival rate (%)
1	*Shorea pinanga*	*Pithoritus*	Cleared	50	20
2	*Shorea pinanga*	*Pithoritus*	Cleared & Fertilized	50	6
3	*Shorea pinanga*	*Scroderma*	Cleared	50	18
4	*Shorea pinanga*	*Scroderma*	Cleared & Fertilized	50	12
5	*Shorea seminis*	*Pithoritus*	Cleared	50	68
6	*Shorea seminis*	*Pithoritus*	Cleared & Fertilized	50	60
7	*Shorea seminis*	*Scroderma*	Cleared	50	62
8	*Shorea seminis*	*Scroderma*	Cleared & Fertilized	50	64
9	*Peronema canescens*	2 weeks	Cleared	50	64
10	*Peronema canescens*	2 weeks	Cleared & Fertilized	50	64
11	*Peronema canescens*	2 months	Cleared	40	15
12	*Peronema canescens*	2 months	Cleared & Fertilized	40	23
13	*Palaquium* sp.		Cleared	20	70
	Shorea balangeran			20	100
14	*Palaquium* sp.		Cleared & Fertilized	20	65
	Shorea balangeran			20	100
15	*Shorea pinanga*	*Pithoritus*	Mounded	20	35
	Shorea pinanga	*Scroderma*		20	55
16	*Shorea seminis*	*Pithoritus*	Mounded	20	65
	Shorea seminis	*Scroderma*		20	60
17	*Peronema canescens*	2 weeks	Mounded	10	100
	Peronema canescens	2 months		20	30
18	*Palaquium* sp.		Mounded	20	90
	Shorea balangeran			20	100
19	*Shorea pinanga*	*Pithoritus*	None	50	34
20	*Shorea pinanga*	*Scroderma*	None	50	38
21	*Shorea seminis*	*Pithoritus*	None	50	48
22	*Shorea seminis*	*Scroderma*	None	50	62
23	*Peronema canescens*	2 weeks	None	50	48
24	*Peronema canescens*	2 months	None	50	6
25	*Palaquium* sp.		None	20	95
	Shorea balangeran			10	100

* Spacing between seedlings: 2 m, between rows: 3 m

* Planting area: 0.75 ha

* Location: On the border between Palangka Raya and Kapuas, 500 m from a paved road.

* Extra: 20 seedlings planted under the canopy of natural trees

2) WF plot

Density of saplings in the WF plot decreased 39400 saplings$\cdot$ha^{-1} to 37500 saplings$\cdot$ha^{-1}, and mortality was 0.049$\cdot$year^{-1} (4.8 %). Sapling density in the WF plot was larger than that in the ND plot, and mortality in the WF plot was smaller than that in the ND plot. Mean relative growth rate of DBH (RDGR) was 1.223 (±0.202 SD). This was considerably larger than that in the ND plot, suggesting that saplings in the WF plot grew vigorously. This RDGR (1.223) means that diameter increased by 3.4 times. As reported in the last year, species composition in the WF plot altered by a wild fire comparing with that in the ND plot, however, individual growth and stand recovery are very fast.

C. Dynamics of seedlings naturally regenerated on the canal bank

To select fast-growing tree species tolerant to intensively disturbed sites, we have set up a fixed plot (500 m^2 in area) on the canal bank in Kalampangan region in 2000. In general, a preceding planting by fast-growing species is favorable for the planting of shade-tolerant and slow-growing tree species. Then, we need to explore tree species suitable to the preceding planting for the rehabilitation of peat swamp forest. We identified and measured all seedlings and saplings for height in 2000 and 2001.

Survival and new regeneration

Table 2 shows the number of seedlings and saplings by species. Most of them survived in 2001 after one rainy and one dry seasons. Abundantly-occurring species are asam-asam (*Mangifera* sp.), garunggang (*Cratoxylum arborescens*) and tumih (*Combretocarpus rotundatus*). Seedlings newly regenerated were abundant in asam-asam and garunggang. No new seedling of the other species regenerated in the investigating period.

Height growth

Figure-1 shows the relationship between initial height and height increment. Height increment of seedlings and saplings ranged from 0.3 to 3.6 $m \cdot year^{-1}$. Height increment of all asam-asam and many garunggang saplings was more than 1 $m \cdot year^{-1}$, and these two species are fast-growing.

Soil moisture and temperature on a canal bank and under a closed forest canopy

Soil moisture and temperature are shown in Table 3 comparing with those under a closed forest canopy. The soil temperature at 5 cm depth of a canal bank measured in October was 34.0±1.0℃, while that under a closed canopy was 30.1±0.8℃. The volumetric water content in the canal soil was 27.0±13.5 %, while that under the closed canopy was 47.4±8.1 %. Therefore, soil condition on the canal bank is drier than that under the closed canopy. However, seedlings and saplings of asam-asam and garunggang, including tumih, survived and grew very fast. It is considered that these three species are tolerant to the dry soil condition and fast-growing species, and are recognized to be suitable as preceding planting species.

Table 2. Dynamics of seedlings and saplings on a canal bank

Latin Name	Vernacular Name	Number			
		Oct. 2000	Nov. 2001	Dead	Regenerated
Combretocarpus rotundatus	Tumih	19	16	3	0
Cratoxylon arborescens	Garunggang	15	21	2	8
Eugenia sp.	Ehang	1	1	0	0
Eugenia sp.	Katakau	1	1	0	0
Eugenia subdecussata	Milas	2	1	1	0
Garcinia sp.	Manggis kalawet	1	1	0	0
Lophopetalum beccarianum	Kayu kapas	1	1	0	0
Mangifera sp.	Asam-asam	25	38	1	14
Mezzetia leptopoda	Karipak/kambalitan	1	1	0	0
	Pisang-pisang				
Xylopia/Sterculia (?)	Banitan	1	0	1	0

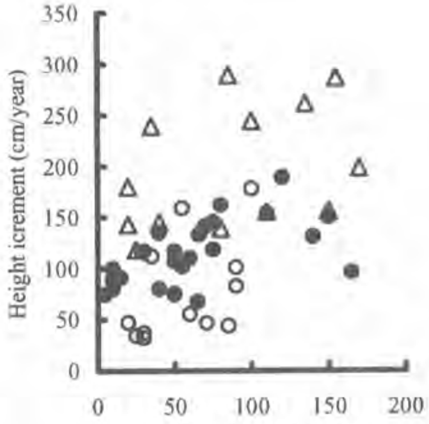

Fig. 1 Relationship between tree height and height increment. Solid and open circles and triangle stand for assam-assam, tumih and garunggang, respectively.

Table 3. Soil moisture and temperature on a canal bank and under a closed forest canopy

	Bank	Understory
Soil moisture (%)	27.0 ± 13.5	47.4 ± 8.1
Soil temperature (°C)	34.0 ± 1.0	30.1 ± 0.8

Values: average±S.D. (n=6).
The measurements were carried out at 14:00 on 6 October 2000.
Soil moisture was presented by volumetric water content measured by FDR sensor.

IV. Establishment of sustainable agro-ecosystems in Kalimantan: *Local rice production system in South Kalimantan*

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South Kalimantan is the largest rice producer in Kalimantan (ca 1.4 million ton), and serves as an important food base of Kalimantan. Sustainable rice production in the marginal areas of peat swamps such as South Kalimantan will be important to alleviate the human pressure on the vulnerable peat swamp areas in Central Kalimantan.

Improved varieties with high yield potentials have been introduced to South Kalimantan, but with a limited success because they can only be planted in the inland area with a good irrigation and drainage system (about 10 % of the total rice production area), and their eating quality was inferior to local varieties. For the other rice ecosystems that cover a large portion of rice production in South Kalimantan, local varieties are of prime importance.

Local varieties are mostly grown with the traditional multiple transplanting practice. Seeds are sown on the upland nurseries in October-November. The seedlings are raised for ca 30-40 d, after which they are transplanted on the lowland nursery with a dense spacing (one hill had more than 50 seedlings). Approximately 40 d later, the seedlings are transplanted again on a larger lowland nursery and raised for ca 60-70 d. Then they are planted on the main paddies with much less dense spacing. Harvesting generally occurs in September.

Information on growth and yield performance as well as various stress tolerances of local is quite limited. Therefore, we initiated a study on local rice productivity under different ecosystems in South Kalimantan. In our previous yield survey of eight paddy fields in three different locations, we found a yield range (un-husked grain) of 181-371 g/m^2. In two of the three locations, application of urea was a common practice, while in one area (Gambut District), almost no fertilizers were applied. Interestingly, however, the location with no urea or super-phosphate application yielded almost as high grain yield as the area with irrigation and fertilizers, but the reasons for this are not clear. Understanding the growth yield performance in relation to soil environmental conditions in this area will provide important information for the sustainable rice production in Kalimantan. We therefore conducted a yield survey of 60 paddocks in Gambut and adjacent Aluh-aluh districts (Fig. 1) to see more closely the yield performance in this region. At the same time, soil properties are being analyzed to examine their relationship with grain yield. We also consider that N balance in the paddocks is of prime importance, so that crop growth, N uptake and indigenous N supply were monitored in a paddock that had relatively high yield without fertilizers. Yield, crop and soil analyses are underway and here we present some of the results obtained in 2001.

The studied area is basically the basin of Aluh-aluh River, a tributary river of Barito (Fig. 1). Paddy fields here in general have acid sulfate soil with the pyrite in the subsoil. The area is generally flat but the closer to the Barito, the longer period the water stays in paddocks. Year 2001 was drier than usual (Fig. 2) so that standing water withdrew in the end of June to July in sites 2-5, but some paddocks still had deep standing water in site 1 (Fig. 3, for example). In all the paddocks studied, traditional multiple transplanting was practiced. At the time of final transplanting, which generally occurs from the end of May to the end of April, seedlings were quite tall (ca 40-50 cm) compared to those in a general single transplanting practice.

Total of 60 paddocks located in two districts (Gambut and Aluh-aluh) were selected for yield survey (Fig. 1). In each paddock, 15 hills (3 rows * 3 hills , equivalent to 1-1.5 m^2) were harvested from three spots in each paddy, after which the area for the 15 hills was recorded. After weighing total shoot mass (fresh and dry) and counting number of panicles, spikelets were threshed to measured rough paddy dry weights. A sub-sample of 40g was used to determine the number of total and filled spikelets, and the weight of filled spikelets. Filled spikelets were selected with water.

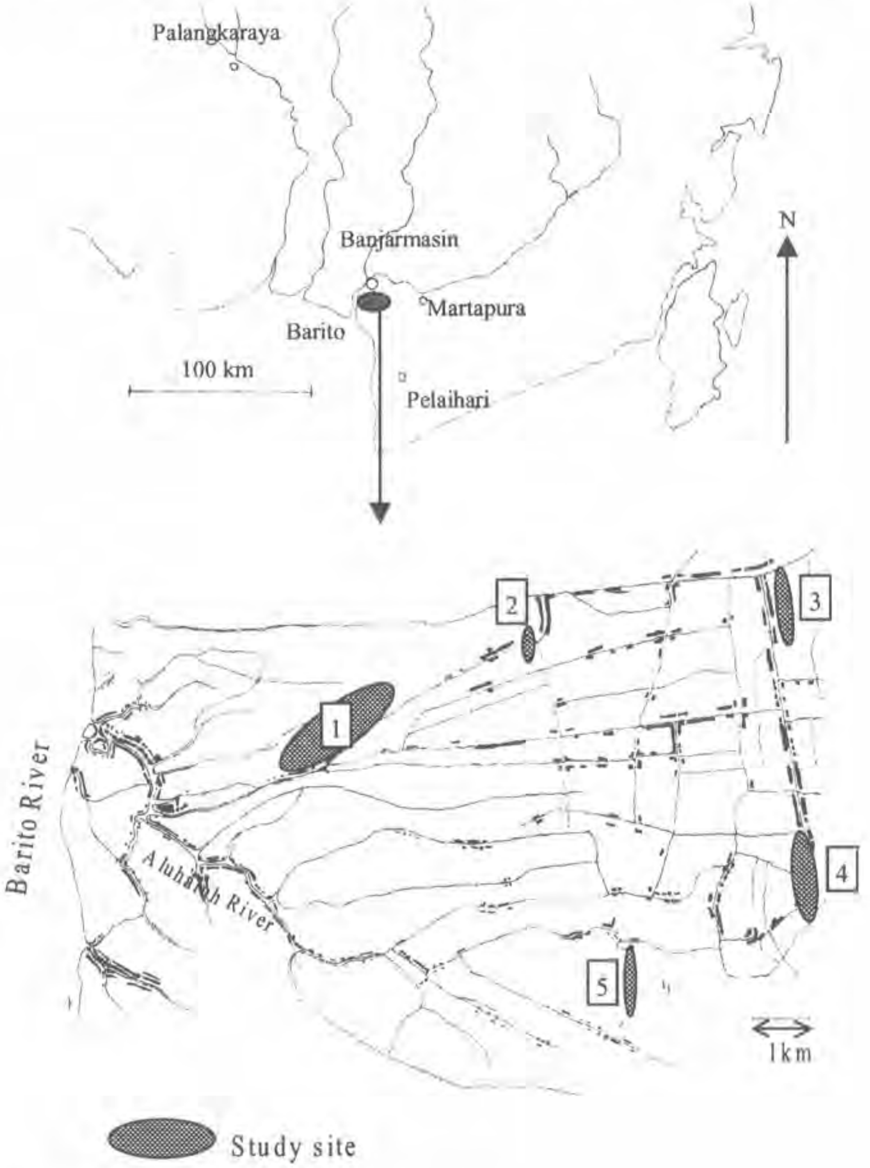

Figure 1. Study site in South Kalimantan.

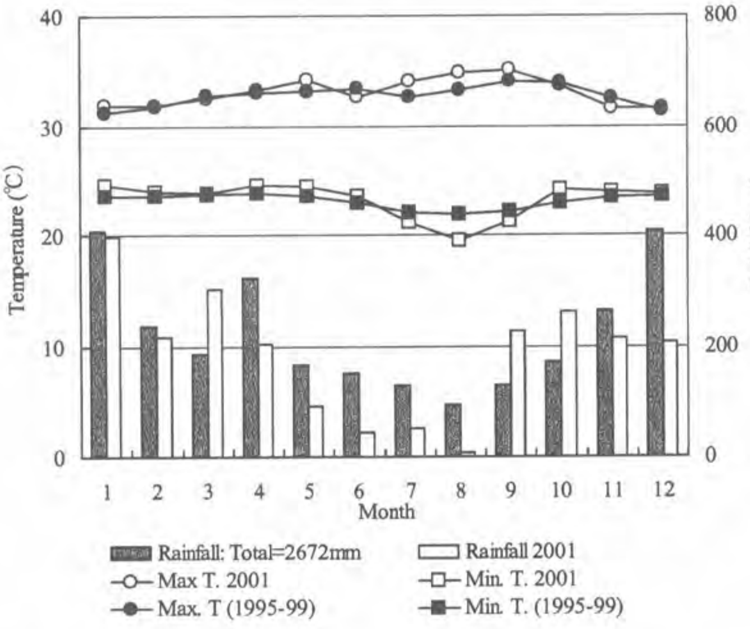

Figure 2. Temperature and rainfall measured at the Weather Bureau in Banjarbaru.

At least 11 local varieties were grown in the studied area. According to Dr. Suhaimi Sulaiman, a rice breeder at the Research Institute for Agriculture in Swampy Areas, there are more than 100 local varieties in South Kalimantan, but lines derived from 'Siam ' are dominant. In early 1980's, there were only three Siam varieties in this region, but currently more than 10. In the surveyed area, Siam Pandak, Siam Unus, Siam Suruk and Siam Abu were recognized and shared a large portion.

Figure 3. Dr. Erry Purnomo of UNLAM walking in the deep and muddy paddock in Site 1 (left) and a good yielding crop of Haji Mahalan without fertilizers at site 3 (right).

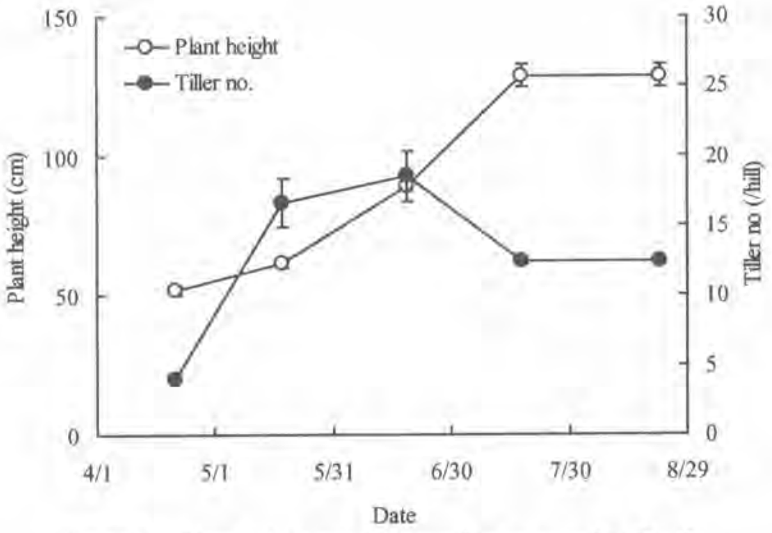

Figure 4. Plant height and tiller number measured at Site 2.

Most of paddocks received no fertilizers or a very limited amount. According to Mustakim, an extension officer at site 1 (Bunipah), total amount of urea applied to all the paddocks (402 ha) here amounts to only 7 t (averages 7 kg N/ha). Among 11 farmers we interviewed this year, only one farmer applied lime (150 kg/ha, site 4). Interestingly, this farmer also applied salt of 150 kg/ha at around panicle initiation stage. He believes that salt amendment makes soil softer.

Plant spacing was sparse and almost equidistant between rows and hills (25-30 cm). A large variation in the final plant height was observed between paddocks ranging from 60 to 180 cm, reflecting the difference in growth. We have just finished yield determination for about 30 paddocks but a substantial variation in grain yield was observed with the highest being slightly over 4 t/ha and the lowest below 1 t/ha.

Growth pattern was monitored in site 2. Tiller number increased from right after transplanting (mid April) and peaked about a month after transplanting (Fig. 4). Flowering occurred in early-mid July, so that the time between the maximum tiller number and panicle initiation (so-called "lag-phase") was quite long. In addition, about 30 % of the tillers did not bear panicles. This confirms the yield limitation associated with the sink size observed last year.

Currently, we are analyzing the relation between grain yield variation and edaphic conditions. N budget of the paddock at site 2 will be evaluated with the crop N and soil N (both total N and mineralized N). In the next experiment, we need to determine the genotypic difference of growth and yield in response to different soil conditions. Two other areas (Handil Manarap and Belandean) in addition to the study sites this year have been selected for the trial. In addition, twenty-one germ-plasms were collected for future experiments (see Table 1).

Table 1. Rice germplasms collected from South Kalimantan.

No.	Genotypes		Location
1	Martapura	Improved x Local	Bred by RIASA*
2	Margasari	Improved x Local	Bred by RIASA*
3	Arjuna	Local	Manarap Peat Potensial
4	Gumpal	Local	Manarap Peat Potensial
5	PX	Local	Manarap Peat Potensial
6	Babirik	Local	Manarap Peat Potensial
7	Karta	Local	Manarap Peat Potensial
8	Perak	Local	Manarap Peat Potensial
9	Unus	Local	Danda Jaya Sulfat Acid
10	Unus Kunung	Local	Danda Jaya Sulfat Acid
11	Ketutut	Local	Danda Jaya Sulfat Acid
12	Pandak	Local	Danda Jaya Sulfat Acid
13	Lantik Putih	Local	Danda Jaya Sulfat Acid
14	Lantik Merah	Local	Danda Jaya Sulfat Acid
15	Karang Dukuh	Local	Danda Jaya Sulfat Acid
16	Teladan	Local	Danda Jaya Sulfat Acid
17	Siam Pandak	Local	Danda Jaya Sulfat Acid
18	Klubut	Local	Danda Jaya Sulfat Acid
19	Pontianak	Local	Danda Jaya Sulfat Acid
20	Pontianak Tingg	Local	Danda Jaya Sulfat Acid
21	Adus	Local	Danda Jaya Sulfat Acid

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V. Rehabilitation of destroyed peat swamp forest using livestock

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Research outlines in FY2001

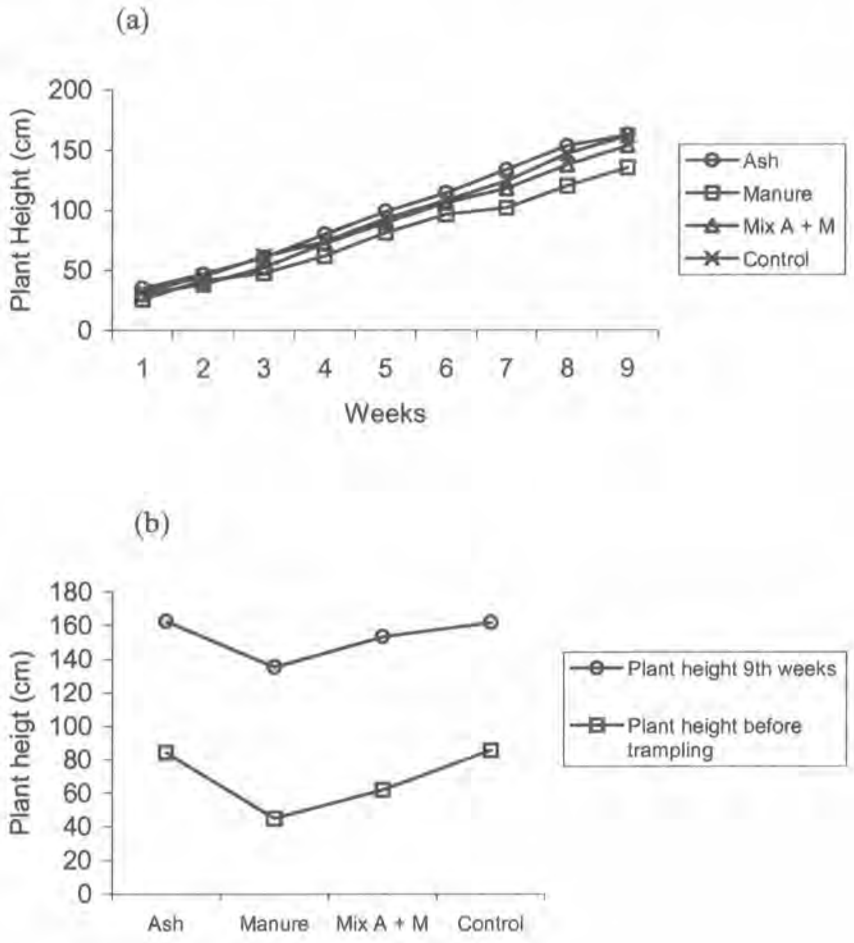
Introducing livestock into zero cultivation technology on peatland can initiate a sustainable agriculture practice. The combine effects of animal manure and urine depositions are more appropriate if used as soil improvers. However, the impact of grazing animal on peatland area has not been evaluated. This study, therefore, were aimed to verifying effectiveness and benefit of introducing livestock into reforestation process and agroforestry farming system. Many aspects related to the vegetation change in fire-damaged area of peat swamp forest with grazing of goats, grazing behavior of goats, and performance of goats in the fire-damaged area have been reported. This current report, hence, dealing with two main aspects such as effect of organic fertilization on growth of *Brachiaria humidicola* and *Stylosantes guyanensis* in fire-damaged area of the peat swamp forest, and vegetation collection.

Results achieved in FY2001

1. Effect of organic fertilization on growth of *Brachiaria humidicola* and *Stylosanthes guyanensis* in fired swamp forest

Organic fertilizer is common way for local people to enhance the productivity of agriculture products in fire-damaged area of peat swamp forest as observed in Central Kalimatan, especially using ash and manure. The easy way and more popular for people to produce ash is through collecting and burning organic matters associated in the surface of the peat soil. This practical method may increasing pH value of the soil and the crop plants can grow well. Another way that applied by local people to increase crop productivity is mixing the soil with manure compos, but the manure source is limited. The first method (peat burning) will threat the sustainable agriculture system in the long term and may lead to the exposure of pyrite layer.

Information on growth and yield performance of introducing forages is quite limited. Therefore, we initiate a study on productivity of exotic forages that adapted in acidic soil. The study was conducted in a field adjacent the Livestock Base Camp at Kalampangan village. Two forage species, namely *Brachiaria humidicola* (Koronivia grass) and *Stylosanthes guyanensis* (Stylo legume) were selected and planted. Both of them are planted by vegetative form i.e. poles for grass and stem for legume. The experiment was designed following a randomized complete with 4 fertilizer treatments and 3 replicates. Total number of plots used for each selected plant are 12 plots. Size of the plot is 2.5 x 1.5 m, were set up in October 2001. The fertilizer treatments were control, without any fertilizer, organic ash, manure and combination of organic ash and manure fertilizer. Before planted the experimental site treated with a row application of 5 ton ha^{-1} for fertilizer treatment. One month after planting, the trampling treatment is applied to allow more homogeneous response. Plant height and biomass are measured and recorded.



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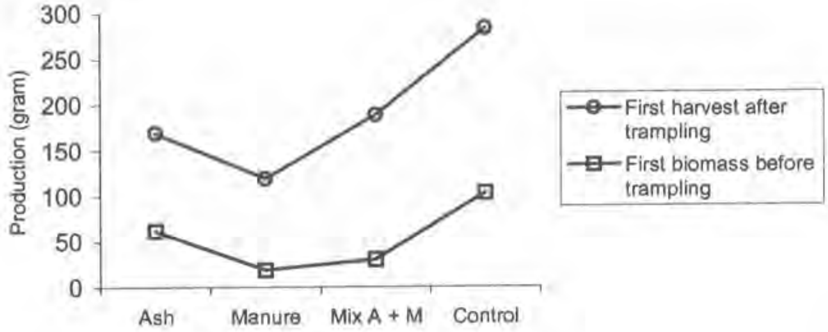

Figure 1. Cumulative growth of Koronivia grass during the establishment phase (a) plant height at 9th weeks and (b) before trampling and (c) yield production

The cumulative increase in height of representative all treatment is shown in Figure 1. Ash fertility attained the greatest height (167,4 cm) in the establishment period (Figure 1a). The slowest growing was treatment with manure fertilizer which is only reaching a height of 153,2 cm before harvesting. Interestingly, the control treatment showing a good result in height response almost as high as the ash fertilizer. The yield of control was higher than mixed ash and manure, ash and manure treatments. More than 50 persen hight compared to manure fertilizer combining of ash and manure had similar yields with ash treatment.

The results have shown that Koronivia grass grows more rapidly without any fertilizer. Burning organic peat soil to produce ash more available for grass growth showing better result compared to manure fertilizer, perhaps due to the decomposition rate manure seems more longer. The fact that the Koronivia grass growing well in acidic soil is probably owing to the interaction of microorganisms such as bacteria, fungus or others.

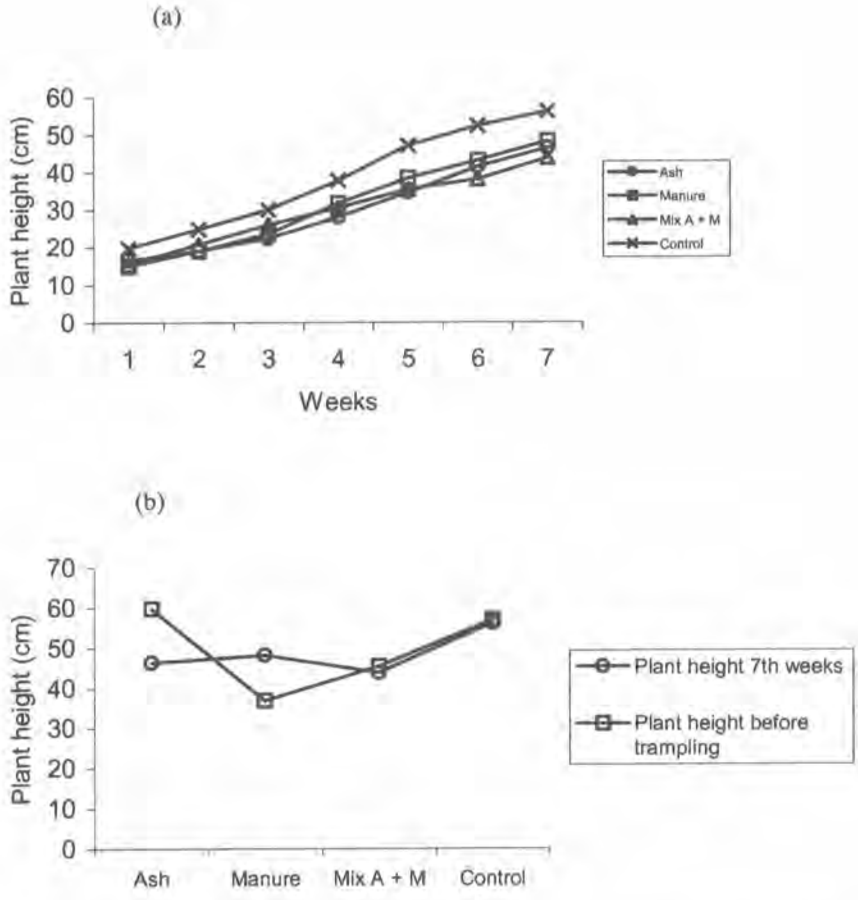

Figure 2. Growth response of *Stylosantes guyanensis* (a) and (b)

Apparently that the growth response of Stylo legume demonstrates a same tendency under various treatments as shown in Figure 2. Until 7th weeks observation, control treatment had the highest response in plant height. It is argued that the growth of Koronivia grass may strongly affected by the mutualistic interaction in rooting rhizosphere.

2. Vegetation Collection

Fixed plots for the purpose of vegetation collection were set up in Mei 2001 located adjacent the Livestock Base Camp. There were 15 species of forages introduced in the plots. Of these, 12 species collected from local resources, and the rest were imported from Bogor Agricultural University. Basically, local forages are edible plants and the forages are widely adapted in acidic soil and have sufficient nutrients for animal feeding. The edible local forages are (1) Sasendok small leaf, (2) Sasendok large leaf, (3) Delingu, (4) Lombokan, (5) Kalakai, (6) Pakis, (7) Pakis Burung, (8) Aseman, (9) Bakauan, (10) Krupukan, (11) Pahitan grass, (12) Jambuan, whereas the introducing species are (1) *Brachiaria humidicola* grass, (2) *Stylosanthes guyanensis*, and *Arachis pintoi*. All these forages were planted by vegetative form (stem , poles and natural nursery) except *Stylosanthes* which generated from seed.

The objectives of vegetation collection plots were to determine and evaluate the forages by simple method such as plant height, biomass production measurement and fertilizer application treatment. Table 1 is an example of evaluation on Delingu grass that harvested on December 21, 2001:

Table 1. Plant height and production biomass of Delingu grass

Number of plants	Plant height (cm)	Production biomass (gram)
1	61.0	150
2	58.0	90
3	54.0	60
4	57.0	60
5	56.0	90
6	55.0	70
7	53.5	80
8	48.0	80
9	62.0	85
10	56.0	130
11	54.5	55
12	57.5	105
13	49.0	100
14	50.0	60
15	49.0	80
16	47.0	95
17	51.0	130
18	47.0	70
19	47.0	90
20	52.0	70
21	55.0	100
22	56.0	115
23	45.0	70
24	48.0	110
25	57.0	110
26	55.0	130
27	48.0	70
28	50.0	90
Average	**52.81**	**90.9**

VI. Field survey on mycorrhiza in several plant species grown in peat soils of Central Kalimantan

Mycorrhizal Research Group:

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1. Introduction

Soil nutrient stress is one of growth limiting factors for plants grown in tropical peat soils. Some plant species can survive in such soils with their specific mechanisms of nutrient acquisition. One of these mechanisms is mycorrhizal symbiosis. Mycorrhizal symbiosis plays many important roles in plant growth. Mycorrhizal colonization increases phosphorus uptake and growth of plant. Mycorrhizal colonization also increases tolerances to drought stress and plant disease. However little is known about role of mycorrhizal in plants grown in tropical peat soils.

Purposes of our group are 1) to clarify, composition and diversity of fungal species, mycorrhizal colonization of crops, trees and native pasture grown in peat soils and 2) to utilize mycorrhizal symbiosis in sustainable crop production, reforestation and reclamation of devastated areas in peat lands of Central Kalimantan.

2. Activities during the Survey

2.1. Effect of ectomycorrhizal fungi on growth of *Shorea pinanga*

Seedlings of *Shorea pinanga* were inoculated with ectomycorrhizal fungus *Pisolithus* or *Scleroderma* as tablet or arginate (Table 1). Inoculated seedlings formed ectomycorrhiza with both species. Ectomycorrhizal colonization increased shoot height, stem diameter and number of leaves. Shoot fresh weight and dry weight of seedlings were increased with mycorrhizal colonization.

Table 1. Shoot growth and ectomycorrhizal colonization of *Shorea pinanga*

Treatments	Height (cm/plant)	Diameter (mm)	Leaf number (per plant)	Fresh Weight (g/plant)	Dry Weight (g/plant)	Colonization (%)
Control	42	5	9	14	4.36	30
Pisolithus (Tablet)	78	8	23	39	13.01	86
Scleroderma (Tablet)	72	8	14	34	10.98	86
Pisolithus (Arginate)	71	8	13	31	9.91	81
Scleroderma (Arginate)	71	8	11	33	11.17	86

2.2. Establishment of field experiment of ectomycorrhiza

Seedlings of *Shorea pinanga* and *Shorea seminis* inoculated with ectomycorrhizal fungi were transplanted to field site of UNPAR campus in order to monitor long-term effect of ectomycorrhizal on growth of *Shorea* seedlings. Five treatments were applied for each species; *Pisolithus* (tablet), *Sclerderma* (tablet), *Pisolithus* (arginate), *Scleroderma* (arginate) and non-inoculated control.

2.3. Inoculation of ectomycorrhizal fungi and arbuscular mycorrhizal fungi to tree species

Shorea selanica seeds were sowed with some kinds of mycorrhizal inoculants. The setting conditions and pot numbers were as follows:

1) VAM (Osaka gus) : 2,597 pots
2) ECM (ECTOFOREST, *Sclerederma* sp.) : 1,755 pots
3) VAM+ECM : 2,135 pots
4) Spore suspension (*Scleroderma* sp. colleted in Finland project area): 100 pots
5) Root tip (Acasia root infected by *Scleroderma* sp.) : 51 pots
6) Control : 923 pots

Three kinds of vegetables were sowed with arbuscular mycorrhizal inoculums as described below:

1) Onion : 30 pots (with 30 controls)
2) Chili : 30 pots (with 30 controls)
3) Tomato : 30 pots (with 30 controls)

2.4. Ectomycorrhizal fungi in plants grown in disturbed peat soil

Acacia is a large genus with over 1300 species, which is widely distributed in the tropics and subtropics. In special, wood chips of plantation-grown *Acacia mangium* are exported to Japan from south-east Asia. In general, it is well-known that the plants of Leguminosae including *Acacia* spp. has symbiotic association with *Rhizobium* in nature. On the other hand, it has been reported that several their plants including *Acacia* spp. are symbiont with *Rhizobium* as well as other fungi such as ectomycorrhizae or VA mycorrhizae. In this study, the symbiotic association of *A. mangium* with an ectomycorrhizal fungus, *Scleroderma* sp. on peat soil in Kalimantan was identified.

Identification of *Scleroderma* sp. At first, the fruit-bodies of *Scleroderma* sp. near or on the butt of *A. mangium* seedling on peat soil were fund in Kalimantan. This fungus is identified with *S. citrinum*. The description of fruit-body of *S. ctrinum* is as follow.

***Scleroderma citrinum* Pers. (Figure 1).** Fruiting body tuberous, spherical, almost stalkless with a constricted base, sometimes rather sunken in the ground, 5-30 mm diameter, peridium simple, with many coarse scales, leathery, tough. When mature the peridium ruptures irregularly at the apex and releases the spores. Stalk only rudimentary with branched, whitish mycelial strands. Occasionally solitary but usually gregarious. Spores globose, irregularly costate-spinose, usually with incomplete and irregular reticulate ornamentation (in KOH), brown, 7.5-15 μm(excluding costae), costae up to 2.5 μm high. Basidia clavate.

Scleroderma citrinum is vary popular species on acid, nutrient-poor, sandy or peaty soil in forest, at forest edges, as well as in grassland under shrubs and trees, almost among mosses. In this study, we had been observed the formation of fruit-body on the butt of *A. mangium* seedling and the whitish mycorrhizal root in peaty soil (Fig.?). It seems that *S. citrinum* together with rhizobium play an important role in the growth and survival of *A. mangium* in peaty soil. Moreover, it is reported that the fungi of *Scleroderma* spp. are very important symbiont with other trees as *Diptrocarpus* spp. and *Shorea* spp. Also, it is considered that the treatment of artificial inoculation using *S. citrinum* to seedling at nursery is needed.

Observation of mycorrhizal occurrence. Five seedling of *A. mangium* grown on peat soil were collected. Size of seedlings as height and butt diameter show in Table 2. The observations of root for the identification of mycorrhizae are conducted (Table 3).

Table 2. Profiles of *A. mangium* seedlings

No. of specimens	Height (cm)	Diameter (mm)
1	30	5
2	81	8
3	27	4
4	40	6
5	18	2

Six types of ectomycorrhizae including *S. citrinum* were identified by morphological characteristics of shapes under microscope in this study. Four specimen of five showed symbiont with *S. citrinum*. As the result, it is considered that *S. citrinum* is very important fungi to growth and survival of *A. mangium* at peat soil in Kalimantan. Also, 5 types of ectomycorrhizae excluded *S. citrinum* showed from *A. mangium*. Although, this tree species has mainly symbiotic association with Rhizobium, it is identified that other mycorrhizal fungi associated with them on growth and survival in nature.

Table 3. Ectomycorrhizal types from *A. mangium* root in peat soil

No. of specimen	Type of ECM*	Color and shape	Species
1	1-1	Yellow to reddish yellow, monopodial branch	**S. citrinum**
	1-2	Light red, monopodial branch	Unknown
2	2-1	Light red, monopodial branch	Similar to 1-2
	2-2	Pink, non-branch	Unknown
	2-3	Pink, monopodial branch	Unknown
3	3-1	Light red, monopodial branch	*S. citrinum*
	3-2	Light red, monopodial branch	Unknown
4	4-1	Light red, monopodial branch	Unknown
	4-2	White, monopodial branch	*S. citrinum*
5	5-1	White, monopodial branch	*S. citrinum*

*ECM; Ectomycorrhizae

Experiments of inoculation in nursery. The spore suspension of *S. citrinum* was inoculated with *Shorea selanica* seeds in 100 plastic pots in nursery. At the same time, peat soil in developed places of *S. citrinum* and roots debris of *A. mangium* in peat soil used in inoculum into 6 and 51 plastic pots, respectively. The results of these will be reported in 2002.

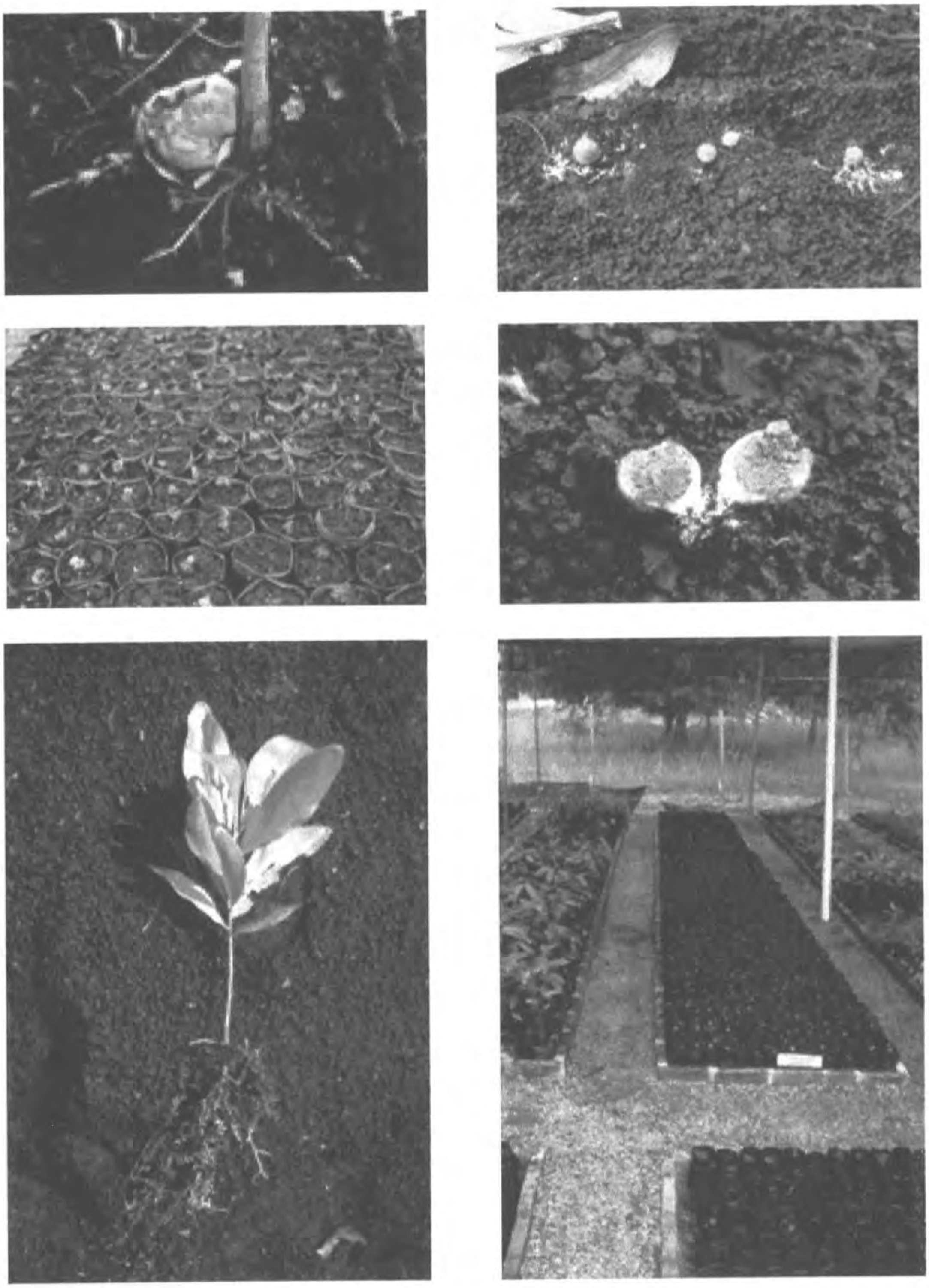

Figure 1. (Top left to down): fruit body of *S. citrinum* on butt of *A. mangium*, pot experiment of *Shorea selanica* seed with mycorrhizal inoculum, ECM formation on root of *A. mangium*. (Top right to down): fruit bodies of *S. citrinum* on peat soil, part of *S. citrinum*, scene of nursery in Kalimantan.

2.5. Arbuscular mycorrhizal colonization of tree species grown in peat soils

Roots and rhizosphere soils of seventeen tree species were collected from peat soils of Central Kalimantan. Roots were stained with 0.05% (w/v) aniline blue. Arbuscular mycorrhizal colonisation was observed under compound microscope.

Arbuscular mycorrhizal colonisation was observed in roots of *Palaquium gutta, Calophyllum soulattri, Campnosperma auriculatum, Cratoxylum arborescens, Tetramerista glabra, Eugenia sp., Shorea teysmanniana, Gonystylus bancanus*, and *Hevea brasiliensis*. Percentage mycorrhizal colonisation was higher in *C. arborescens, G. bancanus and H. brasiliensis*. No arbuscular mycorrhizal colonization was observed in roots of *Combretocarpus rotundatus* and *Tristaniopsis whiteana.* It is suggested that many tree species can form arbuscular mycorrhizal and growth of these species can be improved with arbuscular mycorrhizal fungi.

Table 4. Arbuscular mycorrhizal colonization of tree species grown in peat soils of Central Kalimantan

Order	Genus, Species	Colonisation(%)
Dipterocarpaceae	*Shorea teysmanniana*	10 ± 5
	Shorea teysmanniana	9 ± 8
	Shorea balangeran	14 ± 1
	Shorea balangeran	0 ± 0
	Shorea balangeran	3 ± 3
	Shorea uliginosa	17 ± 6
	Hopea mengarawan	0 ± 0
Guttiferae	*Calophyllum soulattri*	41 ± 26
	Calophyllum sp.	4 ± 3
	Calophyllum sclerophyllum	18 ± 13
Hepericaceae	*Cratoxylum arborescens*	69 ± 4
Tetrameristaceae	*Tetramerista glabra*	15 ± 7
Sapotaceae	*Palaquium gutta*	17 ± 3
Myrtraceae	*Eugenia* sp.	20 ± 5
	Eugenia sp.	7 ± 2
	Tristaniopsis whiteana	0 ± 0
Thymelaeaceae	*Gonystylus* sp.	58 ± 11
Rhizophoraceae	*Combretocapus rotundatus*	0 ± 0
	Combretocapus rotundatus	0 ± 0
Euphorbiaceae	*Hevea brasiliensis*	47 ± 2
Anacardiaceae	*Campnosperma auriculatum*	28 ± 7
	Mangifera sp.	6 ± 4

2.6. Plantation of some tree species

RAMIN (*Gonystylus bancanus*). Ramin plantation area was located at Garung village. The farmer of the plantation has about 2,000 trees. Age of plantation is 4 years-old. Line spacing is 5 m x 5 m. The shading of trees species is Tumih (< 5 years) which is strong for shading. Harvest cycle of trees is 30-40 years. The native seedlings (100-200 cm of height) were collected from the forest. The roots of ramin were taken out together with native peat. The farmer failed to plant of ramin if the roots of ramin were bare without native peat. The farmer will open some tumih trees for give a chance of ramin that will grow after 5 years old. The plantation was managed by family.

SUNGKAI (*Peronema canescens*). Sungkai plantation area was located at Jabiren village. The farmer of the plantation has about 3,000 trees. Age of plantation is 20 years-old. Line spacing is 3 m x 2 m. The trees are planted in open area because the Sungkai does not need shading. Harvest cycle of trees is 30-40 years. Trees are propagated by traditional cutting system like cassava cuttings. The plantation was also managed by family.

VII. Micrometeorology of a tropical peat swamp forest in Central Kalimantan

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1. Introduction

Tropical peatlands in Southeast Asia have accumulated a large amount of carbon as organic matter for over thousands of years. Tropical peat swamp forests have developed on the peatlands, and the forests have an important role to preserve the peatlands. Recently, however, deforestation in the peatlands is advancing rapidly owing to a growing demand for timber and the development of farmlands. The deforestation can promote decomposition of the accumulated organic matter through the change of micrometeorology and water condition. The promoted decomposition causes the release of the carbon fixed in the tropical peat to the atmosphere as CO_2, which is the most important green house gas.

The goal of this study is to estimate the effect of deforestation and drainage on the CO_2 budget of the peatlands through the decomposition of organic matter. As the first step, we started the continuous measurement of micrometeorology on a tower built in a tropical peat swamp forest located in Central Kalimantan, Indonesia, and measured the vertical profile of short-wave radiation.

2. Methods

2.1. Study site

The study site is the natural peat swamp forest remaining in the experimental plot named "Kalampangan" near Palangka Raya, Central Kalimantan, Indonesia. The experimental plot was established in the peatland existing between Kahayan and Sebangau rivers that was devastated by the large-scale deforestation and the excavation of canals for developing farmlands (Fig. 1).

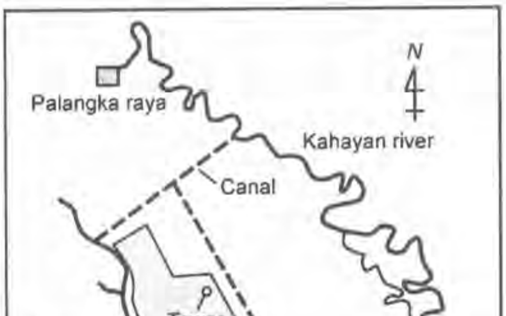


Fig. 1. Schematic map of Kalampangan experimental plot.

2.2. Tower

A tower of 50 m height was constructed in the forest spreading over about 5 km from the east to west and about 15 km from the south to north (2° 20’ 41.6” S, 114° 2’ 11.3” E, Fig. 1). The tower consists of two sub towers; a base tower of 40 m height and top tower of 10 m height (Fig. 2). Since the height of the forest canopy is about 26 m on an average, the height of the tower is almost twice as the canopy height. Moreover, the terrain is flat and the forest canopy is fairly uniform. Therefore this is one of the ideal towers built in forest areas for micrometeorological study.

2.3. Micrometeorological measurement

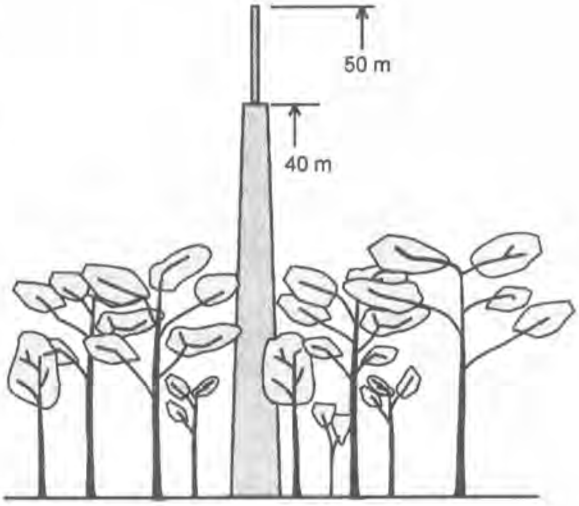


Fig. 2. The tower for micrometeorological measurement.

The continuous measurement of micro- meteorology above the forest was started in the middle of July 2001 by using the tower. The measured items are 6 components of radiation at the height of 40.6 m, air temperature and relative humidity at 49.8, 41.7 and 35.2 m, wind speed at 49.8 and 41.7 m, wind direction at 41.7 m and precipitation at 41.0 m (Table 1). The net radiometer was installed in the north direction; it will be shaded at around noon by the top tower for a few days before and after the winter solstice. The thermometer, hygrometer, cup anemometer and wind vane were installed at the east side of the tower; the thermometers and hygrometers were set in a naturally ventilated radiation shield.

These items are measured every 30 s and their averages are recorded every 30 min by a datalogger (CR10X, CSI) installed at the top of the base tower. Since a commercial electric power isn't available, the measurement system works with the DC power supplied by a solar panel and a car battery. The maintenance of the system and the collection of the data stored in the datalogger were made once or twice a month.

Table 1. Micrometeorological items measured on the tower.

Item	Sensor	Height
Downward long-wave radiation Upward long-wave radiation Downward short-wave radiation Upward short-wave radiation	Net radiometer (CNR-1, Kipp & Zonen)	40.6 m
Downward photosynthetic photon flux density Upward photosynthetic photon flux density	Quantum sensor (LI-190, LI-COR)	
Air temperature Relative humidity	PRT thermometer & HUMICAP (HMP45C, CSI)	49.8, 41.7, 35.2 m
Wind direction & Wind speed	Wind vane & Cup anemometer (03001-5, R.M. Young)	41.7 m
Wind speed	Cup anemometer (03101-5, R.M. Young)	49.8 m
Precipitation	Tipping bucket rain gauge (TE525, CSI)	41.0 m

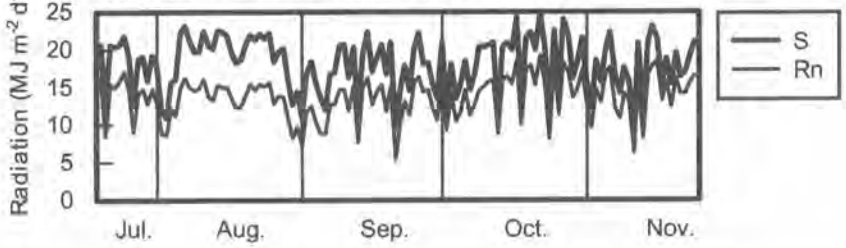
2.4. Radiation budget

Radiation budget of the forest can be estimated by net radiation calculated from the radiation data by using the following equation;

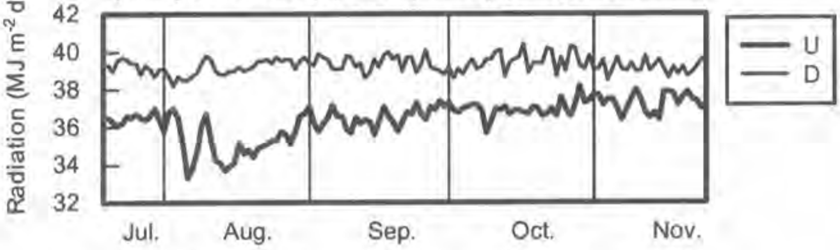
$$R_n = R_{ld} - R_{lu} + R_{sd} - R_{su} \quad (1)$$

where R_{ld} and R_{lu} are downward and upward long-wave radiation, R_{sd} and R_{su} are downward and upward short-wave radiation, respectively. R_{sd} refers to global radiation, and the ratio of R_{su} and R_{sd} is called albedo, which is reflectance of global radiation at the forest. Unit of radiation is W m^{-2}. Moreover, the reflectance of photosynthetic photon flux density (PPFD) at the forest, which is the ratio of downward and upward PPFD, can be one of the indices controlling CO_2 exchange between the atmosphere and forest through photosynthesis.

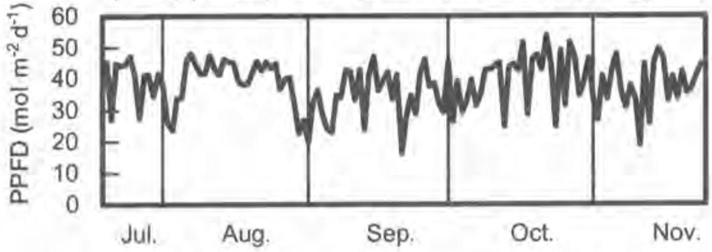
a) Daily solar radiation (S) and net radiation (Rn)



b) Daily downward (D) and upward (U) long-wave radiation



c) Daily photosynthetic photon flux density (PPFD)



d) Albedo and refrectance of PPFD (9:00 to 15:00)

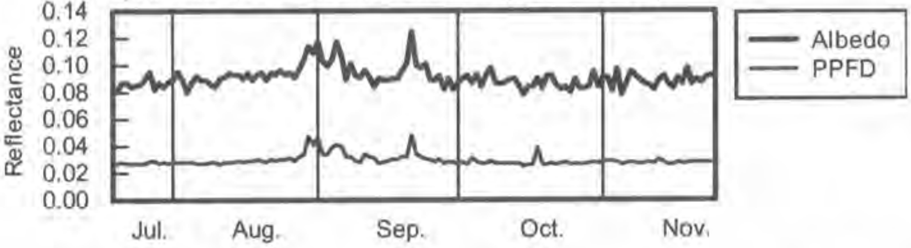
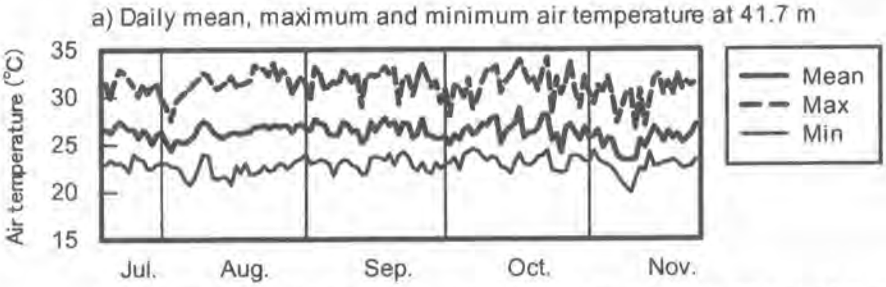
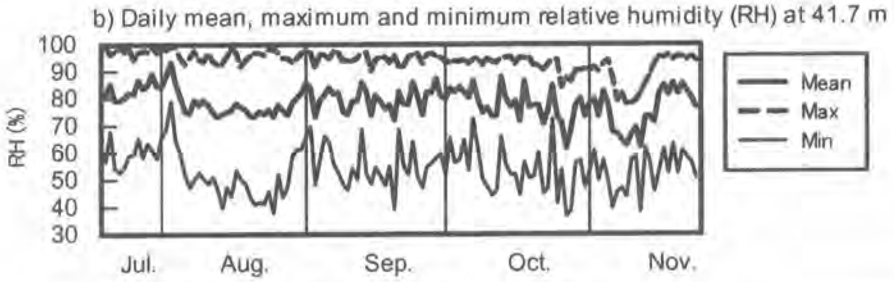


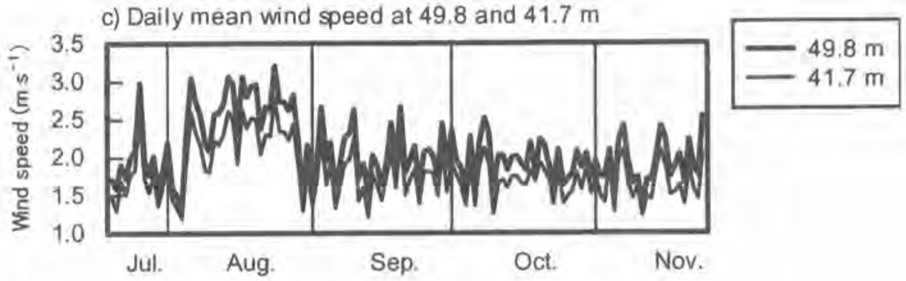
Fig. 3. Variations in the daily values of radiations and the reflectance of short-wave radiation (albedo) and PPFD from the middle of July to the end of November 2001

2.5. Vertical profile of short-wave radiation in the forest

The amount of radiation absorbed by forest canopies is closely related to photosynthesis, dry matter production and energy exchange between the land surface and the atmosphere. The amount of absorbed radiation depends on the incident solar radiation, canopy structure and the optical properties of elements within the canopies. Thus measurement of short-wave radiation in the forest canopy and its vertical profile is important. In order to obtain the profile of integrated short-wave radiation in the forest canopy, we used pigment contained film called 'Simple Measuring System of Integrated Solar Radiation' developed by Taisei Chemical Industries, Ltd. Fading ratio of the pigment is measured to calculate integrated short-wave radiation for the duration of exposure. There are two kinds of films for measurement duration, R-2D for short-term (about 2 days) and Y-1W for long-term (about one week). We placed three pieces of films cut by 35x30 mm horizontally on the observation tower at 0, 5, 10, 15, 20 and 25 m heights. To obtain the fading ratio of the films placed inside the canopy, optical transmittance of the films was measured by T-METER THS-470 manufactured by Taisei Chemical Industries,


a) Daily mean, maximum and minimum air temperature at 41.7 m


b) Daily mean, maximum and minimum relative humidity (RH) at 41.7 m


c) Daily mean wind speed at 49.8 and 41.7 m

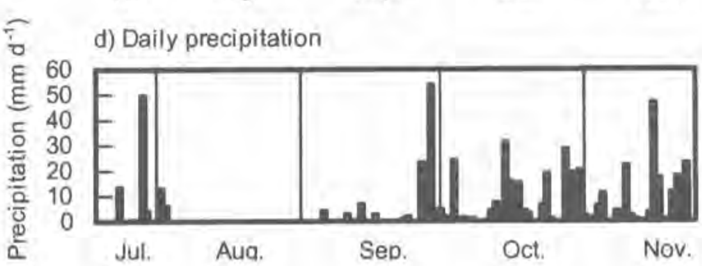

d) Daily precipitation

Fig. 4. Variations in daily values of air temperature, relative humidity, wind speed and precipitation from the middle of July to the end of November 2001

Ltd. Films were exposed from November 23 to 29 and transmittance of those were measured two times within the period.

3. Results and Discussion

3.1. Micrometeorology

In Fig. 3, variations in the daily values of radiations and the reflectance of short-wave radiation (albedo) and PPFD are shown from the middle of July to the end of November 2001. The variations in daily values of air temperature, relative humidity, wind speed and precipitation are also shown in Fig. 4. In this period, daily solar radiation ranged between 8 and 25 MJ m^{-2} d^{-1}, net radiation was 6-18 MJ m^{-2} d^{-1}, PPFD was 18-50 mol m^{-2} d^{-1}. Albedo and the reflectance of PPFD were stable at 0.08-0.09 and 0.03, respectively, except in September. For air temperature, daily mean, maximum and minimum values were 24-28, 27-34 and 20-24 °C, respectively. For relative humidity, daily mean, maximum and minimum values were 60-95, 80-100 and 35-80 %, respectively.

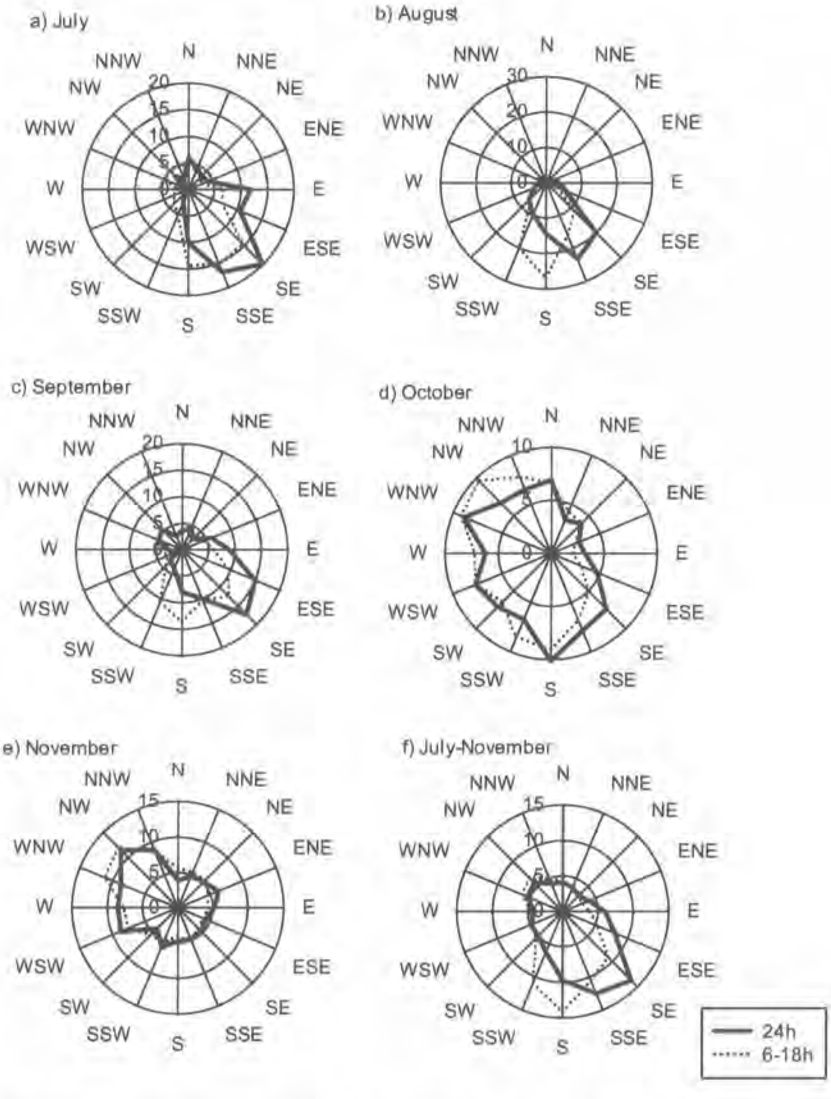


Fig. 5. Monthly distribution of wind direction for whole day (24 h) and daytime (6 to 18 h) from July to November 2001

Wind speed was weak except when a shower came. Its daily mean was lower than 3 m s^{-1}. Except in August, it rained constantly.

In Fig. 5, a wind rose is shown for whole day (24 h) and daytime (6 to 18 h). The dominant wind direction changed clockwise from the southeast in July-September to the west-northwest in November. During the period of the five months, the SE-S wind and SE-SSE wind were prevailing for whole day and daytime, respectively.

3.2. Vertical profile of short-wave radiation

Solar radiation measured at the top of the observation tower for the period of radiation measurement inside canopy is shown in Fig 7. Daily integrated solar radiation ranged from 15.9 MJ m^{-2} (Nov. 29) to 21.1 MJ m^{-2} (Nov. 23).

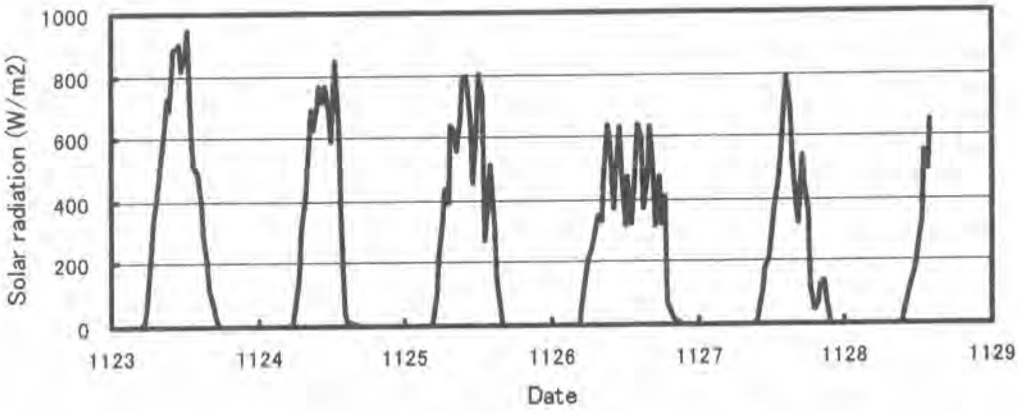


Fig. 6. Solar radiation from November 23 to 28 measured on the top of the tower.

Film sensor measurement showed that integrated short-wave radiation ranged from 25.1 MJ m^{-2} for the ground height to 88.6 MJ m^{-2} for 25 m height for 118 hours between November 23 and 29. We calculated relative short-wave radiation, which is the ratio of integrated short-wave radiation of each height to that of on the top of the observation tower. Fig. 7 indicates vertical distribution of relative short-wave radiation integrated for 118 hours. In this figure we can find that the radiation inside the canopy decreases the most at a layer from 5 to 10 m height.

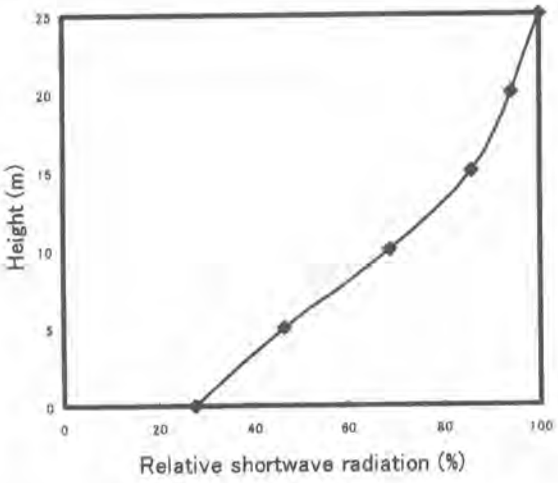


Fig. 7. Vertical distribution of relative short-wave radiation integrated between November 23 and 29.

4. Concluding remarks

We showed some results of the micrometeorological measurements for the first five months. In this period, the system using solar energy worked well without failure. In the end of November, sensors for the flux measurements of CO_2, water vapor and sensible heat were installed on the tower. We will investigate the exchange of CO_2 and energy between the atmosphere and the forest ecosystem.

3. Collaborative study

(3)

Hydrology and peatland technology in Central Kalimantan

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Study on Chemical Characteristics of River and Ground Water in Palangka Raya Region(Prompt Report of the Data)

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1. Introduction

This year we researched the chemical characteristics and behavior of components of Sebangau and Kahayan river water and the ground water in Palangka Raya region. The data of both cases are basic and important for the inhabitants because these qualities are essential to their agriculture and drinking.

2. Method

Waters were sampled from Sebangau, Kahayan River, and ground water of peat land of the mining office and residential area at Palangka Raya with the staff of Palangka Raya University and LIPI from 3rd to 10th March 2002.

3. Results

As the trip to the research area in Indonesia this year was delayed to March of 2002 because of the tribal conflicts, we can not yet have completed chemical analysis for this report. The data we gained now are shown in Table 1. General bacteria and coliform group pollution increase in Kahayan river basin in the Palangka Raya and the tributary. The improvement in the waste water treatment of the Palangka Raya will be desired in future, because the Kahayan river becomes also a water resource in water supply. We will report the results of this year's research together with ones of the next year.

Table 1 Results of Chemical analysis (3.5～3.10/2002)

date	site	Depth of wel m	Ta ℃	Tw ℃	pH	RpH	EC(Lab.) μS/cm	TOC mg/l	DOC mg/l	POC mg/l	TN mg/l	DN mg/l	PN mg/l	NO3--N mg/l	NO2--N mg/l	NH4+-N mg/l
2002.3.5	mining office	12	32.6	29.0	4.8	4.4	13.6	7.5	6.9	0.5	0.74	0.74	0.00	0.00	0.01	0.25
	river near mining office		31.7	31.5	3.9	4.2	64.8	10.7	8.3	2.4	0.83	0.83	0.00	0.00	0.00	0.03
	Eco house	12	33.2	28.7	4.2	4.6	22.2	9.0	9.0	0.0	0.59	0.59	0.00	0.00	0.01	0.24
	house near MINA HOTEL	16	33.2	28.9	4.3	4.5	242.0	4.7	4.6	0.1	8.35	11.92	–	12.80	0.01	0.00
	Juni house	12	31.2	28.8	4.4	4.5	18.6	8.3	8.2	0.0	0.48	0.89	–	0.00	0.01	0.24
	Juli house	3	33.0	28.8	4.2	4.8	20.4	4.8	4.8	0.0	0.44	0.44	–	0.00	0.01	0.12
	Gohong house	12	33.0	29.0	4.4	5.2	69.3	9.4	9.2	0.2	0.76	1.98	–	0.00	0.01	0.54
2002.3.6	KYA(Sebangau river)		30.8	28.5	3.5	3.9	60.6	8.3	8.0	0.4	1.19	1.19	0.00	0.00	0.00	0.04
2002.3.7	Kahayan river		33.5	28.5	6.4	6.1	17.3	9.0	7.9	1.1	1.92	0.59	1.33	0.64	0.00	0.03
	Kahayan river center		33.5	28.5	6.4	6.5	16.5	8.9	7.2	1.7	0.87	0.87	0.00	0.65	0.00	0.02
	Seha river		30.5	28.3	6.0	6.1	16.3	9.6	7.5	2.1	0.44	0.29	0.15	0.00	0.00	0.03
2002.3.6	Ruma hini (Sebangau river st3)			29.4	3.6	3.9	56.0	7.9	7.7	0.2	0.59	–	–	0.00	0.00	0.00
2002.3.7	Source of water supply(Kahayan river)		32.0	28.3	5.3	6.0	15.5	10.9	8.3	2.6	0.72	0.72	0.00	0.65	0.00	0.00
	One point in Upper reaches of Kahayan river		31.0	28.2	5.2	6.4	24.4	9.3	7.1	2.2	1.10	1.10	0.00	0.65	0.00	0.00
	kamelo		29.5	28.5	6.6	7.0	299.0	12.9	11.5	1.4	13.75	1.58	12.17	1.02	0.00	6.20
	kayon(Kahayan river)		31.0	28.5	4.3	4.9	14.0	14.0	12.4	1.6	0.23	–	–	0.00	0.00	0.00
2002.3.8	Sebangau river (st6)		28.3	30.2	4.0	4.4	54.9	7.8	7.6	0.2	0.83	0.83	0.00	0.00	0.00	0.00
	rain(squall)					7.0	44.1	14.2	4.9	9.3		0.76	0.00	0.65	0.01	0.06
	rain					4.9	13.5				0.65		0.65		0.01	0.00
2002.3.10	SAKURA HOTEL					6.6	202.5	2.3	2.3	0.0	3.25	2.80	0.45	2.38	0.05	0.89

date	site	TP mg/l	DP mg/l	PP mg/l	TRP mg/l	DRP mg/l	PRP mg/l	Na+ mg/l	K+ mg/l	Ca2+ mg/l	Mg2+ mg/l	Cl- mg/l	SO42- mg/l	4.3Bx meq/l	SiO2 mg/l
2002.3.5	mining office	0.068	0.012	0.056	0.018	0.008	0.010	0.4	0.0	0.4	0.0	0.4	0.0	0.084	0.3
	river near mining office	0.089	0.080	0.009	0.078	0.078	0.000	0.4	0.7	0.7	0.7	0.5	0.0	0.000	2.2
	Eco house	0.014	0.008	0.006	0.013	0.013	0.000	0.2	0.1	0.4	0.6	0.5	0.0	0.067	0.3
	house near MINA HOTEL	0.006	0.006	0.000	0.002	0.002	0.000	21.1	10.1	15.3	2.3	20.1	18.9	0.093	5.2
	Juni house	0.012	0.006	0.006	0.013	0.013	0.000	0.2	0.1	0.5	0.6	0.6	2.2	0.135	0.4
	Juli house	0.008	0.008	0.000	0.007	0.007	0.000	0.7	0.3	0.5	0.6	1.8	2.6	0.160	0.0
	Gohong house	0.007	0.005	0.015	0.004	0.001	0.003	10.2	3.7	0.9	0.8	11.5	5.9	0.186	0.8
2002.3.6	KYA(Sebangau river)	0.015	0.011	0.004	0.015	0.015	0.000	0.4	0.6	0.5	0.7	0.8	0.0	0.000	2.2
2002.3.7	Kahayan river	0.058	0.011	0.047	0.006	0.000	0.006	1.0	0.3	1.5	1.0	0.4	2.7	0.815	0.3
	Kahayan river center	0.056	0.008	0.049	0.008	0.008	0.000	1.0	0.4	1.6	1.0	0.3	2.6	0.245	0.4
	Seha river	0.074	0.023	0.051	0.030	0.009	0.021	1.0	0.5	1.3	1.0	0.5	2.7	0.245	0.0
2002.3.6	Ruma hini (Sebangau river st3)	0.048	0.010	0.038	0.019	0.019	0.000	0.2	0.4	0.7	0.7	0.5	2.2	0.000	2.2
2002.3.7	Source of water supply(Kahayan river)	0.056	0.008	0.047	0.006	0.000	0.006	1.1	0.5	1.3	1.0	0.4	2.6	0.228	0.3
	One point in Upper reaches of Kahayan river	0.050	0.009	0.041	0.003	0.003	0.000	1.1	0.3	1.5	1.1	0.3	2.7	0.304	0.8
	kamelo	0.454	0.363	0.091	1.790	1.790	0.000	29.5	10.6	13.6	1.6	26.6	8.8	1.974	8.0
	kayon(Kahayan river)	–	0.076	–	0.008	0.003	0.005	0.2	0.4	1.2	0.8	0.4	2.4	0.169	0.0
2002.3.8	Sebangau river (st6)	0.016	0.016	0.000	0.014	0.014	0.000	0.2	0.3	1.0	0.7	0.5	2.2	0.110	2.2
	rain(squall)	0.101	0.036	0.065		0.021		0.4	0.7	3.4	0.9	0.6	2.6	0.405	0.2
	rain	0.025	0.014	0.011		0.004								0.101	0.2
2002.3.10	SAKURA HOTEL	0.011	0.008	0.003	0.006	0.006	0.000	29.5	6.2	8.9	1.5	30.5	10.4	0.801	2.5

Hydrology and Peatland Technology in Central Kalimantan

Survey of Flow Discharges at Several Stations of the Sebangau River

By
K. Hasegawa, A. Mori and H. Sugimoto

1. Introduction

Water stage observation for the Sebangau River has been continued since August 1998 at Kya station. Characteristics of the runoff discharge, which were translated from the water stage data through the H-Q curve, were analyzed by using the storage function method. It was found that the runoff coefficients are 0.38 (Sep.9,1998~Jan.30,1999) and 0.28 (Oct.1,1999~Mar.23,2000), and that the values are smaller than those observed in the Sarobetsu Mire in Hokkaido which lies in the cold region in Japan. The results are shown in the previous Report.

In this Report, results of the flow discharges surveyed at several stations along the Sebangau River are treated. The survey was conducted on 6th, 7th, 8th in March 2002 in order to discuss the effect of the mire (wet land) on the runoff discharges in the Sebangau River.

2. Stations for discharge observations

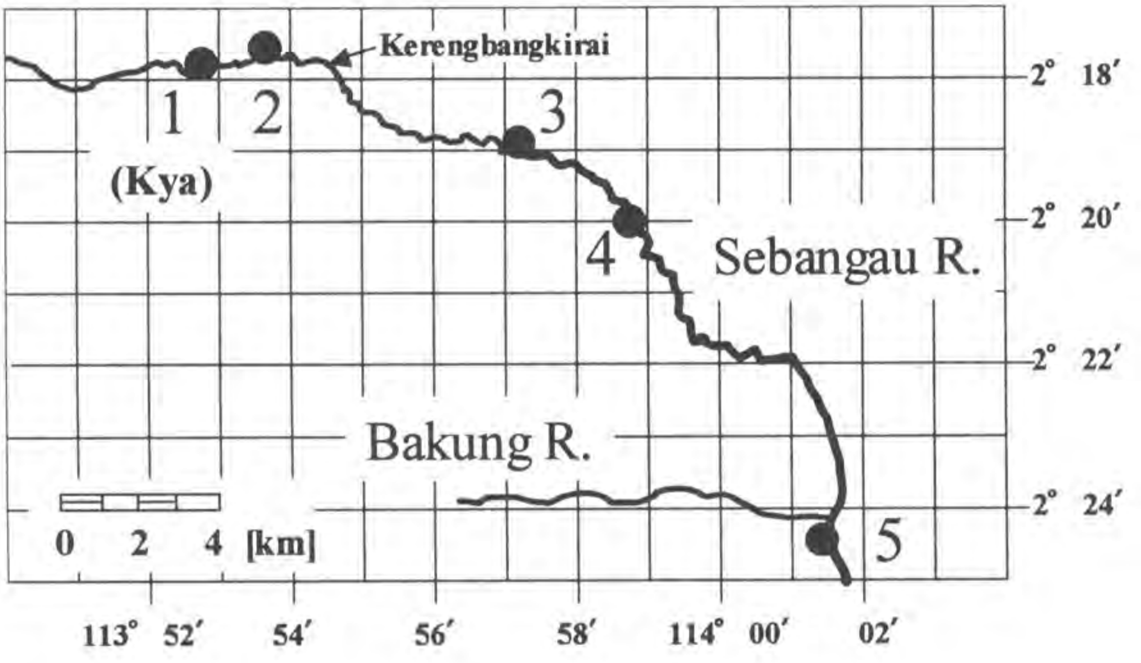

Fig.1 Stations in the Sebangau River

In wet season, flow water runs not only in the law water channel but also on the flood plane i.e. marsh accompanying with inflow to the channel or outflow from that. In order to know the flow rate from or to the marsh, it is necessary to survey the spatial change of flow discharge which is confined within a channel cross section along the river length. Observations of the discharge were made at five stations in the Sebangau River as shown in Fig. 1. Measurements at St. 1 and St. 3 were made on 6, Mar. and the others were on 8, Mar.. The observations at St. 2 were made three times a day to check the daily change of discharge.

3. The method of flow velocity and water depth measurements

● Method I

①The water depth was measured every 5m in the transverse direction, along a rope stretched between the both banks.

②The velocity was measured with a one dimensional electric magnetic current meter every 50cm in the direction of depth at each measurement point of the water depth.

● Method II

①The observation boat was stayed in one position on a cross sectional line.

②The position of the boat was determined by measuring the distance from one point of the river bank to the boat and the deviation angle of the line from the magnetic north. At the same time, the water depth and the velocity were measured at that point, provided the depth for the current meter to be set was 40% of the water depth.

③They were measured at 5-6 points for one cross section, changing the distance in the transverse direction.

● Method III

① The boat was made flow naturally several meters (about the length of the boat), as the locus intersects with the cross section.

②The position of the boat was determined by measuring the distance from one point of the river bank to the boat and the deviation angle of the line from the magnetic north every 20-30 seconds. At the same time, the water depth were measured at that point.

③They were measured at 5-6 points for one cross section, changing the distance in the transverse direction.

④Only water depth was measured along the cross section when the boat came back from the opposite bank.

4. The method of discharge calculation

● Method I

①The cross section wass divided into small subsections as shown in Fig. 2.

②The product of each area and the flow velocity corresponding to the subsection was summarized to obtain the discharge.

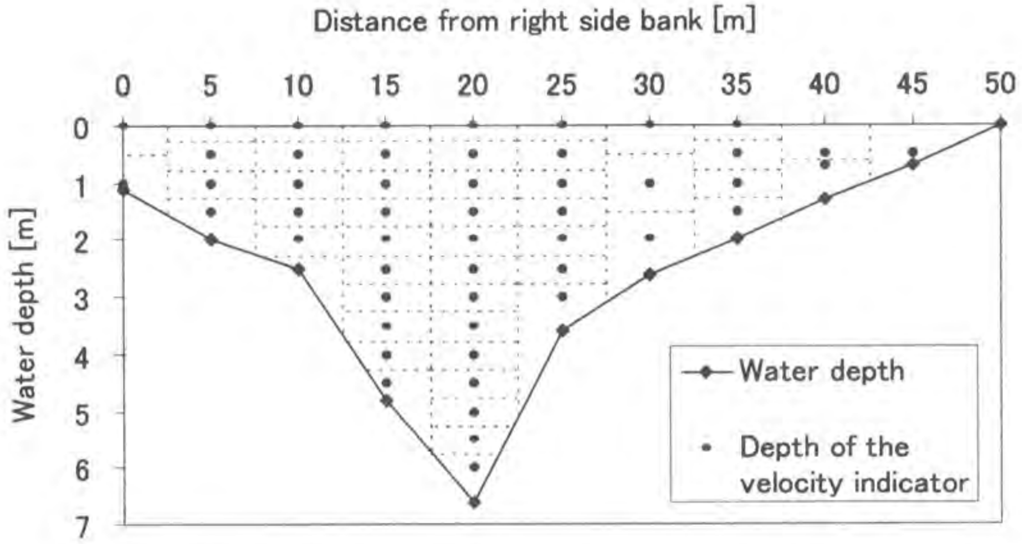

Fig.2 The calculation of discharge by Method Ⅰ (St.1)

● Method Ⅱ

①In this method, a cross section was determined by drawing an approximate straight line to fit all measurement points (Fig. 3).

②A calculation point on the cross section was determined from the foot of the perpendicular line from a given actual measurement point toward the cross sectional line. Then, the river width was obtained from the distance between both end points.

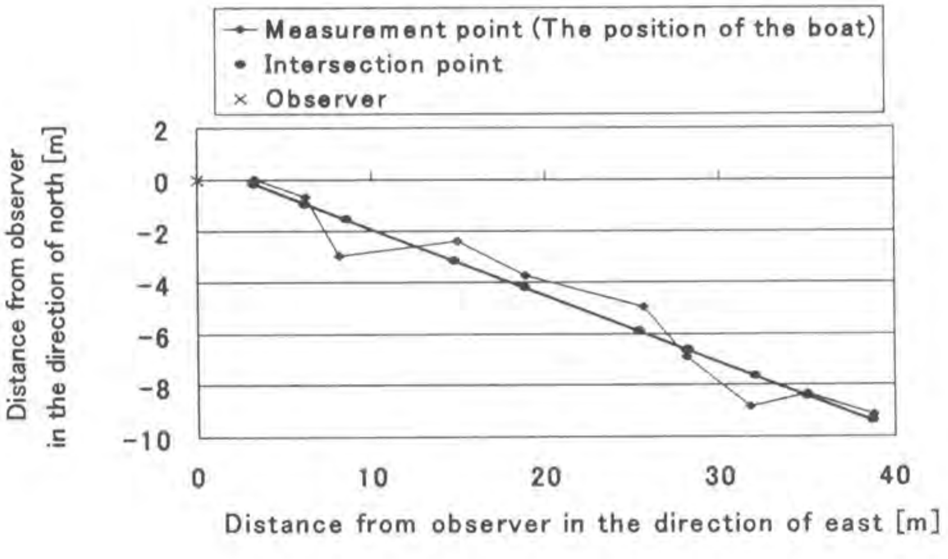

Fig.3 The calculation of discharge by Method Ⅱ (St.3 1st)

● Method Ⅲ

①A cross section was determined from an approximate straight line to fit all end points of the locus of boat (Fig. 4).

②Velocity was obtained from a distance of the locus of boat flowed naturally and the flowing time.

③Mean of the water depths measured 5-6times for one point was taken as the water depth at that point.

④Calculating point on the cross section was determined from the intersectional point between the cross sectional line and a given locus line of the boat.
The river width was obtained from the distance between both ends of those points.

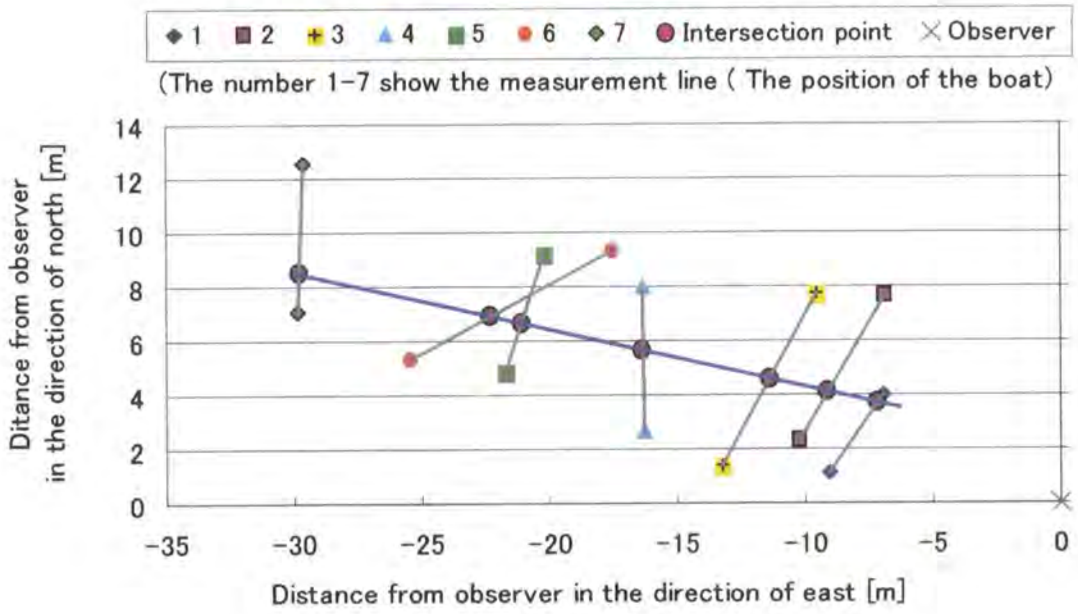

Fig.4 The calculation of discharge by Method III (St.2. Morning)

5. Results of the survey

Table-1 shows results of the discharge observations which were calculated from the Method I, II and III described in the previous section.

1) From the data at St.1, the measurement accuracy for the method II can be estimated, since the method I has the higher accuracy compared with the method II because the measurements of velocity and water depth were conducted with smaller grid size in the former method. By using the values of 11.9 m^3/s (Method I) and 13.1 m^3/s (Method II), the error of the method II becomes 9%.

2) At St.3, two times observations were conducted moving the boat back and forth. Then, if the mean value of the two observed data was employed as the discharge at St.3, the trial error is thought to be about 10%.

3) Investigation for the daily change of discharge was intended to collect the data in the morning, daytime and evening at St.2. If the mean of three data was assumed to be a true discharge at St.2, the trial error in the morning, daytime and evening from the true value become 30%, 23% and 6%, respectively. The trial

errors in the morning and in the daytime are greater than the trial error at St.3, which suggests the discharges in the morning and in the daytime could have significant differences from the mean discharge; the discharge in the morning is greater than that in the daytime. Actually, such a daily change of discharge is seen at Kya St. as shown in Fig. 5 and Fig.6. However, since the observation method at St.2 is different from at St.3, it is difficult to reach a conclusion.

4) If the representative discharge at each station was chosen as 11.99 m³/s at St.1, 6.91 (the mean value) at St.2, 15.67 m³/s (the mean value) at St.3, 21.37 m³/s at St.4 and 17.53 m³/s at St.6, respectively, it could be presumed that outflow from the river channel to the marsh would occur in the regions between St.1 and St.2, and between St.4 and St.6, and the inflow to the channel from the marsh would occur in the region between St.2 and St.4.

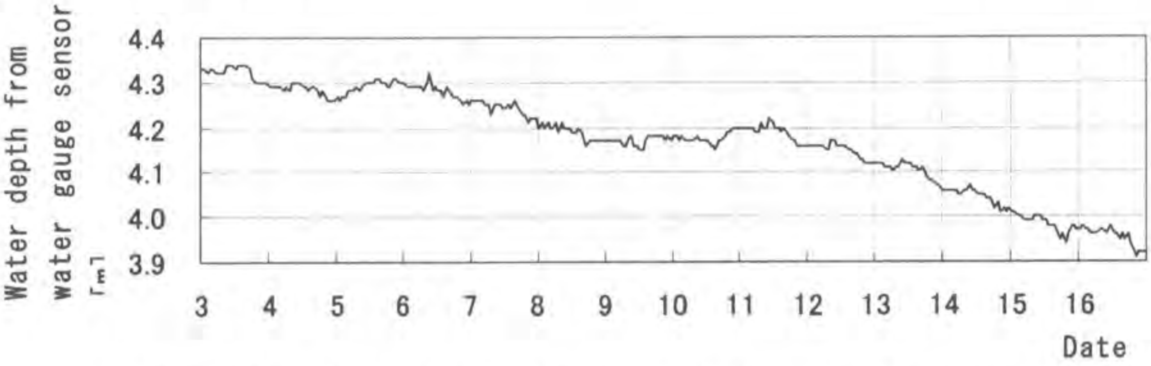

Fig.5 Water depth at Kya in the Sebangau River (Dec.,1999 (Rainy season))

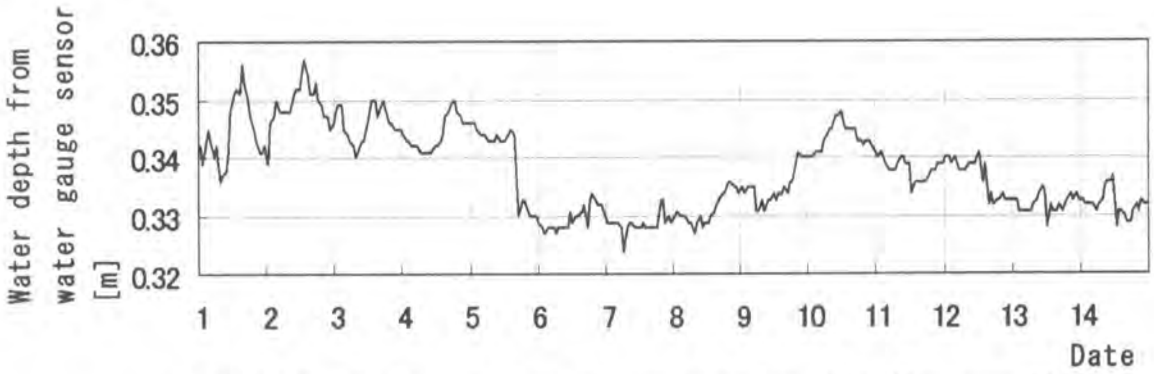

Fig.6 Water depth at Kya in the Sebangau River (Aug.,2001(Dry season))

Table.1 The result of discharge calculations

Station	Date	Local Time	Method	Discharge[m³/s]	Width[m]
1(Kya)	6-Mar	13:27	Ⅰ	11.99	50.0
1(Kya)	6-Mar	14:06	Ⅱ	13.10	38.6
3	6-Mar	15:35	Ⅱ	17.28	36.7
3	6-Mar	15:51	Ⅱ	14.06	39.0
2	8-Mar	10:20	Ⅲ	8.96	23.1
2	8-Mar	13:34	Ⅲ	5.27	20.9
2	8-Mar	16:36	Ⅲ	6.50	27.3
4	8-Mar	11:16	Ⅲ	21.37	27.1
6	8-Mar	15:13	Ⅲ	17.53	45.0

TROPICAL PEAT AND KERANGUS SAND AROUND PALANGKARAYA, CENTRAL KALIMANTAN, INDONESIA - CARBON 14 DATES AND SEDIMENTARY ENVIRONMENT-

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1. INTRODUCTION

Development of the thick lowland peat are frequently reported from the tropical zone of the world. It is said that approximately 6.8 Mha peats entirely occupy the lowland up to ca. 60 m above sea level in central Kalimantan . Thick peat cores and/or their geologic cross sections reported so far are obtaind almostly in the region between the present Kahayan River and the Katingan River including the uppermost Sebangan River basin. However very little is known on the precise distribution of the peats, particularly in terms of distribution and genetic development of Kerangus sand.

The peats in Central Kalimantan have been classified into two types of coastal peat as well as high peat by Sieffermann et al. (1993). In the other paper, Sieffermannn(1988) described the two peat types as the basin peat and the high peat respectivelly. The high peat is refered to be ombrogenous in formation process. Hirakawa & Kurashige (2000) produced a contour map and examined the peat formation from the view of landform evolution. It is absolutely lacking of fundamental knowledge on the formation age of peat from different environments as well as the relation to Kerangus sand.

2. SEDIMENTARY FACIES OF PEAT ALONG THE CANAL BETWEEN KAHAYAN

AND SEBANGAU RIVER NEAR PALANGKARAYA

Along the new cannal connecting Kahayan River and Sebangau Riverat Karanpangan relatively thick peat is continuously observed. The peat is already relatively well decomposed, althogh it conyains still tree roots or stums. The thickness is about 4 m. The base of the peat is of kerangaus sand. At several sites, Kerangus rip up clasts of 30 ~ 50 cm in diameter were contained in the peat formation. These rip up clasts are very significant to examine the environment of the thick peat formation. The rip up clasts must have been eroded by stream water from the nearby river bank while the rainforest tree trunks and the other organic matter had accumulated in the stagnant water condition. Therefore this thick peat is not ombrogernous in origin, but have been developed in or near the (abandoned) river channel. The present fluvial environment of the upper Sebangau River or many abandoned channels during the rainy season appears to represent such a condition . This fluvial environment could be produced by the occurrence of large-scale stream migration.

3. AGE OF PEAT FORMATION

We have so far 7 radiocarbon dates for understanding the tropical peat development as below. The results are as follows. Caribrated results indicated as Calendar years are of 2 sigma, 95 % probability:

A: tree trunk in the peat near Karanpangan:
6670 ~ 6330 Cal BP (Beta-131266)
B: tree trunk in the peat near Karanpangan:
8190 ~ 7950 Cal BP (Beta-131267)
C-1: charcoal layer in the peat near Karanpangan:
7425 ~ 7306 Cal BP
C-2: charcoal layer in the peat near Karanpangan:
6890 ~ 6817 Cal BP
C-3: charcoal layer in the peat near Karanpangan:
6693 ~ 6407 Cal BP
D: buried wood (tree trunk) near Maran:
864 ~ 828 Cal BP (ID1581)
E: buried tree trunk near Karanpangan:

6299 ~ 6170 Cal BP (ID1580)

4. SIGNIFICANCE

C-14 dates

C-14 dates of wood from the uppermost horizon and 120 cm depth are obtained. C-14 dates of three charcoal layers are also obtained. It is very significant that three charcoal layers are intercalated in the peat, because they shows a big fire in the peat land forest about several thousand years age.

Using these C-14 dates of peat, we will examine age and rate of peat formation and eivironmental change of the surrounding kerangas plain due to forest fire during the prehistoric age. As indicated by the charcoal layers in the thick peat, big fire had occurred about 6500yBP,68 00 yBP and 7300 yBP respectively. They must have been in the natural condition . The fire is considered to have influenced to the vegetation at that time. On the basis of pollen analysis of this thick peat, we could examine various issues such as the vegetation change before and after the fire, process of recovery of vegetation and duration for recovery. This knowledge should be a basic data for the consideration of peatland forest fire at present.

Kerangus sand : Grain size distribution and its characteristics

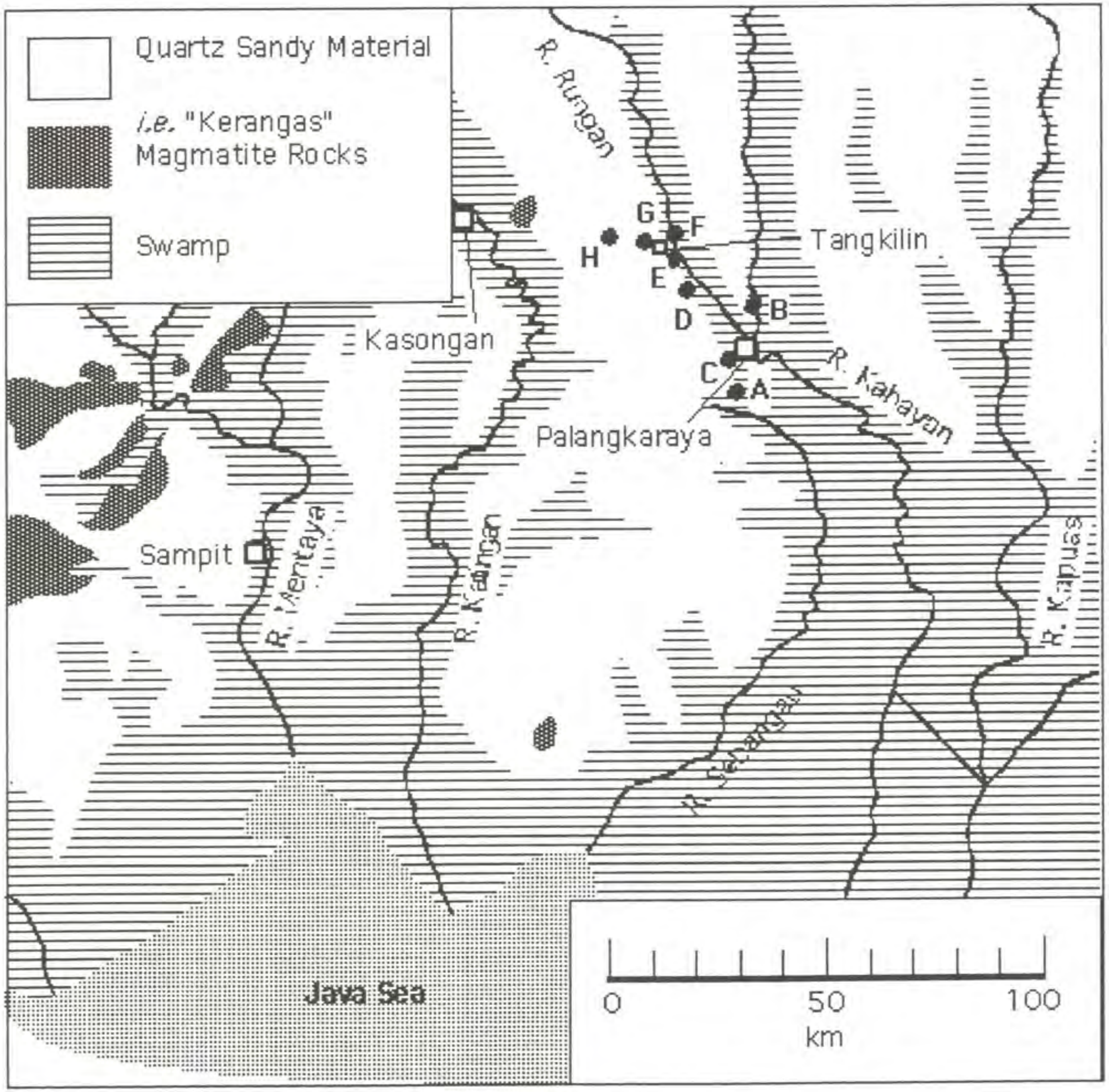
In Central Kalimantan, we can find widely distributed "Kerangas", which is composed of white barren sandy materials. Rivers undercut plateau of Kerangas, and swamps are formed in the undercut valley as well as in wide lowland south of the Kerangas plateau. Small swamps are also sporadically distributed on the Kerangas plateau, in particular where small depressions are formed. These geomorphological features indicate that the formation and distribution of the Kerangas plateau strongly controls the formation of swamps and, accordingly, peatland in Central Kalimantan.

As the first step toward the consideration of the Kerangas plateau formation, grain size distributions of Kerangas sediments were tested at six sites around Palangkaraya city, and were compared with grain-size distribution of a present river-bar sediment and that of a levee sediment.

The grain size distribution of Kerangas sediment were classified into two types: coarse type and fine type. The coarse type has median diameter of about 0.0 phi (2 mm), whereas the fine type has about 1.0 phi (1 mm). Each of the grain-size distribution of

the coarse type sediment could be separated into four lognormal subpopulations: population I (Mf = ca. 0.0), population II (Mf = ca. 2.5), population III (Mf = ca. 4.8) and population IV (Mf = ca. 7.5). The grain-size distribution of the fine type also could be separated into four lognormal subpopulations, whereas median of each subpopulation was finer than that of the coarse type (population I: Mf = ca. 1.0, population II: Mf = ca. 3.6, population III: Mf = ca. 6.2, population IV: Mf = ca. 8.7). Grain size distributions of the levee deposit was similar to that of the fine type. Grain size distribution of the present river-bar sediment could be separated into four subpopulations, and each subpopulation was similar to tha!
t of the fine type. These similarities indicate that the fine type Kerangas is alluvium and were transported and deposited under present alluvial condition. In contrast, the coarse type Kerangas is also alluvium and were considered to be transported under higher stream-power condition, possibly during last glaciation when sea level was lower than present.

We also tested grain-size distribution of podozol and laterite at a site. The grain-size distribution of podozol was similar to that of the fine type Kerangas, whereas the grain-size distribution of laterite was similar to that of the coarse type Kerangas. These indicate that the parent material of the podozol and/or laterite is Kerangas at the site.


Quartz Sandy Material
i.e. "Kerangas"
Magmatite Rocks
Swamp
R. Rungan
Tangkilin
G
F
H
E
D
B
C
A
R. Kahayan
Palangkaraya
Kasongan
Sampit
R. Mentaya
R. Katingan
R. Kapuas
R. Sebangau
Java Sea
0
50
100
km

The characteristics of forest /peat fire in a tropical peatland, Central Kalimantan, Indonesia

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Abstract

Tropical peat land has a important role for the global environment because a great amount of carbon are stored in the peat-layer. Some characteristics of forest/peat fire, which is the most serious human impacts on the tropical peat was studied in a secondary forest after fire. Fuels in a peatland were classified to fore categories of aerial(AF), surface(SF), litters(LF) and peat fuels(PF). Total biomass in the secondary forest was estimated to be 235 t m^{-2} in dry matter. The peat fuel shared 82% in the total biomass fuel and other fuels shared only 5-6% in each fuel. The 43% of AF, 36% of SF and 25% of LF were burnd and lost with the fire test but no loss was found in PF.

Fire temperature in the peat-layer reached to around 180℃ in the field but the fire could not burn the peat continuously longtime.

1. Introduction

Peatland of the earth surface approximately 400 Mha, and most of them situated in the temperate area (90%) while only 10% in the tropical area (Belammy, 1997). The specific function of tropical peatland is storage huge number of carbon (Shimada, et al, 2001) with volumetric carbon density of each types of peat of peatland in Central Kalimantan is ranging from 55-80 kg m^{-3}. While total amount of carbon content in tropical peat of Indonesia approximately around 16-20 Gt; 1 Gt = 10^{15}g (Sorensen, 1993).

Destruction of tropical peatlands was accelerated year by year since 1960's in the world with the over logging, change of land-use and forest/peat fire etc. The forest/peat fire gives the most drastic damage on the carbon storage in the peatlands. The impacts of forest fires change the ground structure above and below surface, the function and processes of peatland ecosystem (Neary, D.G., *et al*., 1999). For example, change or removal of plants in the peat swamp forest can directly affect on the ground system below surface by:

(1) Altering nutrient inputs that in turn, affect soil and litter macro and micro flora and fauna.
(2) Increasing surface soil temperatures as a result of increased solar heating; and
(3) Changing evapotranspiration rates due to losses in vegetation that in turn, alter soil moisture availability.

Many research works on the forest fire were conducted in not only the boreal and temperate forests but also in the tropical forest. But a few studies on the peat fire combined with forest fire were carried out in peatlands in the world.

This study was conducted in field with focus on following items,

(1) To calculate amount of biomass fuel above and below the ground surface

(2) To calculate combustion completeness and fire line intensity,
(3) To make clear the fire behavior.

2. History and general aspects of forest/peat fire in Indonesia

<History of peat/forest fire>

Schindler, S. (1998) pointed out that ninety-nine percents of forest fires in Indonesian was related to human activity. The forest fire has become very serious problem since 1982/1983 when the forest fire destroyed thousands square kilometers of selective logged *dipterocarpus* forest in East Kalimantan (Leighton and Wirawan, 1986, Uhl and Kauffman, 1990). Since then the forest fire occurred every year, especially it was very serious in 1984, 1991, 1994 and 1997 (Fig.1).

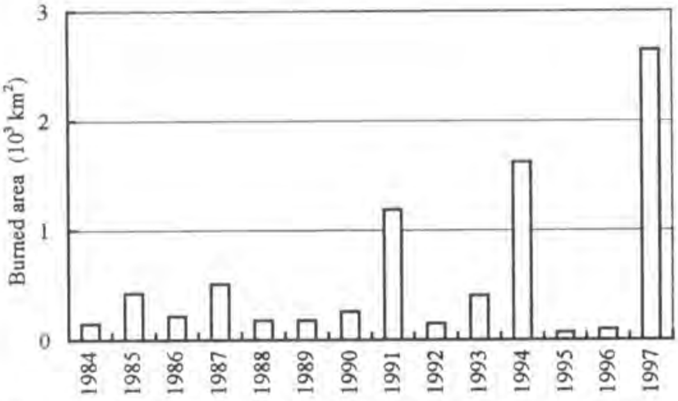


Fig. 1 . The annual total areas burned by forest fires for 1984-1997 in Indonesia

According to the statistical data of forest fires in Indonesia from 1984 to 1997 (Dirjen PHPH, 1997), forest fire in Central Kalimantan has started in 1987 but total burned area was not so wide (0.30 ha). But it became serious one in 1991, 1994 and 1997, with the burned areas of 18,429 ha, 2,330 ha and 12,632 ha respectively.

<Causes of forest/peat fire>

The large area was opened and wasted by the mega rice project in the peat swamp forest of Central Kalimantan since middle of 1990's. The ground surface including subsurface peat layer was drought by construction of the drainage canals in the forest. Total length of the canal reached to 140 km. A lot of woods and branches were left on the forest floor without removal and became a huge amount of biomass fuels. The biomass fuels on the forest floor and the drought subsurface peat layer were triggers of the large forest/peat fire in 1997. Inoue (1999) mentioned that the most causes of the 1997/98 forest fire in Indonesia were the escaped fire from the intended burning by the developer and the local people.

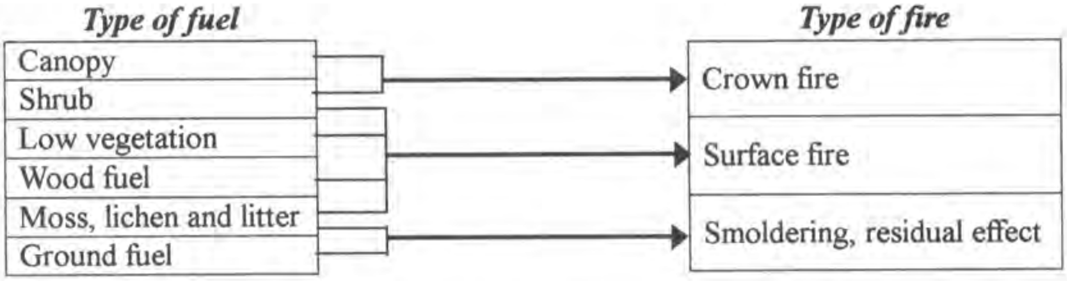


Fig.2. Categories of fuel in the forest and the combustion types (Cushon *et al.*, 2001)

<Fuels in the forest>

Cuson, *et all.* (2001) has classified the fuels in a forest with the characteristics of the fire behavior as Fig.2. Pyne *et al.* (1984) has classified the fuels in a forest based on vertical layer, to three categories of aerial, surface and ground fuels. The aerial fuels include the tree branches, moss and snag, while the surface fuels include the low vegetation and large logs, and the ground fuels include leaves grass and limb wood, duff and roots.

<Models of fire behavior>

Fire behavior spreading out to surroundings is very important for management of the fire (Perry, G.L.W. 1998). Fire behavior is strongly related to the environment in which fire is burning. This concept has been developed by Countrymen (1972), he used at first the term of "fire environment triangle" which means fuel, weather and topography. Those components are important to determine fire behavior. Fire behavior should include an energy release from combustion, fire intensity, rate of fire spread, and other phenomenon related to fire event.

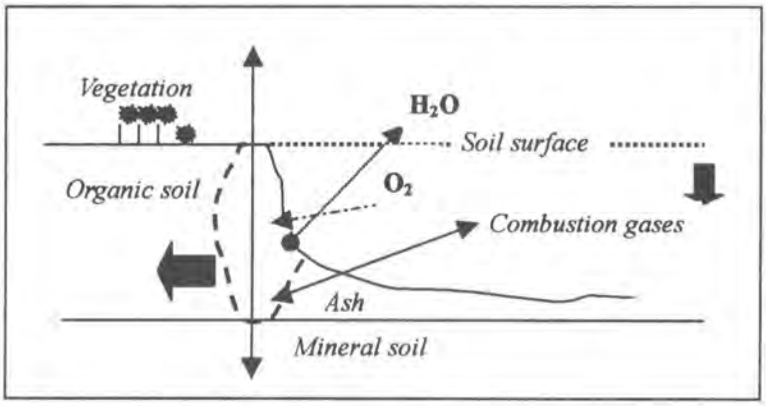


Fig.3. A model of fire behavior in organic soil (Wein, 1983)

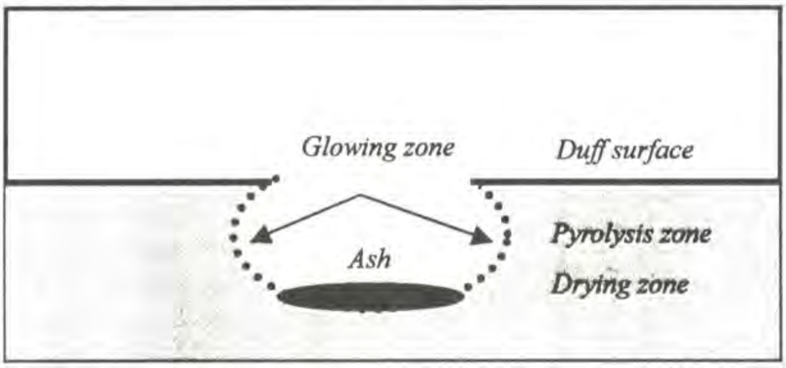


Fig.4. A model of ground fire behavior on the duff material (Hungerford *et al.*, 1995)

Wein, R. W. (1983), developed a fire behavior model in organic soil as shown in Fig.3. The fire spreads out in the organics soil consuming it from surface to bottom. The behavior model of the duff fire developed by Hungerford (1995), and the model was a very appropriated one for the peat fire in the tropical peatland (Fig.4). The most important factor is the thickness of the fuel layer because the smoldering can continue and propagated a heat for pyrolysis in a limited zone. Palmer (1957) found that the depth was greater than critical minimum depth, it necessary for sustained smoldering, and the rate of smoldering varied with the depth of the fuel layers. Bakmand (1993) found that a smoldering temperature was initiated decreased with increasing the thickness of the fuel. The minimum layer for sustained smoldering combustion was 47 mm.

<Fire temperature under the ground>

Wein R.W.,(1983) reported about a behavior of fire temperature in the organic soil.

He found that the fire temperature was kept long time and penetrated into deep layer under the ground. While in the case of mineral soil, the surface soil temperature becomes so high as around 700°C during burning of such surface materials as woods, shrubs, and grasses. But the heat does not penetrate into the deeper layer because the fire does not continue long time.

Fig.5 shows the effects of surface heating on the temperature under the ground. The effect of high temperature on the surface of dry organic soil penetrated into the deeper layer, at 2-4 cm deep after 60 minutes, and 4-6 cm deep after 600 minutes. On the other hand, the surface temperature of the wet organic soil did not increase higher than 300°C with evaporation of water in soil.

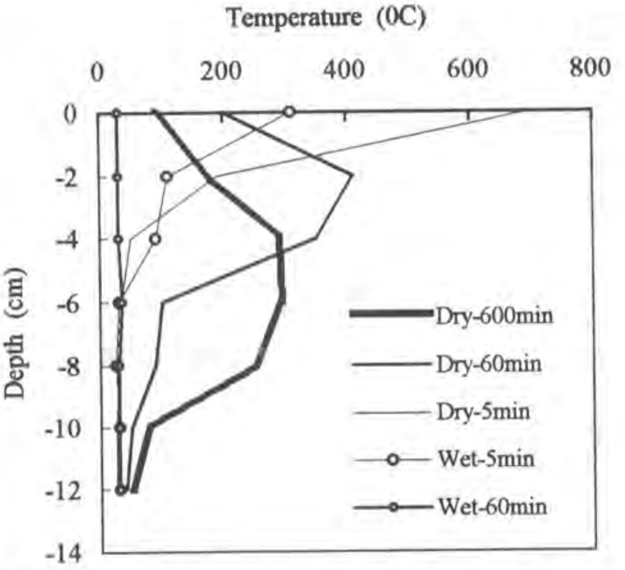
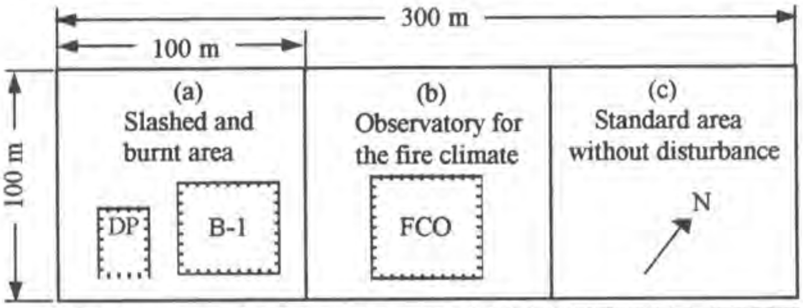


Fig.5. Soil temperature profiles after surface heating artificially on the dry and the wet organic soil surfaces (modified from Wein, 1983)

3. Study site and the fire climate observation

<Location and vegetation>

Study site was located in the secondary peat swamp forest, 2°13'58.8"S, 113°56'79.6"E, about 3 km west of the main campus of the University of Palangka Raya, Central Kalimantan. The total area of the study site was 3 ha and divided into three one hectare sections according to the aims of usage for (a) the test of slashed and burn, (b) the measurements of climatic and hydrological conditions related to forest/peat fire and (c) the standard of the secondary forest without disturbances, as shown in Fig.6.



Legends

FCO (900 m^2) : Fire Climate Station

B-1 (900 m^2) : slashed and burnt in August, 2000.

DP (30 m^2) : burnt the mounded and dried peat in August 2001.

Fig.6. Schematic diagram of the study site and sections for the experiments.

Forest canopy of the study site was dominated by *Combretucarpus rotundatus* (local name : tumih), and *Cratoxylum aborescens* (local name: Garunggang) with trees density of DBH> 5cm was 559 ind.ha^{-1}. Vegetation on the forest floor were dominated at least by three types of local grasses as cinnamon fern, vegetable fern, and bracken fern with the covering rate of 80%, 10% and 3% on peat surface, respectively.

<Peat>

Peat depth in the study site ranged from 60-110 cm, it has been disturbed by forest fire around 15 years ago. Peat in this site was categorized as *fibrist peat* or young peat, with the small decomposing rate less than 33% (USDA, 1975).

<Instruments>

Fire climate observatory (FCO) have been established on the open area of 30m by 30m square. Air temperature, relative humidity, rainfall, wind speed and wind direction, soil temperature, ground water level, and solar radiation were measured automatically with the interval of one hour. All data were recorded using the data loggers (KADEC series, KONA System Co. Ltd.). Locations and types of the sensor were as follows,

#The air temperature and humidity: at the height of 120 cm above the ground with a thin-film polymer sensor for air humidity and a Pt electro resistance sensor for air temperature (HMP-35D, Vaisala Co. Ltd.).

#Rain fall: at the height of 120 cm with a tapping bucket type rain gauge (34-T, Ota Keiki).

#Wind speed and direction: at the height of 5 m with a wind vane (M-05103-16B, Young Co. Ltd.)

#Ground water level: in a well with a pressure sensor (PDCR-940, Druck Co. Ltd.)

#Soil temperature: at the depth of 0 cm (surface), 10 cm, 20 cm, 40 cm with the Pt resistance sensors.

#Solar radiation: at the height of 1.5 m with a thermopile sensor (PCM-01, Prede Co. Ltd.)

4. Field fire experiment

<Biomass estimation before burning>

Weights of the fresh biomass in the experimental site B-1 (Fig.6) were measured along the six 100 m transects which were set with 20 m interval.

Biomass in the study site such as trees, grasses, litters and peat were determined before slashed and after burning. Moistures of biomass and peat were determined by drying in a oven at 85°C for four days. Fresh weight of biomass was measured by weighing directly in the field. Peat depth was determined by boring at around 360 points in the study site.

<Biomass estimation after burning>

The onsite un-burnt residues were measured in the 5m x 5m plots by weighing, and the values are used for calculating the combustion factors. The un-burnt residues also girth class with take note of wood prior burning class girth.

<Fire temperature measurement>

Fire temperature above and bellow the ground surface were measured at the height of 1 m above the ground surface and the depth of 0 cm, 5 cm, 10 cm, 30 cm and 50 cm using the cupper-constantan thermocouple sensors and the data logger.

<Fire experiment in the field>

Trees in a half of the fire experimental area were cut down one month before the experiment on 2nd September, 2000. The surface biomass fuels were ignited at the southeastern part of the experimental site.

5. Results and discussions

5-1. Conditions of biomass before fire experiment

Table 1. Density of grasses on the ground in the study site. Local name is in the parentheses.

Surface fuel categories	Clump Density ha^{-1}	Area %	Biomass ton ha^{-1}
Cinnamon fern (*Pakis*)*	20.64	85	7.33
Vegetable fern (*Kalakai*)*	3.04	10	1.22
Bracken fern (*Hawuk*)*	1.46	3	0.37
Others	*ns*	2	0.24
Total	24.96	100	9.16

Grasses: Abundant local grasses, such as cinnamon fern, vegetable fern, and bracken fern dominated in the open area of secondary tropical peat swamp forest. Such grasses are suitable to growth in the wet soil condition and survive against fire damage with the hard cuticular surface and containing much mucus. Density of the cinnamon fern was 20.64 clumps ha^{-1}, growing evenly in the site with heights of 1 - 3 m. The total amount of the cinnamon fern was about 7.3 ton ha^{-1}, while vegetable fern was about 1.2 ton ha^{-1}. The grass condition before fire experiment was showed in Table 1.

Table 2. Density of trees in the study site before the fire experiment.

Tree species	Density ha^{-1}	Area %	Biomass ton ha^{-1}
Combretocarpus rotundatus	391	68	19.55
Craxtoxylum arborescens	133	23	6.65
Others	35	9	1.18
Total	559	100	26.20

Trees Density of trees before fire experiment was showed in Table 2. The *Combretocarpus rotundatus* dominated with the covering rate of 68% in the site and a total biomass weight of 7.33 tons ha^{-1}. The *Cratoxylum arborescens* covered 10% with a total mass weight of 6.65 tons ha-1. Total biomass weight in the study site was 9.16 tons ha-1.

Table 3. Wood debris compositions in the study site

Wood debris in different diameter	Fuel Composition	Amount of biomass
	(%)	ton ha^{-1}
D < 2.5 cm	0.65	2.61
2.5<D<5cm	1.63	6.54
Large fallen wood	1.69	6.78
Total	3.97	15.93

Wood debris The one of most important fuels is such a wood debris on the ground as the fallen large branches and trunks. The wood debris was classified with a diameter and shown in the Table 3. Mass of wood debris before fire experiment such as D< 2.5cm was about 2.6ton ha^{-1}, 2,5<D<5cm was about 6.5 ton ha^{-1} and large wood fallen D>5 cm was about 6.7 ton ha^{-1}, respectively. The

Table 4. Composition of litters and surface peat in the study site.

Materials	Fuel composition	Amount of biomass
	(%)	ton ha^{-1}
Litters	4.1	16.2
Peat 0-20 cm	83.4	334.3
Total	87.5	350.5

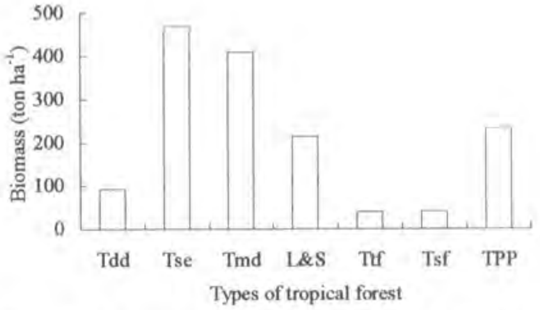


Fig. 7. Amount of biomass fuel in the tropical forests. Tdd: a tropical dry deciduous, Tse: a tropical semi-evergreen, Tmd: a tropical moist deciduous, L&S: a littoral and swampy, Ttf: a tropical thorn, Tsf: a tropical secondary forests, and TPP: a tropical peat forests of study site.

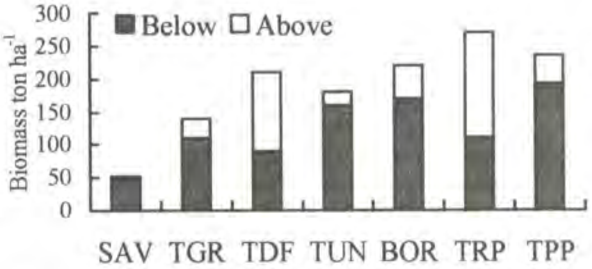


Fig. 8. Amount of the organic matters above and below the ground surface in SAV: savanna, TGR: temperate grassland, TDF: temperate deciduous forest, TUN: tundra, BOR: boreal forest, TRF: tropical forest and TPP: secondary tropical peat forest in the study site.

composition of this fuel to the fuel total of study site of secondary peat swamp forest was about 3.97%.

Litters. Litter is also important as s fuel in a tropical peat swamp forest which definite as an organic matter (OM) on the surface of the ground without decomposing. Organic matters were consisted mainly from grasses, and mixed with leaves, twigs in this site. The total weight of litters was 16 tons ha^{-1} and sharing rate of this type of fuel was 4% in this site.

Peat surface

Ground water level was usually lower than 10 cm in the forest during dry season, and dropped down to lower than 50 cm in a dry year which coincided with el nino event. The peat layer from surface to 20 cm deep was assumed to take a part of the forest/peat fire in such a dry year. The most of the surface peat in the forest still keeps the high ratio of the organic material content of more than 60%. The peat surface layer to 20 cm deep has a fuel potential of 334.3 ton ha-1 which shares 83% of total fuel biomass.

The amount of biomass fuel, 234 ton ha^{-1} in a tropical peat forest of study site was around a half of a tropical semi-evergreen, 468 ton ha^{-1}, and a tropical moist deciduous, 409 ton ha^{-1} forests, and similar to a littoral and swampy forest, 200 ton ha^{-1} (Fig. 7). However, it was more than double of that in a tropical deciduas forest, 93 ton ha^{-1}, and four times of that in a tropical thorn forest, 40 ton ha^{-1} and a tropical secondary forest, 41 tons ha^{-1}. The amount of biomass above the ground in this study site was 42 tons ha^{-1} which was a quarter of a tropical forest and one third of a temperate deciduous forest (Fig. 8). However, the amount of biomass below the ground surface, 193 tons ha^{-1} in the study site was the largest one among the other types of the forest. A boreal forest, 170 tons ha^{-1} and a tundra, 160 tons ha^{-1} followed it. The ratio of biomass above the ground in the total biomass was 18 % in the study site which was larger than in savanna 10% and in tundra 11%, but similar with temperate grassland 21% and boreal forest 23%.

5-2. Fire damage on the biomass and peat fuels in the field

The lost of biomass in each biomass fuels after the fire experiment in the study site are shown in Table 5.

The aerial fuel biomass 15.7 tons ha^{-1} in dry matter which includes trunks, blanches and leaves of trees was reduced to 9.1 tons ha^{-1} after the experiment. The ratio of the burned aerial biomass was 42.6%. However the 91.2% of the leaves was burned.

Table 5, Amounts of biomass fuels in the study site before and after the fire experiment on 2nd September, 2000.

Fuel Classifications	Before fire		After fire	
	Fresh biomass	Dry biomass	Remained dry biomass	Ratio of burned biomass
	ton ha^{-1}	ton ha^{-1}	ton ha^{-1}	%
1. Aerial Fuel Biomass (AFB)	**27.4**	**15.7**	**9.0**	**42.6**
a. Combretocarpus rotundatus	19.6	11.2	6.8	39.6
b. Cratoxylum arborescens	6.7	4.0	2.1	45.7
c. Leaves	1.2	0.5	0.1	91.2
2. Surface Fuel Biomass (SFB)	**24.9**	**13.3**	**9.3**	**35.9**
a. Cinnamon fern	7.3	1.6	0.4	70.2
b. Vegetable fern	1.2	0.4	0.1	67.4
c. Bracken fern	0.4	0.3	0.1	52.4
d. Wood debris (< 2.5 cm)	2.6	2.1	1.7	20.3
e. Wood debris (–5- 2.5 cm)	6.5	4.9	3.7	24.5
f. Large wood fallen	6.8	4.1	3.3	20.6
3. Litters Fuel Biomass (LFB)	**16.2**	**12.1**	**9.1**	**25.3**
4. Peat fuel (PF) *	**334.3**	**193.7**	**193.7**	**0.0**
Total	**402.5**	**234.8**	**221.1**	**6.8**

The 35.9% f the surface biomass fuels has burned. Grasses in the forest floor showed the high loss ratios by burning. The 70% of cinnamon and 67% of vegetable ferns were burned but the loss ratio of the wood debris and fallen woods were less than 25%. The peat fuel were not burned in this experiment. The difficulty for peat being burned in this study site suggested that the quality of peat as a fuel were very important for the peat fire events.

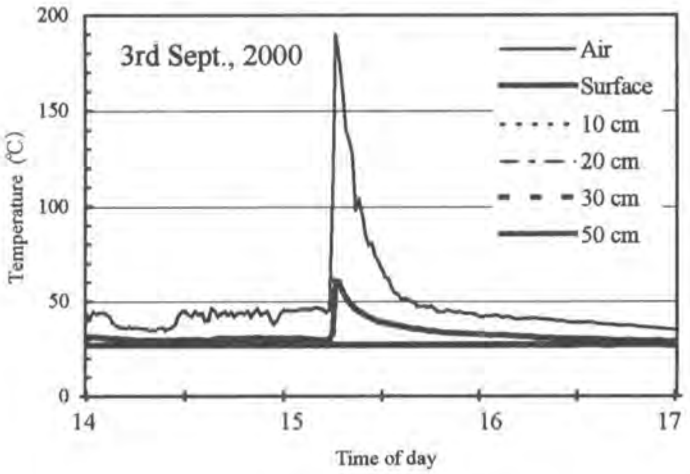


Fig. 9. Fire temperatures in the air, on the soil surface and peat layers at 10, 20 and 50 cm deep in the study site.

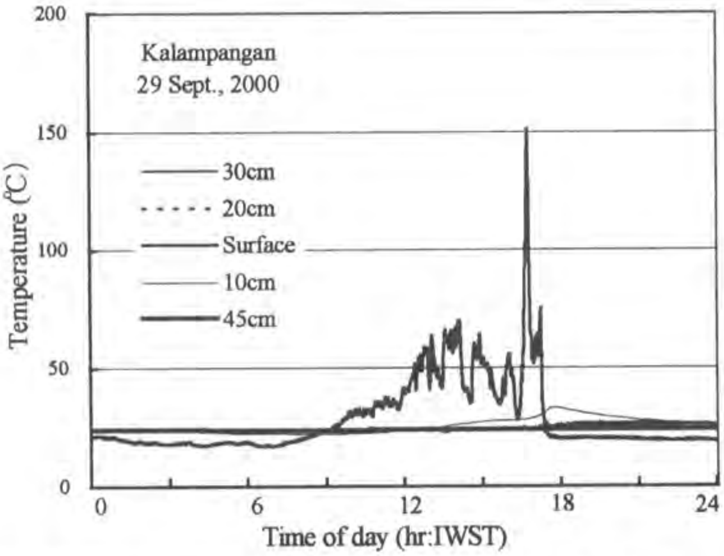


Fig.10. Temperature changes at the surface and peat layers at 10, 20, 30, 15 cm deep during the wild fire on the peatland at Kalampangan, 29th September, 2000.

5-3. Fire temperatures in air and peat layers

The air temperature at 1 m high and the temperatures on the ground surface and in the layers at 10, 20, 30 and 50 cm deep were measured at the center of the fire experimental plot of 20 m square. Trees on the plot were cut before the test and dried for several days. Ground water level was 60 cm below the ground surface. Debris and litters on the southern fringe of the plot were ignited at 1500 in local time. The fire front spreads quickly toward inside of the plot and reached the center of the plot at 1515 in local time.

Air temperature increased suddenly to 180℃ when the fire front reached the center of the experimental plot. But the temperature of ground surface increased to only 60℃. This low temperature means that the burning of debris above the ground can not ignite the peat surface if the peat layer is wet and supply easily water from deeper layer to surface.

However the temperatures in deeper layers at 10, 20, 30 and 50 cm deep, have not been effected by fire and kept 27 ℃.

Fig. 10 shows the temperatures on the surface and in the peat layers at the wasteland in Kalampangan when the area was burning by wild fire on 29th September, 2000. The peat surface was dry at that time, so the surface temperature showed a typical diurnal change affected by solar radiation. Surface temperature rose suddenly to 150 ℃ at 1630 hr in local time. But the surface temperature dropped to normal temperature until 1800 hr when the fire front reached this point. The temperature of peat layer at 10 cm deep increased to 30 ℃ at around 1800 hr. But it was not clear that this small rise of temperature was caused by the fire front or the ordinary changes of soil temperature. However, the effect of peat fire was limited on the ground surface in this case.

6. Conclusions

The field experiments on the characteristics of peat fire were conducted in a secondary tropical peat forest of Central Kalimantan. An experimental plot of one hectare in area was used for estimation of biomass amount before the fire. A part of the plot, 30 m by 30 m square was used for the burning experiment of peat and biomass in the field.

Based on the field experiments, we concluded as follows,

1. The 82% of the biomass fuels in a secondary tropical peat forest were sheared by the peat layer from surface to 20 cm deep.
2. The 43% of the aerial fuels, the 36% of the surface fuels and 25% of the litter fuels were burned by the fire experiment. But no peat fuel was burned.
3. The fire temperature in the air rose to 180 °C when the fire front reached to the measuring point. But the temperature on the ground surface rose only to 60 °C. And the peat layer did not burned by itself in the fire experiment.
4. The temperatures of the ground surface at the fire front of wild fire in Kalampangan rose to 150 °C, but the temperature of the peat layer at 10 cm deep did not rise above 30 °C. The difference of the burning behaviors in the experimental site and the wild fire in Kalampangan means the such characteristics of peat as moisture, density and other chemical/physical properties have important roles in the burning of peat layers.

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Transpiration of trees and evapotranspiration estimated from ground water level change in a tropical peat swamp forest in Central Kalimantan, Indonesia

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Abstract

Tropical peat swamp forests play an important role in stabilizing the bio-ecosystem, regional hydrology and carbon dynamics. They host a rich biodiversity, including several commercially important tree species that are endemic in this habitat, such as Ramin (*Gonystylus bancanus)* and Meranti (*Shorea balangeran*). However, despite the economical and hydrological significance of these tree species, relatively little information exist about their ecophysiology, and in particular about their transpiration behavior and water use under natural conditions. Transpiration behavior and water use of Ramin and Meranti were studied at tree level in a peat swamp forest in Kalimantan.

Hourly evapotranspiration from a forest were estimated from the changes of ground water level near the plot of sap flow measurement and compared with the behaviors of transpiration from Ramin and Meranti.

The study was conducted in the Setia Alam Natural Forest Laboratory, Central Kalimantan, Indonesia during the dry season from July to September 2001. One Ramin and one Meranti tree were chosen to measure the sap flow using a thermal dissipation probe (TDP-30). The study showed that average daily transpiration was 0.81 mm d^{-1} and 1.32 mm d^{-1} in Ramin (*Gonystylus bancanus*) and in Meranti (*Shorea balangeran*), respectively. This difference was due to a large difference in sap velocity.

Diurnal changes in transpiration rates in the two trees were found to be strongly dependent on vapor pressure deficit (VPD). However, the relationship between the transpiration of Ramin and solar radiation (Sr) was not high ($R^2 = 0.64$). A time lag of 1-2 hours was observed between diurnal changes of solar radiation and transpiration rates.

Ramin and Meranti exhibited a similar responses to vapor pressure deficit (VPD), though the transpiration rate in Ramin as lower than Meranti. In the two species, transpiration rates increased with increasing VPD and reached a maximum value at a VPD of about 2.9 kPa. Above the value of 2.9 kPa, transpiration rate decreased. The same response was also observed in evapotranspiration rates, but the threshold was slightly lower at a VPD of about 2.7 kPa.

Diurnal variation of transpiration (Tr) in the two species was strongly correlated with diurnal variation in evapotranspiration (Et). They also exhibited similar trends to, and were well correlated with the variation of the vapor pressure deficit (VPD). The ratio of transpiration (Tr) to evapotranspiration (Et) in the two species and was 0.30 and 0.35 for Ramin and Meranti, respectively.

1. Introduction

Characteristics of tropical peat swamp forests are in high ground water level and deep peat accumulation above the mineral soil. The heat capacity of a high water level and the thermal characteristics of a peat soil lead to a different microclimate near the ground compared to a dry areas with mineral soil in the temperate zone. The evaluation of well-established microclimates in such ecosystem is also relatively rare (Takahashi & Yonetani, 1997).

The forest provides an important reservoir of biodiversity, containing a number of tree species which are endemic to this habitat, including several of commercial importance, such as Ramin (*Gonystylus bancanus)* and Mearnti (*Shorea* sp) (Shepherd, 1997). Ramin (*Gonystylus* spp) is a tropical hardwood tree species, growing in lowland freshwater swamp and peat swamp forests. Its distribution is confined to Borneo, Sumatra and Peninsular Malaysia and all of the 27 different species of Ramin for which data exist have been classified as vulnerable. The status of Ramin was discussed in the 1994 meeting of the Convention on International Trade in Endangered Species (CITES). Concerns were raised over the effect of over-exploitation and habitat loss on the survival of the species. Although Ramin is the most valuable tree species found in Borneo's swamp forest, it is vulnerable to commercial extraction due to low generation rates in this ecosystem and it has never been successfully cultivated as a plantation timber.

Roles of a tropical peat swamp forest on the global environment are increasing year by year after the Second War. But the situation of the forest now became very fragile due to the over logging and development for agriculture with drainage system. Peat swamp forests which has been dried by drainage are in danger of forest/peat fire.

However, despite of the importance of tropical peat swamp forest in the global environment and hydrological significance of the trees, relatively little information exist about the ecology and physiology of these species, particularly with regard to transpiration behavior and water use relations in their natural conditions.

The transpiration rate of whole plants can be closely approximated by the sap flow rate in the main stem or trunk. One method was proposed by Granier (1985, 1987), measures xylem sap flow (i.e. TDP method) and gives an accurate and inexpensive estimate of whole-tree transpiration. The method was applied o some trees in boreal forest, subtropical forest, and tropical dryland rain forest, yet there is no information for trees in tropical peat swamp forests.

Daily evapotranspiration were estimated from the changes of ground water level in a boreal peat swamp (Umeda and Inoue, 1982) and in a tropical peat swamp forest (Takahashi, 1999). Hourly evapotranspiration also estimated from ground water level change in a boreal mire and compared with the zap flow behavior of (Takahashi et al., 1999). But such a detail estimation of hourly evapotranspiration has not yet conducted in a tropical peat swamp forest.

The one objective of this study is to investigate the transpiration behaviors and to quantify water use of Ramin (*Gonystylus bancanus* Kurz) and Meranti (*Shorea balangeran*) tree at the tree level in peat swamp forest. And second one is to evaluate the hourly evapotranspiration which is estimated from ground water level change using the diurnal behaviors of sap flows in trees.

2. Materials and Methods

2.1. Study site

The study site was located in Setia Alam Natural Forest Laboratory, in the Kota Madya Regency of Central Kalimantan Province of Indonesia. The site is in the upper catchment of the Sebangau River, about 20 km from Palangka Raya.

A one ha (100 m by 100m) plot with sides orientated east to west and north to south was established, approximately 3.5 km from the river bank of Sebangau river and 150 m from the extraction railways of the Setia Alam logging concession.

The forest floor of the plot is uneven with prominent hummocks and hollows. In the rainy season, the forest floor is very wet, with a series of interconnected pools. Water flows out from this forest towards the river through a rough and permeable subsurface or above the rough surface with a lot of hollows. In the dry season the ground water table falls below the surface of the hollows and by the end of the dry season there is usually no water in either the pools or outflow stream.

In the marginal mixed swamp forest, where the plot is established, both peat depth and surface elevation increase, achieving a maximum depth of 4 m and elevation of 4 m above the Sebangau River. The averaged peat depth in the forest is 3 m (Shepherd, 1997).

2.2. Diameter, height, and canopy area measurements

To obtain information of the structure and the tree composition in the plot, inventory activities were conducted. In the plot, all trees with a minimum diameter at breast height (dbh) being 10 cm was identified by attaching a numbered aluminum tree tag. The diameter at breast height (dbh, at standard height of 1.3 m above the ground), height and canopy area were determined for all measurable trees in each plot.

The dbh was obtained by using a diameter tape; height was determined by using a haga (Germany) and canopy area was calculated from vertical projections (north, south, west and east direction) to the ground of the crown perimeter. While crown status was visually assessed base on the crown characteristics.

2.3. Tree selection and sapwood area measurement.

One Ramin tree and one Meranti tree in the plot were chosen for measurement of sap flow, and sapwood cross-section of the studied trees were estimated from cores by using a core borer. Sapwood thickness was manually measured, the distinction between sapwood and heartwood being made from the difference in color or in transparency, due to differences in water content. The research was conducted during a dry season, for a 3 months period in 2001.

2.4. Sap flow measurements

Sap flow for each tree was calculated as the product of sap velocity, cross-sectional sapwood and the fraction of sapwood function in water transport. Sap velocity rates were determined with thermal dissipation probe (TDP-30 , Dynamax Inc, Houston, TX, USA). For each stem of the study trees 2 pair probes were installed. These probes operated on the constant power principle (Granier, 1987), and each pair of probes consisted of two cylindrical probes of 1.2 mm diameter stainless steel tube, that was 30 mm long and was inserted 3 cm into the sapwood of the tree. The two probes were inserted one above the other and separated along the stem by 4 cm. The upper probe was installed at a height 1.5 m and contained a heating element that heated at 200 mW with a 110 mA constant power source. The lower probe served as an unheated reference. Each probe contained a copper-constantan thermocouple and the temperature difference between the probes was influenced by sap velocity in the vicinity of the heated probe. All probes were installed on the northern side of trees to avoid direct solar heating and shielded with aluminum foil to minimize temperature fluctuation in the sapwood. Sap velocity rates were monitored every 1 minute interval and recorded as a half-hour averages using a CR10X logger (Campbell Scientific, Inc. Houston, TX, USA).

As both thermocouples were connected in opposition, this gives the temperature difference between the two needles directly, and the dimensionless "flow index "(K) can be calculated as:

$$K = (dT_M - dT)/dT \qquad (1)$$

where dT_M is the value of dT when there is no sap flow (zero set value) and dT is the measured difference in temperature between the two needles.

Laboratory experiments have shown that a reliable relationship exists between the observed temperature difference and the velocity of sap flow (V), that is :

$$V = 0.0119K^{1.231} \qquad [\text{cm s}^{-1}] \qquad (2)$$

where V is average sap flow velocity along the length of the probe (cm s^{-1}) and K is a dimensionless flow index.

Sap flow flux (Fs, volume per unit time) can be computed as :

$$Fs = AsV \qquad [\text{cm}^3\ \text{s}^{-1}] \qquad (3a)$$

$$Fs = 3600AsV \qquad [\text{cm}^3\ \text{h}^{-1}] \qquad (3b)$$

where F_s is the sap flow flux (cm^3 h^{-1}) and A_s is the cross-sectional area of sap conducting wood (cm^2).

Transpiration of an individual tree (Tr) can be estimated with :

$$Tr = Fc / Ac \qquad (4)$$

where Ac is the projected ground area of the tree crown.

2.5. Weather measurements

Air temperature and humidity at 1.5 m above ground level were measured at the camp station with a thermo-hygrometer (Vaisala Co. Ltd, Finland and Kadec-HTV, KONA System Co. Ltd, Japan). Solar radiation was measured at Plot-1b with a solarimeter (PC-01, Meiwa Co. Ltd) and a data logger (Kadec-Up, JAPAN). All measurements were made each minute and hourly means were recorded. Vapor pressure deficit was calculated from air temperature and humidity data.

2.6. Ground water level measurement

Ground water level was measured using a pressure sensor (PDCR940, Druck Co. Ltd, UK) and associated data logger (Kadec-UN, JAPAN) with one hour interval. The instrument was set up in Plot-1c, near the trees on which the sap flow probes were installed. Another ground water sensor was also set up in Plot-1b.

2.7. Estimation of evapotranspiration from ground water level

The hourly evapotranspiration from a forest was estimated from the ground water level changes (Takahashi *et al.*,2001) with:

$$Et_{hr} = c_{rg}(\Delta G_{wl} - Sp_{hr})$$

where Et_{hr}: the estimated hourly evapotranspiration (mm h^{-1}), c_{rg}: the ratio of increasing of ground water level to precipitation, ΔG_{wl}: the ground water level changes per unit time (mm h^{-1}) and Sp_{hr}: the seepage ratio of ground water (mm h^{-1}). Seepage ratio (Sp_{hr}) was calculated from changes of ground water level from 20 pm to 4 am, during which time evapotranspiration was negligible.

2.8. Statistical analysis

The statistical significance of species effects was determined by analysis of variance (ANOVA). The significances of differences between individual species were analyzed using t-tests. Regression analysis was used to determine the relationships between water use of trees and climate components

2.9. Duration of observation

Sap flow, air temperature, humidity and ground water level measurements that were measured in the dry season from 23 July – 27 September 2001. Global solar radiation was measured from 20 August to 27 September 2001. The plot was established in 2000 and an inventory of the plot to collect information of characteristic and composition of the trees was conducted until 2001.

3. RESULTS

3.1. Structure and composition of forest

Based on the inventory of all trees being larger than 10 cm in diameter, total of 597 trees of approximately 47 genera were located in the plot. Maximum height of trees was 30 m and maximum diameter at breast height (dbh) was 70 cm.

3.2. Meteorological and ground water level conditions

Conditions at the study site during the 2001 measurement period were characterized by high humidity and air temperature. The average relative humidity was 83.3 % and the averaged air temperature was 26.6 °C. Dew usually occurred during the early morning hours with forest vegetation often wet until 09.30 local time. Solar radiation was sometimes reduced by overcast conditions.

Ground water level tended to decrease from the beginning (July) to the end (September) of the measurement period, but increased on certain days rainfall. The average water level during the measurement period was 53.95 cm below ground surface and range from 34.17 to 71.30 cm below the ground surface.

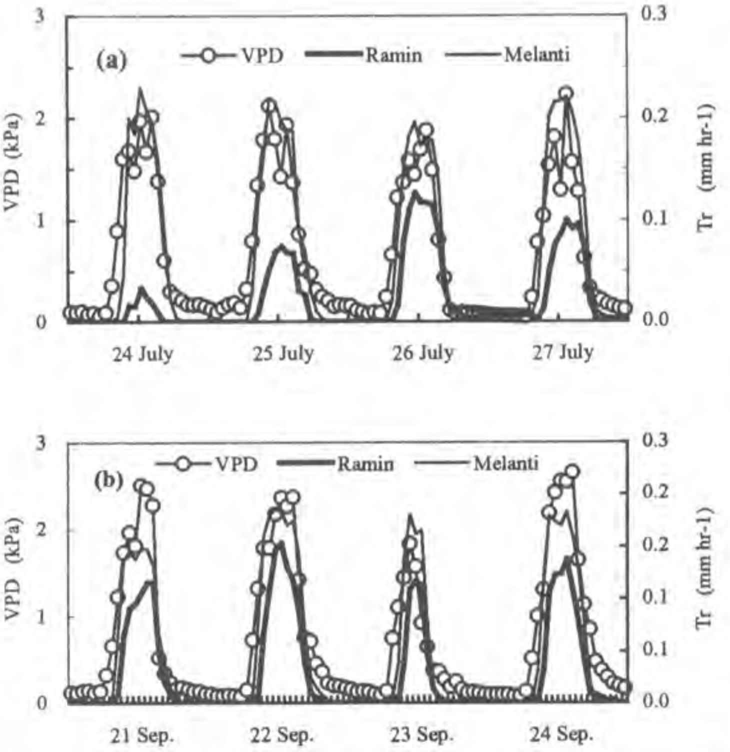

Fig.1 Diurnal change of VPD and transpiration rate (Tr) of Ramin and Melanti at (a): beginning of dry season and (b): end of dry season in 2001.

3.3. Species comparison of sap velocity

Interestingly, although Ramin was bigger and taller than Meranti, the mean sap velocity from 23 July to 27 September 2001 was lower in the former species. Meranti tree has more than twice the daily mean sap velocity than Ramin tree. Daily mean sap velocities during the measurement period were 0.0244 mm s^{-1} and 0.0117 mm s^{-1} for Meranti and Ramin, respectively. This difference between these two species was statistically significant ($P< 0.001$).

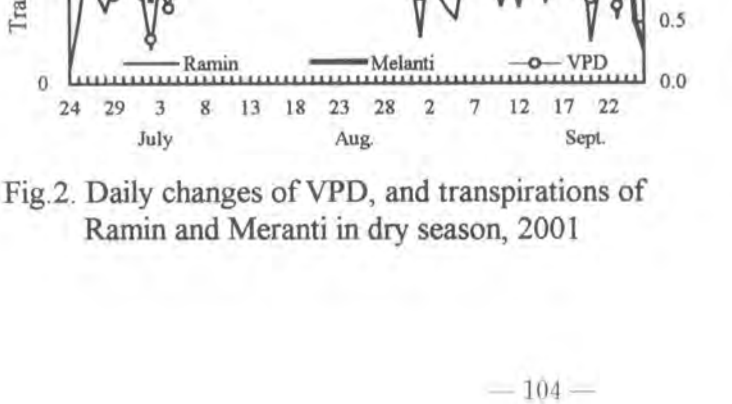

Fig.2. Daily changes of VPD, and transpirations of Ramin and Meranti in dry season, 2001

3.4. Response of transpiration to VPD in two species

Diurnal change of sap flow (transpiration Tr) in Ramin and Meranti were followed the diurnal change of VPD with around one hour lug through duration of dry season (Fig. 1). Around the middle of August, transpirations were relatively high in the two species. There was variation between the two species, and the differences were statistically significant. This period included several hot days with low humidity, when daytime vapor pressure deficit (VPD) sometimes peaked at between 3.6 and 3.9 kPa.

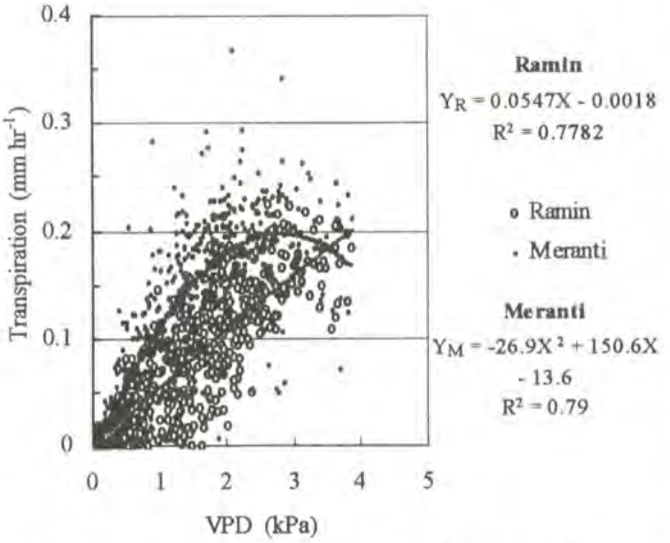

Fig.3. Relationships between the VPD and the transpiration of Ramin and Meranti

Daily transpirations of Ramin changed following to daily mean VPD during the experiment from July to September (Fig.2). On 16 August, transpiration Meranti reached its highest value of 2.2 mm day^{-1} although the VPD on that day was only at 1.12 kPa in diurnal mean, and then kept relatively high level constantly, though the VPD increased to the maximum value of 1.69 kPa in daily mean on 24 August. The VPD was kept relatively in constant in the range 20 – 60 kPa during September. But the transpiration of Meranti decreased from around 1.5 mm d^{-1} in the beginning of September to 1.0 mm day^{-1} in the end of September. The plot of the hourly transpiration in the daytime against the hourly VPD during the experiment period is shown in Fig.3. Responses of transpiration in the two species to VPD were different in pattern. Transpiration in Ramin increased linearly with relatively high correlation (R^2=0.78), on the other hand transpiration in Meranti increased up to 2.5 kPa in VPD and showed a threshold at around 0.2 mm hr-1 of transpiration.

3.4. Species comparison of water use per tree

During 23 July to 27 September 2001 period, Meranti (*Shorea balangeran*) had daily water use 1.5 times greater than Ramin (*Gonystylus bancanus*). Average daily water use was 7.8×10^3 cm^3 d^{-1} and 11.9×10^3 cm^3 d^{-1} in Ramin and Meranti. This difference was largely due to differences in sap velocity. The sap velocity in Meranti was more than twofold of that in Ramin tree, whereas differences in conducting wood area and canopy area were comparatively small.

3.5. Species comparison of transpiration per unit canopy area

During the experiment of July – September 2001, the difference of transpiration per unit canopy area between the two species was high, Meranti had daily a water use per unit canopy area 1.6 times greater than Ramin on average, where average daily

Table. Dimensions and the sap flows of Ramin and Meranti trees measured from 22 July to 27 September, 2001.

Species	Diameter at 1.5 m in height (cm)	Sapwood area (cm^2)	Canopy area (m2)	Height (m)	Sap flow velocity (mm s^{-1})	Transpiration per tree (litter d^{-1})	Transpiration per unit area (mm d^{-1})
Ramin	15	126	9.62	21	0.0244	7.8	0.81
Meranti	14	93	9.07	17	0.0117	11.9	1.32

transpiration of Ramin was 0.81 mm day^{-1} (range from 0.12 to 1.36 mm d^{-1}) and that of Meranti was 1.32 mm d^{-1} (range from 0.23 to 2.16 mm d^{-1}).

3.6 Relationship between tree transpiration, VPD and solar radiation

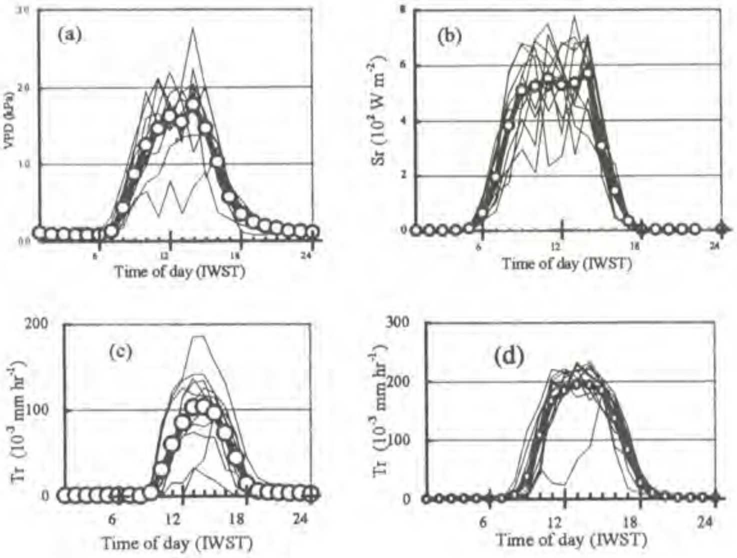

Fig.4. Diurnal changes of (a)VPD, (b) Solar radiation, (c) Transpiration of Ramin and (d) Meranti from 24 July – 3 Aug.,2001. Thin solid lines: daily changes, thick solid line with circle: mean values .

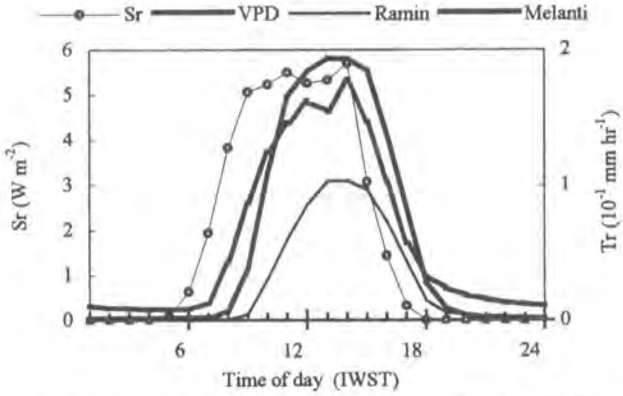

Fig.5. Patterns of diurnal changes in Sr, VPD, Trs of Ramin and Meranti which were obtained from the 11 days averages of each daily values

Diurnal variation of transpiration rates in Ramin and Meranti , vapour pressure deficit (VPD) and solar radiation (Sr) during a representative days from 24 July to 3 August 2001 is showed in Fig.4. The VPD during night were less than 1 kPa and increased largely after 7h (in Indonesian Western Standard Time, IWST) in the most of days. In the afternoon, VPD decreased rapidly from around 15h until 17h, after that it decreased gradually till 21 h. Difference of the daily patterns in VPD changes were not so large without one or two days (Fig.4a).

The solar radiation increased from 5h until around 10h and decreased quickly after 14h to 17h (Fig.4b). Transpirations of Ramin and Meranti increased quickly from 10h and 8h in the morning respectively. The time lugs between the patterns of the four items are clearly shown in Fig.5.. Diurnal change of VPD increased with around one hour lug and decreased gradually in the afternoon. VPD kept the relatively higher level than 0.1 kPa for 3-4 hours after sunset.

Transpiration of Meranti started to increase two and a half hour after the sunrise and reached to peak at around 13h. After that it decreased to zero. But the transpiration was still active after sunset. Transpiration of Ramin also started to increase more than three hours after sunrise.

3.6. Relationship between tree transpiration and evapotranspiration

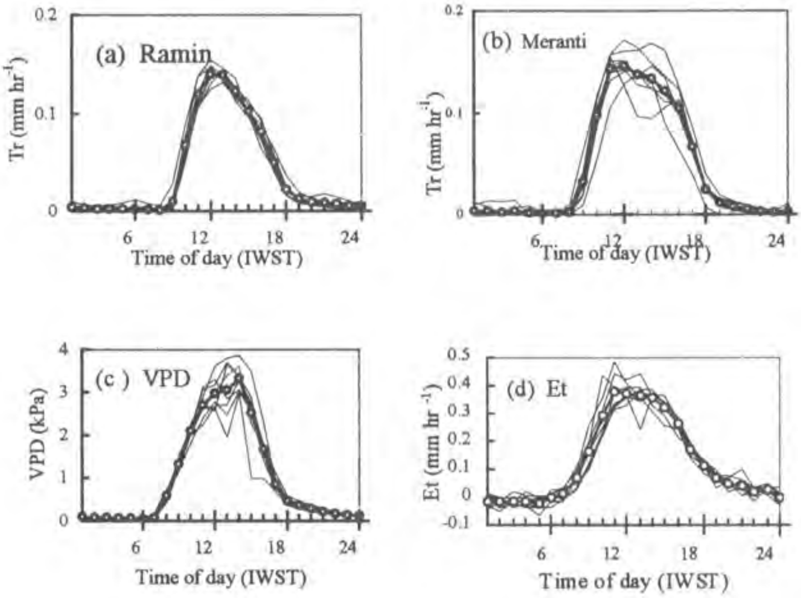

Fig.6. Diurnal changes of transpiration from (a)Ramin and (b) Meranti, (c) VPD and (d) evapotranspiration from 17 to 24 Aug., 2001. Thin solid lines: daily changes, thick solid line with circle: mean values.

Fig. 6 shows the diurnal changes of transpiration from the two species, VPD and evapotranspiration from the forest at Plot-1b with mean values of them during 17 – 24 August, 2001. Daily fluctuation of each items are similar for each day, especially in the case of the transpiration from Ramin and the evapotranspiration from a forest.

Fig.7 shows the diurnal patterns of (a) the average transpiration in the two species and the evapotranspiration, and (b) VPD and the evapotranspiration, during the period. In Ramin and Meranti transpiration started to increase sharply at around 8h, which is one hour later than the increasing of VPD, and the evapotranspiration which started at 7h. They peaked at around 13h in Meranti and Ramin.

Then, they had the tendency to gradually decreased toward evening. The same pattern is also found in evapotranspiration. The peak time for evapotranspiration and VPD were 13h and 10 minute to 13h, respectively. This suggests that the diurnal variation of transpiration in the two species had the same pattern with evapo- transpiration (Fig.7a) and the evapo- transpiration also exhibited a remarkable coincidence with the VPD (Fig.7b). The evapotranspiration was still continued after sunset at around 18h till 21h and showed minus value from 0h to 7h with minimum at 6h in the morning

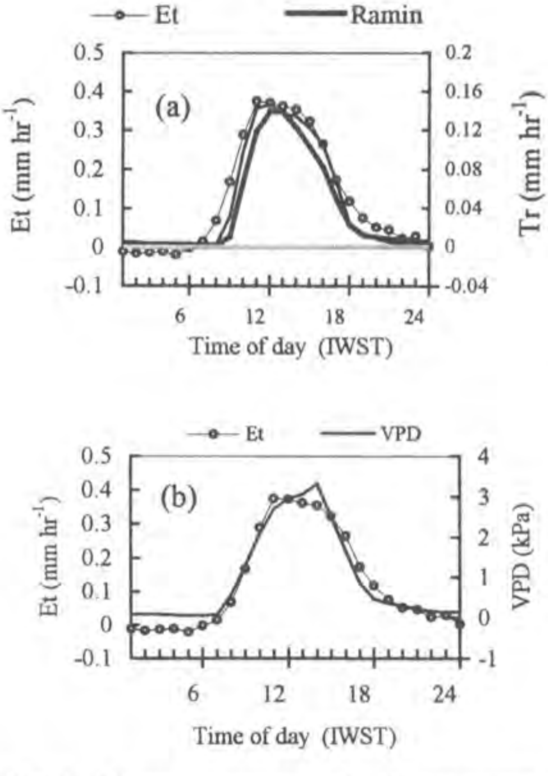

Fig.7. Diurnal changes of (a) transpiration from Ramin and Meranti, evapo- transpiration, (b) VPD and evapo- transpiration from 17 to 24 Aug., 2001.

There were a good linear correlation between hourly evapotranspiration which was estimated using the ground water level, and the hourly transpirations in Ramin ($R^2 = 0.85$) and Meranti ($R^2 = 0.83$). A good linear relationship also existed between the evapotranspiration and VPD with $R^2 = 0.83$.

The ratio of transpirations to the evapotranspiration from the forest were 0.30 and 0.35 for Ramin and Meranti, respectively.

4. Discussion

4.1. Species differences in transpiration

Over the experimental period in the dry season (July – September 2001), it was found that Ramin had a lower in transpiration rate than Meranti, although Ramin was bigger and higher than Meranti. Presumably this difference was largely due to species differences in sap velocity (Figs.1 and 2) that occurred as a result of species differences in stomatal response to climatic drivers, e.g. VPD and solar radiation. Meranti had a faster sap velocity than Ramin and this may be attributed to stronger stomatal response to the climatic components. Thus, there is strong possibility that Meranti is amphistomatous, whereas Ramin is hypostomatous. Or this may be due to a species differences in exposure to incident solar radiation. Meranti grew relatively nearer to the forest gap and more open from the neighboring tree crown than Ramin. Consequently, Meranti was more exposed to incident solar radiation. Differences in microclimate condition within the canopy between the two species could also have resulted in a difference in transpiration (Benyon, et al., 2001). Another possibility is species differences in leaf area index between the tree crowns. Meranti may be larger in leaf area. And the larger amount of leaves provided a wider leaf surface for transpiration. The amount of foliage along substantially longer and denser crowns can also result in higher transpiration (Cermak, et al., 1995). Furthermore, Meranti had a higher sap flow rate per unit sap wood area than Ramin, suggesting that these trees utilize their structure more efficiently (Jimenez et al., 1996). Giambelluca, et al., (2001, in preparation) also reported a similar case between *Garcinia plantonii* (dbh 35 cm) and *Alphonsea tonkinensis* (dbh 12 cm) that grow in the same forest patch in Hoa Binh, Vietnam. *Alphonsea tonkinensis* showed higher transpiration (0.82 mm d^{-1}) than *Garcinia plantonii* (0.56 mm d^{-1}). They also reported that significant differences were found not only among species, but also among individual trees, that may be attributed to differences in solar exposure due to location relative to the forest edge, topographic features, vertical and horizontal position of crown relative to neighboring tree crowns, and to differences in leaf area index among the different tree crowns.

4.2. Response of species water use to VPD and solar radiation

Sap velocities were relatively higher in the two species at around the middle of August 2001 (17 – 24 August). This period included several hot days with low humidity, when the daytime vapor pressure deficit (VPD) sometimes peaked to between 3.6 and 3.9 kPa .On 17 August, the sap velocity in Ramin reached its highest value of 0.048 mm s^{-1} but the VPD at that time were only 2.9 kPa, and then although the VPD increased, the sap velocities were remained relatively constant at an average of 0.04 mm s^{-1}. As the VPD achieved its maximum value of about 3.9 kPa, sap velocity in Ramin was decreased to 0.042 mm s^{-1}.

The plot of daytime hourly transpiration against daytime hourly VPD during the experiment period showed that the response of transpiration in the two species to VPD showed a different pattern. Transpiration in Meranti increased up to the VPD of about 2.9 kPa and above this threshold, the transpiration had a tendency to decrease indicating stomatal closure (Fig.3). On the other hand, the transpiration in Ramin had no threshold until the VPD reached to around 3.5 kPa.

The response of canopy transpiration to VPD has been the subject of some debate, mainly regarding whether the rate of canopy transpiration increases monotonically with increasing VPD or whether they instead reach a plateau where stomatal closure beyond a threshold value of VPD restricts further increases in canopy transpiration (Wullchelleger, et al., 2000). Myers et al. (1998) reported a strong, positive correlation between daily transpiration and daytime mean VPD for a young *Eucalyptus grandis* stand, but noted that as mean daytime VPD increased above ca. 1.5 kPa there where no further increases in transpiration. On the contrary, Wullchelleger et al. (2000) reported there was a steady increased in canopy transpiration for red maple beyond a threshold of 2.0 – 2.5 kPa. Results of this study were similar with those of Myer et al. (1998) in that there were no further increases in transpiration beyond the thresholds of VPD (Fig. 3).

Meranti (*Shorea belangeran*) had daily water use per sap conducting wood 1.5 times greater than Ramin and 1.6 times greater in transpiration per unit canopy. Presumbly this difference was mainly due to species differences in sap velocity. The sap velocity in Meranti was more than twofold that of Ramin tree (Fig. 6), whereas differences in conducting wood area and canopy area were comparatively small (Table 1). This result is different from the result from temperate areas in eucalypt trees, that grow on a saline discharge site where differences in water use between species were largely due to the differences in tree size (Benyon et al,. 2001). In their work, the differences in sap velocity were small and statistically not significant but differences in sapwood area, basal area and leaf area were higher and statistically significant. In this study, species differences in sap velocity are high and statistically significant but species differences in sap wood area and projected crown area were comparatively small.

Variation in transpiration both in Ramin and Meranti exhibited remarkable coincidence with the variation of vapor pressure deficit (VPD). In general, diurnal and daily variation of transpiration in Ramin and Meranti followed the diurnal and daily changes vapor pressure deficit. Presumably these behaviors due to the transpirations on Ramin tree were strongly coupled with VPD. Also, it found that there was a 1-2 hour lag in solar radiation to the transpiration rates in these species (Fig. 5). The same behavior was also found in several species, such as *Eperua falcate, Eperua grandifolia* and *Dicornia guainensis*, from the tropical rain forest in French Guiana (Granier, et al, 1996).

Regression analysis shown there were good relationship between the transpiration rate in the two species and VPD (Fig. 3). But the relationship between transpiration in Ramin and solar radiation was not high ($R^2 = 0.64$) compared to Meranti ($R^2 = 0.79$). Such phenomena was also found by Granier et al (1996), who measured transpiration on several species from the tropical rain forest in French Guiana and found that transpiration was closely dependant on air vapor pressure deficit and less correlated to global radiation. They assumed that this behavior could be attributed to a low threshold of saturation for light, so that radiation was not limiting during most of the day for a particular tree.

Analysis of the diurnal pattern between transpiration and solar radiation also suggests there was of around a 1-2 hour lag in solar radiation to the transpiration rate on the two species. Presumably this 1-2 hours lag is due to evaporation of dew on the surface of the leaves prior to a real transpiration exist, or alternatively, this suggests that a significant amount of water from tissue storage was used for transpiration in the morning hours (Cermak et al., 1995). In order to fit the relationship between transpiration on two species and solar radiation, it is needed to shift 1-2 hours upward from the solar radiation data. The observed strong relationship of transpiration rate to climatic variables also suggests that the resistance along the conductive pathway not limiting water transport. This also means that the tree water storage was small, and indicates that during the measurement period, soil water was available to the trees in sufficient amounts.

4.3. Relationship between tree water use and evapotranspiration

During a 17-24 August period, diurnal variation of transpiration in Ramin was relatively small compared of those in Meranti. At the same time, variation in vapor pressure deficit (VPD) and evapotranspiration was comparatively high (Fig.16). This suggests that transpiration in Meranti may be more sensitive to variation in vapor pressure deficit and ground water level than in Ramin.

Diurnal pattern of transpiration in the two species and evapotranspiration showed a similar pattern and clear correlation and also exhibited a remarkable coincidence with the variation of vapor pressure deficit (Fig.7). In Ramin and Meranti, transpiration started to increase sharply at around 8:00, which was one hour later than the increase of vapor pressure deficit and evapotranspiration that started at 7:00. They reached their peak at around 10 minute passed 13h for Meranti and Ramin, respectively. Then, they had the tendency to gradually decrease toward evening. The same pattern also found in evapotranspiration. The peak time for evapotranspiration and vapor pressure deficit was 13h and 10 minutes to12h, respectively. This suggests that the diurnal variation of transpiration in the two species had the same pattern with evapotranspiration (Fig.7a) and they also exhibited a remarkable correlation to the variation vapor pressure deficit (VPD). This result is relatively different with the result which was found by Takahashi et al, 2001 in a peat of the temperate zone, where the diurnal pattern between transpiration of species and evapotranspiration did not show a direct and clear correlation.

During the study period, diurnal changes of transpiration rates in Meranti, VPD and the evapotranspiration showed a strong polynomial shape (Fig.3). Moreover, the correlation among transpiration in two species, evapotranspiration from the forest, and VPD were high. Evapotranspiration increased as VPD increased, and it reached its peak (0.38 mm h^{-1}) when the VPD were at a value of about 2.7 kPa. Above the VPD value of 2.7 kPa, evapotranspiration started gradually to decrease. The same pattern was also observed in the transpiration rates of Ramin and Meranti, in correlation with VPD. Such a behavior of relationship between the evaporation/transpiration and VPD were observed in a boreal sphagnum mire in Hokkaido Japan (Takagi et al., 1998).

5. Conclusions

Average daily transpiration was 0.81 mm d^{-1} and 1.32 mm d^{-1} in Ramin (*Gonystylus bancanus*) and in Meranti (*Shorea balangeran*), respectively. This difference was due to a large difference in sap velocity.

Diurnal changes in transpiration in the two trees were found to be strongly dependent on vapour pressure deficit (VPD), but the relationship between transpiration in Ramin and solar radiation (Sr) was not high (R^2 = 0.64). The reason for this difference may due to a difference position of the trees in expose to incident radiation. A time lag of 1-2 hour was observed between diurnal changes of solar radiation and transpiration rates.

Ramin and Meranti exhibited a similar responses to VPD, although the transpiration rate in Ramin was lower than Meranti. In the two species, transpiration rates increased with increasing VPD and reached a maximum value at a VPD of about

2.9 kPa. Above the value of 2.9 kPa, transpiration rates decreased. The same response was also observed in evapotranspiration rates, but the threshold was slightly lower at a VPD of about 2.7 kPa.

Diurnal variation of the transpiration in the two species was strongly correlated with diurnal variation in the evapotranspiration. They also exhibited similar trends to, and were well correlated with the variation of VPD.

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Appendix 3-1

Meteorological Data at the weather station
in University of Palangka Raya

Location

S 02° 12' 55.3"
E 113° 54' 00.0"

Climatic elements and dimension

Air temperature (°C): Daily mean, max.and min.

Air relative humidity (%): Daily min.

Precipitation (mm day^{-1}): Daily total

Solar radiation (MJ m^{-2} day^{-1}): Daily total

Climatic Table Draied Area (UNPAR) Nov. 2000

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20001101	26.7	33.0	23.0	57.3	55.0	13.17
20001102	26.8	33.2	22.7	55.1	1.5	19.20
20001103	26.5	32.8	23.1	56.5	25.5	15.37
20001104	27.3	34.0	22.4	57.3	12.0	14.93
20001105	27.3	34.9	22.7	51.0	1.0	18.60
20001106	27.1	34.1	22.9	49.9	34.0	17.11
20001107	27.5	33.6	24.0	52.0	0.0	11.78
20001108	28.0	36.7	22.6	40.7	1.5	20.21
20001109	26.5	31.8	22.9	64.4	4.5	12.33
20001110	26.9	33.8	23.4	56.4	66.0	15.04
20001111	27.2	34.0	23.2	55.3	0.0	15.74
20001112	26.6	35.2	23.2	47.2	11.0	11.52
20001113	27.3	34.7	23.4	50.9	6.0	12.97
20001114	27.4	34.4	22.3	50.5	3.0	13.93
20001115	28.8	36.4	24.3	44.8	21.0	18.23
20001116	26.8	34.1	22.5	52.6	45.5	16.14
20001117	27.2	33.1	22.4	57.7	0.0	16.25
20001118	27.4	33.8	24.0	58.2	5.0	10.94
20001119	26.7	33.0	24.4	58.4	8.5	11.97
20001120	26.2	33.3	23.8	56.0	15.0	11.56
20001121	26.5	32.6	23.0	56.5	0.5	12.13
20001122	27.9	35.0	23.3	45.8	0.0	16.66
20001123	25.3	28.3	23.4	76.2	19.0	5.57
20001124	28.0	35.4	22.3	41.4	1.5	18.81
20001125	26.2	35.4	22.0	48.5	45.5	15.13
20001126	26.4	33.4	21.6	55.4	52.0	16.71
20001127	26.8	33.1	22.7	56.2	0.0	15.30
20001128	26.4	34.7	22.5	52.2	3.0	15.84
20001129	25.7	29.9	22.3	68.0	1.5	9.52
20001130	26.1	31.8	22.4	61.7	0.0	9.59
1st decade	27.1	33.8	23.0	54.1	201.0	157.74
2st decade	27.2	34.2	23.4	53.2	115.0	139.25
3st decade	26.5	33.0	22.6	56.2	123.0	135.26
mean/total	26.9	33.7	23.0	54.5	439.0	432.25
max	28.8	36.7	24.4	76.2	66.0	20.21
min	25.3	28.3	21.6	40.7	0.0	5.57

Climatic Table Draied Area (UNPAR) Dec. 2000

Draied (UNPAR) yymmdd	Air Temp mean (˚C)	Air Temp max (˚C)	Air Temp min (˚C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20001201	26.1	33.1	22.7	56.8	3.0	11.83
20001202	25.7	28.9	23.5	71.5	3.0	8.22
20001203	26.4	32.5	22.6	60.2	0.0	13.36
20001204	27.6	34.0	21.6	51.4	8.5	17.52
20001205	27.4	33.8	21.3	53.1	0.0	16.23
20001206	28.2	36.6	22.4	43.7	0.0	18.57
20001207	27.2	36.0	22.6	47.1	0.0	16.79
20001208	26.1	34.4	21.5	51.5	11.5	12.06
20001209	26.7	33.0	22.3	59.1	0.0	12.62
20001210	28.0	35.1	22.6	48.0	0.0	16.11
20001211	27.5	33.2	24.9	60.1	0.0	12.70
20001212	26.5	32.1	23.9	64.4	0.5	8.51
20001213	27.1	34.3	23.2	51.3	21.0	13.60
20001214	26.5	33.8	23.0	56.0	0.5	12.43
20001215	27.1	33.1	22.5	53.6	0.5	13.75
20001216	28.0	35.8	22.4	48.5	4.0	17.15
20001217	26.8	35.5	23.5	47.1	6.0	14.88
20001218	28.2	34.9	24.0	46.6	0.0	15.67
20001219	27.9	34.4	22.9	55.5	12.0	15.84
20001220	27.2	33.3	23.5	54.4	6.0	15.73
20001221	27.1	33.4	23.6	56.9	6.5	12.19
20001222	28.0	35.1	23.7	47.6	4.0	17.76
20001223	26.1	33.6	23.5	57.5	9.0	8.76
20001224	26.3	31.8	23.0	62.8	0.0	11.48
20001225	25.6	32.8	22.6	61.0	2.0	10.38
20001226	25.5	32.4	22.9	61.3	2.0	9.04
20001227	24.9	31.6	22.0	65.6	18.0	8.92
20001228	27.4	35.0	22.5	46.2	0.0	16.94
20001229	27.2	33.3	22.0	57.3	0.0	14.49
20001230	26.6	34.5	23.2	50.2	2.0	10.62
20001231	27.2	33.6	23.0	51.2	0.0	15.96
1st decade	26.9	33.7	22.3	54.2	26.00	143.31
2st decade	27.3	34.0	23.4	53.8	50.50	140.26
3st decade	26.5	33.4	22.9	56.1	43.50	136.54
mean/total	26.9	33.7	22.9	54.8	120.00	420.11
max	28.2	36.6	24.9	71.5	21.00	18.57
min	24.9	28.9	21.3	43.7	0.00	8.22

Climatic Table Draied Area (UNPAR) Jan. 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010101	26.6	31.9	23.0	62.4	13.5	11.23
20010102	26.6	32.5	22.8	56.5	0.0	12.82
20010103	27.4	34.1	23.2	51.5	20.5	14.15
20010104	24.9	28.4	22.6	71.8	58.5	6.86
20010105	26.5	31.9	22.5	58.4	0.0	10.26
20010106	25.9	32.8	22.8	57.9	3.5	12.44
20010107	27.4	34.5	22.7	54.4	23.0	15.58
20010108	26.5	32.6	22.3	61.5	18.5	15.19
20010109	26.6	32.8	22.6	55.1	0.0	15.64
20010110	26.0	32.7	22.5	56.6	9.5	15.60
20010111	25.3	29.0	22.0	70.8	1.0	7.68
20010112	27.7	34.7	21.5	49.7	0.0	17.92
20010113	25.9	31.7	22.1	56.8	8.5	11.87
20010114	26.7	32.5	21.9	58.2	0.0	11.30
20010115	27.8	35.5	22.7	45.4	0.0	19.21
20010116	25.7	31.0	22.4	69.9	0.0	8.16
20010117	26.8	33.4	22.3	52.5	4.5	13.98
20010118	27.3	33.8	23.5	51.7	7.0	15.96
20010119	25.1	28.3	22.3	73.5	1.0	6.38
20010120	28.4	35.6	23.3	45.5	0.0	20.49
20010121	23.9	25.7	22.4	86.1	79.5	3.43
20010122	27.1	33.9	21.7	52.3	0.0	18.50
20010123	26.4	32.0	23.8	62.5	0.5	14.27
20010124	27.4	33.9	23.1	53.0	0.5	14.78
20010125	26.8	32.6	23.2	58.4	0.0	14.37
20010126	27.4	34.5	22.3	55.7	1.0	15.56
20010127	27.4	33.2	23.9	59.4	2.5	15.42
20010128	26.3	34.6	22.2	57.5	51.5	14.32
20010129	26.8	33.6	23.0	55.2	6.5	17.22
20010130	26.9	35.1	22.0	53.2	0.5	15.39
20010131	27.6	33.8	23.6	55.5	26.0	19.01
1st decade	26.4	32.4	22.7	58.6	147.0	129.77
2st decade	26.7	32.6	22.4	57.4	22.0	132.95
3st decade	26.7	33.0	22.8	59.0	168.5	162.27
mean/total	26.6	32.7	22.7	58.4	337.5	424.99
max	28.4	35.6	23.9	86.1	79.5	20.49
min	23.9	25.7	21.5	45.4	0.0	3.43

Climatic Table Draied Area (UNPAR) Feb. 2001

Draied (UNPAR) yymmdd	Air Temp mean (˚C)	Air Temp max (˚C)	Air Temp min (˚C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010201					20.5	10.40
20010202					0.5	9.88
20010203					0.5	7.26
20010204	26.0	33.5	22.4	56.3	14.0	14.91
20010205	25.7	32.0	22.0	58.9	0.5	15.45
20010206	26.6	32.1	22.1	58.5	0.0	14.21
20010207	26.7	32.0	23.9	65.4	0.0	10.78
20010208	25.5	31.4	22.8	66.9	7.0	9.91
20010209	24.0	29.1	22.4	75.7	9.0	4.98
20010210	26.6	33.2	22.6	52.8	0.0	16.53
20010211	26.5	31.5	22.2	63.3	0.0	12.23
20010212	27.3	34.0	21.6	51.7	0.0	17.61
20010213	27.3	33.8	23.0	52.9	5.5	17.93
20010214	27.0	34.6	22.4	53.6	0.5	17.32
20010215	28.8	36.7	23.4	42.7	78.5	19.69
20010216	25.9	32.4	23.1	64.2	97.5	14.53
20010217	26.9	32.2	23.2	63.5	0.0	15.74
20010218	27.5	33.9	23.5	60.3	3.5	17.00
20010219	27.5	34.0	23.1	51.4	0.0	18.03
20010220	27.8	34.9	22.5	45.2	0.0	21.01
20010221	28.5	36.1	22.7	42.1	0.0	20.76
20010222	27.6	34.3	23.1	49.3	0.0	15.39
20010223	26.8	34.3	22.2	51.9	5.5	15.77
20010224	27.9	35.7	22.0	43.2	21.5	
20010225	25.3	29.2	22.3	73.6	37.0	
20010226	26.6	34.5	22.3	51.5	0.0	
20010227	27.7	34.7	23.1	51.1	0.0	
20010228	24.7	28.2	22.8	77.5	22.5	
1st decade	25.9	31.9	22.6	62.1	52.0	114.3
2st decade	27.3	33.8	22.8	54.9	185.5	171.1
3st decade	26.9	33.4	22.6	55.0	86.5	51.9
mean/total	26.7	33.1	22.7	56.9	324.0	337.3
max	28.8	36.7	23.9	77.5	97.5	21.0
min	24.0	28.2	21.6	42.1	0.0	5.0

Climatic Table Draied Area (UNPAR) Mar. 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010301	27.8	34.2	22.8	49.4	0.0	
20010302	26.3	32.5	23.2	62.2	15.5	
20010303	27.4	34.5	23.3	53.4	0.0	
20010304	26.6	34.3	22.3	57.7	26.0	
20010305	27.4	34.7	22.9	52.3	5.5	
20010306	27.6	35.2	23.5	49.7	18.0	
20010307	26.0	30.9	23.4	66.1	16.0	
20010308	27.6	34.4	23.2	52.7	4.0	
20010309	25.7	29.4	22.8	75.1	12.5	
20010310	27.1	33.9	22.5	53.9	34.0	
20010311	26.3	31.1	22.9	62.2	4.0	
20010312	25.8	33.0	23.4	54.0	17.5	
20010313	26.4	31.2	23.3	62.1	0.5	
20010314	26.6	33.9	22.5	52.5	3.5	
20010315	28.1	35.7	21.7	47.2	0.5	
20010316	27.1	34.6	22.7	50.7	9.0	
20010317	27.7	34.6	22.0	51.3	0.5	
20010318	28.5	35.1	22.9	48.3	0.0	
20010319	28.0	35.2	22.8	47.3	3.5	
20010320	27.6	35.6	23.1	49.9	3.0	
20010321	25.7	30.9	21.4	72.6	50.5	
20010322	27.8	35.5	22.7	49.6	0.5	
20010323	27.6	35.0	22.5	50.5	0.0	
20010324	25.5	30.2	21.9	69.7	1.5	
20010325	27.3	35.1	21.3	44.2	0.0	
20010326	27.8	34.7	23.0	48.7	0.5	
20010327	26.9	32.7	23.3	58.4	0.0	
20010328	27.3	34.6	23.6	51.9	0.0	
20010329	27.3	33.6	23.7	53.6	4.5	
20010330	27.3	34.1	23.3	53.2	19.0	
20010331	26.9	33.3	22.9	50.4	18.0	
1st decade	27.0	33.4	23.0	57.3	131.5	
2st decade	27.2	34.0	22.7	52.6	42.0	
3st decade	27.0	33.6	22.7	54.8	94.5	
mean/total	27.1	33.7	22.8	54.9	268.00	
max	28.5	35.7	23.7	75.1	50.50	
min	25.5	29.4	21.3	44.2	0.00	

Climatic Table Draied Area (UNPAR) Apr. 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010401	26.6	32.4	22.4	59.8	0.0	
20010402	28.0	35.0	22.3	50.4	0.0	
20010403	27.6	33.9	23.2	54.4	0.0	
20010404	27.4	34.2	23.9	51.5	15.0	
20010405	28.2	35.9	22.8	47.3	2.5	
20010406	25.3	27.6	23.9	80.6	7.0	
20010407	27.5	34.1	23.3	53.4	13.5	
20010408	26.2	32.6	23.7	65.1	77.5	
20010409					0.5	
20010410					2.5	
20010411					0.5	
20010412					1.5	
20010413					45.5	
20010414					6.5	
20010415					0.0	16.33
20010416					3.0	14.43
20010417					14.5	4.73
20010418					7.5	15.00
20010419					19.5	15.04
20010420					0.5	11.56
20010421					7.0	13.63
20010422					0.0	20.28
20010423					1.5	15.47
20010424					7.0	
20010425					2.0	8.02
20010426					0.0	19.23
20010427					2.5	16.36
20010428					0.0	10.83
20010429					0.0	16.10
20010430					8.5	4.31
1st decade	27.1	33.2	23.2	57.8	118.50	
2st decade					99.00	77.09
3st decade					28.50	124.23
mean/total					246.00	
max					77.50	
min					0.00	

Climatic Table Draied Area (UNPAR) May 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ m^{-2})
20010501					0.0	9.48
20010502					0.0	16.61
20010503					13.5	12.17
20010504					5.0	17.28
20010505					7.5	11.29
20010506					0.0	15.95
20010507					0.0	19.30
20010508					0.0	12.34
20010509					9.0	15.41
20010510					1.0	13.80
20010511					0.0	14.61
20010512					23.5	16.44
20010513					2.0	10.56
20010514					0.5	13.00
20010515					0.0	14.19
20010516					0.0	16.90
20010517					2.5	13.66
20010518					6.0	13.00
20010519					38.0	6.97
20010520					0.0	18.20
20010521					0.0	13.45
20010522					3.5	13.92
20010523					0.0	17.34
20010524					0.0	15.89
20010525					0.0	10.95
20010526					0.0	10.50
20010527					8.0	7.79
20010528					0.5	13.71
20010529					4.5	6.25
20010530					44.5	9.86
20010531					0.0	16.47
1st decade					36.0	143.63
2st decade					72.5	137.53
3st decade					61.0	136.13
mean/total					169.5	417.29
max					44.5	19.30
min					0.0	6.25

Climatic Table Draied Area (UNPAR) June 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010601					0.0	11.82
20010602					0.5	13.42
20010603					12.0	10.97
20010604					0.5	11.83
20010605					34.0	11.25
20010606					0.0	13.21
20010607					5.5	12.01
20010608					1.0	12.27
20010609					59.0	11.38
20010610					0.0	7.40
20010611					0.0	15.23
20010612					0.0	9.21
20010613					13.0	15.45
20010614					0.5	16.30
20010615					13.0	5.31
20010616					31.5	10.36
20010617					0.0	10.43
20010618					0.0	12.80
20010619					0.0	15.36
20010620					0.0	14.75
20010621					0.0	16.93
20010622					0.0	16.68
20010623					0.0	15.54
20010624					0.0	15.03
20010625					0.0	16.00
20010626					0.0	15.51
20010627					0.0	9.08
20010628					0.0	15.70
20010629					0.0	16.83
20010630					0.0	11.86
1st decade					112.5	115.56
2st decade					58.0	125.20
3st decade					0.0	149.16
mean/total					170.5	389.92
max					59.0	16.93
min					0.0	5.31

Climatic Table   Draied Area (UNPAR)   July 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010701					0.0	12.55
20010702					0.0	14.44
20010703					0.0	13.43
20010704					0.0	11.83
20010705					0.0	13.52
20010706					0.0	13.56
20010707					0.0	15.41
20010708					0.0	10.44
20010709					0.0	15.13
20010710					0.0	16.11
20010711					0.0	14.61
20010712					0.0	10.31
20010713					1.3	9.73
20010714					0.0	14.09
20010715					0.0	9.72
20010716					1.9	9.37
20010717					0.0	9.70
20010718					3.9	17.75
20010719					0.0	15.76
20010720					0.0	6.76
20010721					0.0	13.16
20010722					0.0	16.49
20010723					5.8	
20010724	26.7	33.0	21.8	59.3	0.0	
20010725	27.1	32.9	23.9	57.7	0.0	
20010726	26.2	32.5	22.6	61.7	0.0	
20010727	26.4	33.1	21.9	56.0	0.5	
20010728	26.5	33.6	23.1	56.5	4.5	
20010729	26.2	32.8	23.4	58.9	0.0	
20010730	27.0	34.5	22.4	49.6	0.2	
20010731	26.7	32.6	22.0	57.4	0.0	
1st decade					0.0	136.42
2st decade					7.1	117.80
3st decade	26.6	33.1	22.6	57.1	11.0	
mean/total					18.1	
max					5.8	
min					0.0	

Climatic Table Draied Area (UNPAR) Aug. 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010801	26.3	32.4	22.5	63.2	44.0	
20010802	25.2	29.8	22.6	78.6	0.3	
20010803	25.8	32.5	22.2	58.2	12.0	
20010804	24.6	31.8	20.6	60.7	0.7	
20010805	24.2	32.3	18.9	54.8	0.0	
20010806	25.1	33.9	18.6	38.1	0.0	
20010807	25.5	34.8	19.1	50.8	0.0	
20010808	26.7	34.0	21.7	54.2	0.0	
20010809	27.7	35.6	23.1	51.0	0.0	
20010810	26.7	35.2	21.3	45.0	0.0	
20010811	25.7	34.4	19.5	45.1	0.0	
20010812	25.5	33.6	20.5	50.3	0.0	
20010813	25.5	34.6	20.3	47.5	0.0	
20010814	25.3	34.6	19.2	49.1	0.0	
20010815	25.9	34.4	19.1	45.5	0.0	
20010816	26.0	34.8	20.6	49.0	0.0	
20010817	25.9	34.8	19.8	46.4	0.0	
20010818	26.5	34.7	21.8	45.2	0.0	
20010819	26.2	34.6	20.0	40.0	0.0	
20010820	26.6	36.0	20.3	37.4	0.0	
20010821	27.0	35.9	20.6	38.1	0.0	
20010822	27.1	36.4	21.4	39.1	0.0	
20010823	26.7	35.8	20.7	44.0	0.0	
20010824	26.9	35.8	20.1	34.0	0.0	
20010825	27.0	35.1	21.3	49.8	0.0	
20010826	27.3	35.8	21.2	43.6	0.0	
20010827	27.0	36.1	20.9	38.1	0.0	
20010828	26.1	33.5	21.5	52.9	0.0	
20010829	26.9	32.7	22.4	60.2	0.0	
20010830	26.9	35.4	23.1	55.4	0.0	
20000831	26.2	33.3	22.9	66.4	0.4	
1st decade	25.8	33.2	21.1	55.5	57.0	
2st decade	25.9	34.7	20.1	45.6	0.0	
3st decade	26.8	35.1	21.5	47.4	0.4	
mean/total	26.2	34.3	20.9	49.4	57.40	
max	27.7	36.4	23.1	78.6	44.00	
min	24.2	29.8	18.6	34.0	0.00	

Climatic Table Draied Area (UNPAR) Sept. 2001

Draied (UNPAR) yymmdd	Air Temp mean (˚C)	Air Temp max (˚C)	Air Temp min (˚C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20010901	26.5	32.9	22.9	60.8	0.0	
20010902	27.4	35.6	21.5	44.5	0.0	
20010903	27.0	34.3	21.9	54.6	0.0	
20010904	27.4	33.3	22.5	61.8	0.0	
20010905	26.6	32.9	22.7	60.8	0.0	
20010906	26.4	34.5	21.6	58.0	0.0	
20010907	26.4	33.2	22.2	51.9	0.0	
20010908	27.6	35.1	22.3	47.9	0.0	
20010909	27.5	36.4	21.6	39.7	0.0	
20010910	26.7	34.7	22.1	56.0	0.0	
20010911	26.9	34.6	21.9	48.4	0.0	
20010912	25.9	31.2	21.5	63.6	0.0	
20010913	26.7	35.9	21.7	48.0	0.0	
20010914	27.5	36.3	21.4	36.6	0.0	
20010915	26.6	36.1	22.3	54.0	0.0	
20010916	27.7	35.6	23.2	45.0	0.0	
20010917	27.5	35.5	22.2	48.1	0.0	
20010918	27.4	35.6	22.8	54.5	0.0	
20010919	27.8	36.0	21.7	42.1	0.0	
20010920	26.5	31.5	23.8	67.4	0.0	
20010921	27.3	34.0	23.7	52.7	0.0	
20010922	27.7	35.0	22.6	55.9	0.0	
20010923	26.0	32.5	22.7	62.7	0.0	
20010924	27.4	34.7	22.4	52.2	0.0	
20010925	28.2	36.6	22.1	40.0	0.0	
20010926	26.7	35.9	22.7	47.5	0.0	
20010927					0.0	
20010928					0.0	
20010929					0.0	
20010930					4.9	
1st decade	27.0	34.3	22.1	53.6	0.0	0.00
2st decade	27.1	34.8	22.3	50.8	0.0	0.00
3st decade	27.2	34.8	22.7	51.8	4.9	0.00
mean/total	27.1	34.6	22.3	52.1	4.9	0.00
max	28.2	36.6	23.8	67.4	4.9	0.00
min	25.9	31.2	21.4	36.6	0.0	0.00

Climatic Table Draied Area (UNPAR) Oct. 2001

Draied (UNPAR) yymmdd	Air Temp mean (˚C)	Air Temp max (˚C)	Air Temp min (˚C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20011001	25.1	29.1	22.8	67.7		
20011002	26.8	34.2	22.3	49.2	23.5	
20011003	26.1	32.2	21.9	56.0	1.0	
20011004	26.8	31.8	23.7	65.0	36.5	
20011005	26.9	34.3	23.6	49.9	8.5	
20011006	26.3	30.7	24.2	67.5	1.5	
20011007	25.9	30.6	22.3	63.9	0.0	
20011008	26.9	33.5	21.7	51.8	0.0	
20011009	26.9	33.3	21.0	51.1	0.0	
20011010	27.6	34.7	22.5	47.4	0.0	
20011011	28.0	34.8	21.6	45.5	3.0	
20011012	26.5	34.1	22.0	55.8	0.5	
20011013	27.4	34.7	21.1	48.4	0.0	
20011014	26.8	34.0	21.9	53.8	50.5	
20011015	27.3	35.9	22.4	47.0	1.5	
20011016	28.3	35.4	22.4	44.6	0.0	
20011017	25.9	33.5	22.8	59.4	7.0	
20011018	26.4	33.9	21.9	54.3	8.0	
20011019	27.0	34.8	23.0	52.0	36.0	
20011020	26.6	32.6	21.8	64.4	0.0	
20011021	27.7	34.4	23.1	52.3	0.0	
20011022	28.0	35.1	21.5	46.0	22.0	
20011023	25.5	30.3	22.1	62.6	16.5	
20011024	27.2	34.7	22.2	50.8	12.0	
20011025	26.3	33.1	22.9	55.6	0.0	
20011026	27.5	35.3	21.4	48.0	0.0	
20011027	27.8	35.5	22.5	50.9	16.5	
20011028	27.4	34.6	23.2	53.5	1.0	
20011029	25.8	31.2	22.9	66.6	0.0	
20011030	27.2	34.6	22.6	49.2	44.0	
20011031	26.3	30.2	23.0	68.6	0.5	
1st decade	26.5	32.4	22.6	57.0	71.0	
2st decade	27.0	34.4	22.1	52.5	106.5	
3st decade	27.0	33.5	22.5	54.9	112.5	
mean/total	26.8	33.5	22.4	54.8	290.0	
max	28.3	35.9	24.2	68.6	50.5	
min	25.1	29.1	21.0	44.6	0.0	

Climatic Table Draied Area (UNPAR) Nov. 2001

Draied (UNPAR) yymmdd	Air Temp mean (˚C)	Air Temp max (˚C)	Air Temp min (˚C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20011101	26.5	30.6	23.9	69.2	4.5	
20011102	27.0	33.6	22.6	55.4	1.5	
20011103	25.5	34.1	22.5	52.1	9.5	
20011104	26.4	34.0	22.7	54.1	24.0	
20011105	26.3	34.1	23.5	56.5	17.5	
20011106	26.0	32.0	22.8	62.0	6.0	
20011107	26.3	32.5	21.8	61.7	5.5	
20011108	26.5	33.9	22.6	59.1	4.0	
20011109	26.3	33.1	23.7	60.8	7.5	
20011110	25.6	30.3	23.3	71.6	0.5	
20011111	27.4	34.5	23.0	54.7	1.0	
20011112	26.1	30.2	22.3	68.1	1.0	
20011113	25.3	32.2	21.5	62.3	10.5	
20011114	26.8	35.2	22.1	48.4	61.5	
20011115	26.9	33.6	23.1	55.7	62.0	
20011116	25.7	31.8	22.4	59.2	5.5	
20011117	26.3	33.2	23.1	53.7	0.0	
20011118	25.4	32.2	22.4	66.3	2.0	
20011119	26.2	33.5	22.9	55.2	3.0	
20011120	25.6	32.0	22.9	62.0	22.5	
20011121	25.7	32.6	22.9	61.0	22.5	
20011122	26.3	31.8	22.6	62.7	0.0	
20011123	27.2	33.6	22.7	56.3	0.0	
20011124	25.8	31.9	22.8	63.5	29.0	
20011125	26.2	32.7	21.3	61.5	33.0	
20011126	25.9	32.0	22.9	64.6	3.0	
20011127	25.8	32.8	22.5	57.5	3.0	
20011128	25.3	30.9	23.2	69.4	25.5	
20011129	25.8	32.5	23.5	61.4	9.5	
20011130	26.4	32.1	22.4	60.8	4.0	
1st decade	26.2	32.8	22.9	60.3	80.5	
2st decade	26.2	32.8	22.6	58.6	169.0	
3st decade	26.0	32.3	22.7	61.9	129.5	
mean/total	26.2	32.7	22.7	60.2	379.0	
max	27.4	35.2	23.9	71.6	62.0	
min	25.3	30.2	21.3	48.4	0.0	

Climatic Table Draied Area (UNPAR) Dec. 2001

Draied (UNPAR) yymmdd	Air Temp mean (°C)	Air Temp max (°C)	Air Temp min (°C)	Humid. min (%)	Precip. total (mm)	Solar R. total (MJ/m/m)
20011201	24.8	30.1	22.5	64.7	11.5	
20011202	25.1	32.6	20.7	58.3	1.0	
20011203	26.0	32.9	20.3	53.7	0.0	
20011204	26.8	32.5	22.1	55.7	3.0	
20011205	25.7	34.2	21.5	51.7	8.0	
20011206	25.0	32.7	20.8	56.5	2.0	
20011207	25.4	33.5	21.7	53.9	9.0	
20011208	26.5	32.8	21.1	48.5	0.5	
20011209	26.0	31.7	22.1	62.5	0.0	
20011210	25.5	33.0	20.7	59.8	4.5	
20011211	25.5	32.1	20.8	60.5	4.5	
20011212	26.6	33.0	21.7	56.3	5.0	
20011213	27.9	34.5	23.2	49.4	0.5	
20011214	24.4	28.4	22.4	75.7	11.5	
20011215	24.9	33.5	21.7	60.1	32.0	
20011216	26.6	33.6	21.7	50.1	1.0	
20011217	25.9	32.1	23.1	57.5	1.5	
20011218	27.3	33.4	22.5	54.2	1.0	
20011219	25.8	28.9	23.6	76.7	2.5	
20011220	25.6	31.1	22.3	64.3	6.0	
20011221	26.0	32.6	22.4	54.3	5.5	
20011222	25.9	33.1	22.8	56.6	23.0	
20011223	25.7	33.2	22.6	55.1	6.0	
20011224	24.8	30.9	22.5	62.3	31.5	
20011225	27.0	33.6	22.6	50.4	0.0	
20011226	25.1	28.4	23.0	76.1	13.0	
20011227	25.7	32.5	22.1	60.4	1.5	
20011228	25.8	30.6	23.4	67.4	4.5	
20011229	26.4	32.9	22.9	59.4	0.5	
20011230	26.7	32.7	23.1	56.0	0.0	
20011231	25.9	32.0	23.3	63.4	19.5	
1st decade	25.7	32.6	21.4	56.5	39.50	
2st decade	26.1	32.1	22.3	60.5	65.50	
3st decade	25.9	32.0	22.8	60.1	105.00	
mean/total	25.9	32.2	22.2	59.1	210.00	
max	27.9	34.5	23.6	76.7	32.00	
min	24.4	28.4	20.3	48.5	0.00	

3. Collaborative study

(4)

Function of aquatic ecosystems in Central Kalimantan

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Function of aquatic ecosystems in Central Kalimantan

Report of the Aquatic Ecosystem Team in FY2001
in relation to JAPS-LIPI Core University Program:
"Environmental Conservation and Land-Use Management of
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Activities of the FY2001

Japanese team visited the Research and Development Centre for Limnology-LIPI, Research and Development Center for Biology-LIPI, Research and Development Center for Geotechnology-LIPI, Bogor Agricultural University, the University of Palangkaraya and the Geological Research and Development Centre to exchange information and performed field survey in the FY2001. The field survey was made mainly in the oxbow lakes in the Central Kalimantan and additionally in the lakes and ponds in West Jawa. The major results obtained for the FY2001 were as follows:

(1) Studies on maintenance mechanisms of biodiversity in oxbow lake ecosystems

(a) Zooplankton community

The zooplankton samples collected from two humic oxbow lakes, Lake Sabuah and Lake Tundai of Kalimantan, during the period from May 1999 until October 2000 were analyzed. Lake Tundai (02°12'30"S; 114°00'37"E at the center of the lake; surface area ca. 2.8 km^2; depth at the center 4.9-6.7 m during the observation period) is located ca. 10 km south of Palangkaraya, Central Kalimantan, Indonesia. The lake is permanently open both at inlet and outlet to the Kahayan River. Lake Sabuah (02°3'19"S; 113°56'37"E at the center of the lake; surface area ca. 1.2 km^2; depth at the center 7.2-10.9 m during the observation period) is located ca. 15 km north of Palangkaraya.

The results revealed that due to their difference in hydrological connectivity to the main river, both studied lakes exhibited different patterns of dynamics of physico-chemical conditions. Lake Sabuah was characterized by strong stratifications of water temperature and dissolved oxygen and low concentrations of dissolved organic carbon (DOC), whereas Lake Tundai was characterized by high pH values and low concentration of DOC during high water level period, and very low pH values and high DOC concentrations during low water level season. Throughout the year, water temperature and dissolved oxygen penetrated down to the bottom of Lake Tundai.

Zooplankton communities in both lakes exhibited similar patterns of seasonal dynamics of density and biomass, but differed remarkably in terms of vertical distribution and community composition. The alternation of wet and dry seasons seemed to be the major external determinant for the seasonal patterns of zooplankton density and biomass, whereas the penetration of dissolved oxygen appeared to be a factor causing different patterns of zooplankton vertical distribution in water columns of both lakes. Lunar cycle seemed also to induce inverse patterns of density fluctuations between cladocerans and rotifers over one month period. The nature of fish predation was the likely factor in inducing the changes in the zooplankton community from rotifers dominance during high water level to the dominance of cladocerans and adult copepods during low water level period in Lake Tundai, whereas the scarcity of larger sized zooplankters at all times in Lake Sabuah seemed to be induced by a continuous predation by fishes upon larger-sized zooplankton due to the scarcity of alternative diet for fishes i.e. chironomid larvae in this lake.

(b) Zoobenthos community

The present comparative study was conducted at two oxbow lakes (Lakes Sabuah and Tundai) with different levels of connectivity to their main channel to clarify the seasonal trend of macrozoobenthic communities under such seemingly unfavorable environmental conditions. Observation and sampling were conducted monthly from November 1999 to October 2000 at the station near inlet and at the center both in Lake Tundai and in Lake Sabuah.

We collected a total of 24 taxa from Lake Tundai (22 taxa at the station near inlet and 18 taxa at the center of the lake). They included a nematode (Nygolaimus), oligochaetes(*Aelosoma*, *Lumbriculus*, *Aulophorus*, *Dero*, *Naidium*, *Branchiura* and *Limnodrilus*), larvae of 9 chronomid genera (*Clinotanypus*, *Larsia*, *Tanypus*, *Chironomus*, *Dicrotendipes*, *Microtendipes*, *Stenochironomus*, *Micropsectra* and other unidentified Chironomidae). Annual mean density of macrozoobenthos was 738 individuals m^{-2} at the station near inlet, in which *Chironomus* larvae were predominant (402 indivs m^{-2}) followed by *Larsia* larvae (116 indivs m^{-2}). Annual mean density of macrozoobenthos was 486 indivs m^{-2} at the center of the lake, in which *Chironomus* larvae were also predominant (207 indivs m^{-2}) followed by *Aulophorus* (Nididae) (77 indivs m^{-2}). The highest density of *Chironomus* larvae was observed in February both at the station near inlet (933±489 indivs m^{-2}, mean±range) and at the center of the lake (578±267 indivs m^{-2}).

From Lake Sabuah, 15 taxa of macrozoobenthos were recorded. Both number of taxa and annual mean density were smaller at the center of the lake (8 taxa and 40 indivs m^{-2}) than the station near inlet (14 taxa and 244 indivs m^{-2}). The nematode (*Nygolaimus*) was predominant (136 indivs m^{-2}) at the station near inlet followed by *Aelosoma* (36 indivs m^{-2}) and *Chironomus* (18 indivs m^{-2}). The nematode was also predominant at the center of the lake (16 indivs m^{-2}). *Chironomus* was the only genus identified from this lake.

Dissolved oxygen concentrations at bottom were very low in lake Sabuah mostly throughout the year. Although the lake experienced occasional mixing of water column with oxygenated water at both stations, the events might have not favored the macrozoobenthos even for *Chironomus* larvae. In comparison to this lake, dissolved oxygen conditions seemed to be better in Lake Tundai, i.e., 0.4-1.9 mg L^{-1} at the station near inlet and 0.1-1.7 mg L^{-1} at the center of the lake. Frequent mixing of the water column occurred when the oxygen concentrations were elevated to levels of 2.0-2.9 mg L^{-1} at bottom. The difference in oxygen condition between the two lakes was apparently due to their difference in hydrological conditions or connectivity to the main channel.

(2) Field survey of aquatic macrophytes growing in rivers and small canals in Jakarta

Main purpose of the present visit was to know the present status of aquatic macrophyte composition in some rivers and small canals in a capital city Jakarta, West Java. During the stay at Jakarta, several places were visited and aquatic macrophyte composition was recorded.

In result, no floating-leaved aquatic macrophytes were found but Hydrilla verticillata, a submerged macrophyte, was found even under the conditions of severe organic pollution, and it made a dense stand in some shallow waters.

(3) Mercury pollution in West Java

Studies were made in the polluted rivers and a eutrophic pond around Bogor, i.e., the CiLiung River, the CiKeas River, the CiKaniki River and Lake Cikaret.

Water quality parameters were measured with a combined electrodes and sensors (Horiba, water quality checker) or with combined EC and pH meter (Horiba ES-14). COD values were estimated by the pack colorimetry method (Kyoritu Kagaku). Water samples for the analysis of chemicals and heavy metals were collected directly in 50-ml plastic tubes. Zoobenthos samples were collected with a D-frame net (opening 0.5 mm). Zoobenthos were picked up in situ and preserved in 100% ethanol or stored in bottles according to the taxonomic groups, e.g., snails, leeches, shrimps or prawns, crabs, ephemeropteran larvae, trichopteran larvae, Chironomidae larvae. Samples which were not preserved were then frozen for mercury analysis. Fish were collected using an electric-shocker. The samples were then measured for wet weight to within 0.1 mg, measured for

Total mercury concentrations are to be analyzed with an atomic absorption spectroscopy and methylmercury with a gas chromatograph equipped with an electron-capture detector. The determination of mercury is to be performed both in Japan and in Indonesia (Research Center for Limnology) for inter-laboratory comparison.

To clarify whether some endocrine disrupters will be detected in the river and lake water near by Bogor, enzyme immunoassay is to be performed using antibodies against bisphenol-A and nonylphenol (Takeda, Japan). Both chemicals are well known as endocrine disruptors which effect on estrogen receptors. If the chemicals will be found in the water samples, we are going to carry out subsequently cell culture in the medium containing river water to analyze DNA damage and to evaluate cell differentiation. The river water is to be passed thorough 0.2 □m filter to sterilize before the culture. In addition, heavy metal concentrations such as lead, cadmium, zinc and copper in the water samples are to be measured with ICP mass spectrometry (Seiko, Japan) to estimate the degree of heavy metal pollutant for rivers.

The waters were generally organically polluted with COD values of more than or equal to 10 mg/l except for the main stream of the CiKaniki River and the CiSaura River. However the COD values of the river water were variable according to the rain events which apparently lowered the value of the CiLiwung River from 40-80 mg/l to 4 mg/l. Most of the river bed consisted of rock and gravels where net spinning trichopteran larvae and ephemeropterans were dominant. In contrast to these torrent rivers, in small streams (Sta. 2 of the CiLiwug River) and stagnant waters, Chironomidae of the genus *Chironomus* was by far the abundant.

EPIPHYTIC ALGAE OF AQUATIC MACROPHYTES FROM LAKE TABIRI AND LAKE LUTAN, CENTRAL KALIMANTAN

SULASTRI, D.I HARTOTO AND M.S. SYAWAL

INTRODUCTION.

Aquatic macrophytes such as water hyacinth *(Eichhornia crassipes) and* water fern *(Salvinia* spp) are commonly found blooming in eutrophic inland waters in Java and Sumatera. These aquatic macrophytes are also found in humic floodplain lakes of River Kahayan, such as in Lake Lutan and Lake Tabiri in Central Kalimantan. These two lakes have the range of pH values from 4.72 to 5.08 and from 5.96 to 6.79, respectively.

It means that the contribution of phytoplankton as food resources for aquatic organisms such as fishes is low in that humic aquatic ecosystem. Beside the insects' community, the food resources of aquatic organism also come much from allochthonous materials and aquatic macrophytes in that humic oxbow lake ecosystem. Aquatic macrophytes are also the habitat for macroinvertebrate and epiphytic algae because some of the plant parts play as a kind of detritus filter and rich in nutrient. Gallanti and Romo (1977) and Guissani as cited by Cattaneo (1998) reported that epiphyton contribute significantly to carbon supply and food resources on fish in Italian lake ecosystem. This study was conducted to reveal the composition and abundance of epiphytic algae in immersed parts of some aquatic macrophytes found in humic floodplain lakes, such as Lake Tabiri and Lake Lutan.

MATERIALS AND METHODS.

Samples of epiphytic algae were collected from the submerged parts of aquatic macrophytes such as *E. crassipes*, *Salvinia molesta* and Kumpai Lengo (*Polygonum lapathifolium* L.: Polygonaceae) especially in Lake Tabiri. While in Lake Lutan epiphytic algae were collected from water hyacinths roots because only this plant is found as dominant species in this lake. *E. crassipes* and *S. molesta* are floating aquatic macrophytes while *P. lapathifolium* is a submerged aquatic macrophyte that grow from the bottom reaching to the surface of the lake. Epiphytic algae were collected from a part of root especially for *E. crassipes* and from all parts of aquatic macrophytes for *S. molesta*. Epiphytic algae collected from *P. lapathifolium* were from the part of the plant that immersed in the water.

Two methods were applied to collect epiphytic algae in Lake Lutan and Lake Tabiri. In Lake Lutan, epiphytic algae were collected by harvesting all the individuals of *E. crassipes* in 60 x 60 m plots, then the plant was weighed to know the total biomass and sub sampling the 140 grams of the root. Then sample of the root of *E. crassipes* was preserved with formalin. In the laboratory, the sample roots were washed with 500 ml of water then shaken around 1 hour. The washing of these sample were replicated three times and 1500 ml of sample water was obtained. Then the water samples were filtered using plankton net and preserved with 1 % Lugol solution. Samples of epiphytic algae from Lake Tabiri was collected by sampling aquatic macrophytes from 50 x 50 cm plots for each group of aquatic macrophyte species and weighed for the total biomass. Sub sample was taken from the total biomass and washed with 1000 ml sterile water and then manually shaken for around ten minutes. After shaking of plant part samples, the water was filtered using plankton net (40 μm) and preserved with 1 % Lugol solution.

The individual epiphytic algae were counted using the Lackey drop microtransect method (Anonymous, 1976). The epiphytic algae species were identified according to the identification keys of Prescott (1963) and Scott and Prescott (1961). The water quality parameters such as water temperature, turbidity, conductivity, oxidative reductive potentials (ORP), pH, dissolved oxygen (DO) and total dissolved solids (TDS) were measured using a YSI Water Quality Checker. The data for nutrient concentration in the water column was obtained from examination of the samples taken from the lakes. Analyses of ammonium, nitrite, nitrate and orthophosphate were performed according to the method proposed by Anonymous (1976).

RESULTS AND DISCUSSION

Same parameters of water quality condition of Lake Tabiri and Lake Lutan were presented in Table 1 and Table 2. The water quality condition showed a little different between Lake Tabiri and Lake Lutan, especially the pH, turbidity and conductivity. In Lake Tabiri, the pH and turbidity values were lower than those parameters in Lake Lutan. Lake Lutan is an oxbow lake Type I that exchange water with lower segment of the Kahayan River (Hartoto 2000) and Lake Tabiri is a floodplain lake of the Kahayan River (Fig. 1). The lower part of a river usually receive much more suspended materials come from the upper river. On the other hand, Lake Lutan receives the water directly from the Kahayan River with higher pH value. Lake Tabiri is the lakes that exchange water with Lake Takapan that is another of type of oxbow lakes (Type II of Oxbow Lake). Lake Takapan is the lakes that strongly influenced by the water exchange with the Rungan River, a tributary of the Kahayan River. Besides exchange water with Lake Takapan, Lake Tabiri also exchange water directly with the Kahayan River. The water of the Rungan River is humic with an average pH of 4.72 (Hartoto, 2000). The concentrations of nutrients in Lake Tabiri was also lower than those in Lake Lutan. The average NO_2-N, NO_3-N and NH_4-N concentrations in Lake Lutan were 5.62, 561 and 118.6 μg/l, respectively (Sulastri and Hartoto, 2000). The nutrient concentration in Lake Lutan were higher than lakes Takapan and Tabiri due presumably to the location of Lake Lutan and the existence of a village around the lake.

Table 1. Some physical and chemical characteristics of Lake Lutan and Lake Tabiri

Depth (m)	Water temperature(°C)	Turbidity (NTU)	Conductivity (mS/m)	TDS (g/L)	ORP (mV)	pH	DO (mg/L)
Lake Lutan							
0	32.3	55.6	4	0.02	114.6	6.68	3.0
0.5	30.7	69	4	0.02	82.6	6.34	1.7
1.0	29.7	88.4	4	0.03	41	6.04	0.7
Lake Tabiri							
0	30.5	8	1	0.01	292.6	5.08	3.7
0.5	28.5	9	1	0.01	356	4.93	2.1
1.0	28.2	11	1	0.01	278.6	4.88	0.5

Table 2. Nutrient concentration in the water of Lake Tabiri

Depth (m)	NO_2–N (mg/l)	NO_3-N (mg/l)	NH_4-N (mg/l)	PO_4-P (mg/l)
0	0.0039	< 0.1	0.0374	0.0243
0.5	0.0046	< 0.1	0.0075	0.0148
1.0	0.0034	0.001	0.0139	0.0215
1.5	0.0088	< 0.1	0.0370	0.0167
2.0	0.0068	0.0145	0.0064	0.0224
2.5	0.0077	0.0164	0.0101	0.0177

The composition and abundance of epiphytic algae is presented in Table 3. The diversity and abundance of epiphytic algae were higher on *S. molesta* as compared with those on *E. crassipes* and *P. lapathifolium*. Cattaneo et al. (1998) have reported that the architecture of aquatic macrophyte significantly affectes the abundance and community structure of epiphytic algae. *S. molesta* is a floating aquatic macrophyte the root and the leaves of which are immersed in the water thereby providing additional surface area available for attached epiphytic algae. The root has a role to filter excess detritus and provides suitable nutrient-rich habitat for epiphytic algae. Furthermore the root is not too long around 5 cm and consequently epiphytic algae are able to obtain sufficient light for photosynthesis and their growth. While the root of *E. crassipes* is the only part that is immersed in the water and longer than the root of *S. molesta*. Since *E. crassipes* has wider leaves and is more crowded while growing in the water, the light intensity penetrating into the water is limited. The light is mainly utilized by the plant's leaves for photosynthesis. *P. lapathifolium* is the plant with different architecture compared with *S. molesta* and *E.* crassipes. The part of *P. lapathifolium* immersed in the water is mostly a stem. It means that the epiphytic algae attached on the stem have little detritus and nutrients on the stem. This condition might have caused the lower diversity and abundance of epiphytic algae on the *P. lapathifolium* than on *E. crassipes*.

Table 3. Composition and abundance of epiphytic algae on some aquatic macrophytes in Lake Lutan and Tabiri.

Taxon group	L. Tabiri			L. Lutan			
	S. molesta (ind/586g plant)	*E. crassipes* (ind/484g root)	K. lengo (ind/342g plant)	*E. crassipe* (ind/140g root)	*E. crassipe* (ind/140g root)	*E. crassipe* (ind/140g root)	*E crassipes* (ind/140g root)
Chrysophyta							
Chrysophyceae							
Dinobriyon	576	60					
Baccilariophycae							
Asteronella	11808	2700	2430	180			
Cymbella	9216	274	45				72
Diatoma	14400	454		90	45		
Diatoma elongatum	3456	360		225			
Eunotia	20736	5040	180	315	315	120	225
E. robusta	288						
E. mondon	4050						36
Fragillaria	18144	1260		180	45		72
Frustulia	97056	540	225				
Gyrosigma				45			
Navicula	13536	3700	135	315	90	30	36
Pinnularia	3168	274		180			
Synedra.	8352	1140	45	180	90		
Synedra ulna						30	
Surirella linearis		180					
Chlorophyta							
Ankistrodesmus				45			
Bambusina	288						
Cladophora	288		225				
Closterium	576			270	180		
Cosmarium	288						
Euastrum	576						
Gonatozygon					45		
Peurotaenium						30	
S. megacantum	288						
Scenedesmus	288						
Spirotaenia condensata		80					
Stigeoclonium						30	
Tetraedron	864						
Zygnemopsis	576						
Cyanophyta							
Anabaena	25506						
Aphanocapsa	2304		90				
Oscillatoria				865	405	60	36
O. limnetica						210	
Euglenophyta							
Phacus	288	360					
Trachelomonas			90				
Total number of genera	26	14	10	13	8	10	6
Total individual/l	236466	16512	3645	2835	1215	1215	600

Diatom or Bacillariophyceae group dominated the community of epiphytic algae. This group is commonly found in humic lake ecosystems because the cell wall is more resistant to acidic water. Besides diatoms, *Anabaena* group of Cyanophyta was also abundant especially on *S. molesta*. In lake Lutan the total number of individuals and the diversity of epiphytic algae were lower than those in Lake Tabiri on the same aquatic macrophyte, *E. crassipes* possibly because of the different methods applied and/or the higher of turbidity in the former lake.

The present study shows that aquatic macrophytes have important roles in providing habitat of epiphytic algae and in turn the algae serve as food resources for fish and zooplankton in humic waters.

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IMPLEMENTATION OF META-POPULATION CONCEPT FOR CONSERVATION OF FISH BIODIVERSITY THROUGH DEVELOPMENT OF INLAND FISHERY RESERVES IN JAMBI PROVINCE

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ABSTRACT

*A fishery reserve is expected to sustain fish catch based on natural population in adjacent water and to conserve fish biodiversity. There were up to 199,755 hectares of inland fishery reserve recorded Indonesia in 1986, but most of them were badly managed and was developed without clear theoretical background. Population dynamics study in temperate area has developed the meta-population concept that indicated the existence of sink and source population structure in freshwater fish community. In the period of 1994 to 1998, the Government of Jambi Province introduced four inland fishery reserves that applied the basic principles of meta-population concept. Those reserves are Lubuk Sahap Fishery Reserve (LSFR), Taman Ciri Fishery Reserve (TCFR), Teluk Kayu Putih Fishery Reserve (TKFR) and Danau Mahligai Fishery Reserve (DMFR). To guarantee the interaction between sources and sink population the core, buffer and economic zones were introduced in those reserves. The zonation system was applied in combination with the concept of community based in natural resources management. The objective of this study, which was done in the period of 1995 to 1999, was to evaluate these fishery reserves. Evaluation was conducted in terms of their potentiality to support fish biodiversity, to increase fish catch, to restore depleted fish stock, limnological condition and management status. The results showed that the new fishery reserve in Jambi is potential to conserve 113 freshwater species, which include the endangered bony-tongued fish (*Scleropages formosus*) and several other rare species. The results also showed that the introduction of DMFR and TCFR already contributed to restoration of depleted fish stock and increasing fish production. Increase of indicator species, such as Rasbora spp and Tor douronensis, was recorded in TKFR and LSFR. The management status evaluation showed that TCFR and DMFR are considered as the best managed (Class III) and LSFR is the worst managed reserve (Class I) in Jambi Province. Limnological condition of the waters, at the time before introduction, was not differed significantly.*

INTRODUCTION

Fishery reserve is defined as a water body, whether it was marine or inland, that have parts where the fishes is prohibited to be capture by anyone, with any methods at any time. Fishery reserve is expected to sustain fish production based on the natural population in adjacent water and to conserve the biodiversity of fishery resources (HARTOTO *et al*, 1998). Legal existence of fishery reserve system was protected under Republic Indonesia Act Number 9 on Fishery of 1985 (LEMBARAN NEGARA REPUBLIK INDONESIA Nomor 46, 1985).

The Directorate General of Fishery reported the existence of 199,175 hectares inland fishery reserve in 1986 (DIREKTORAT JENDERAL PERIKANAN, 1986). Although criteria to select marine fishery reserve were available (ISMAIL *et al*. 1996), there is not a single marine fishery reserve that was formally introduced by the government. The 1986 report only listed the name and total area of inland water that was regarded as fishery reserves, but without clear definition of fishery reserve. There is also no explanation on theoretical background of its development and the boundaries of those reserves are also not clearly defined. Publication in the following years also did not discuss the definition and theoretical concept of fishery reserve development (SARNITA 1993a, SARNITA 1993b, PURNOMO *et al.* 1995, SARNITA *et al.* 1995, SARNITA 1995). Consequently, management condition on most inland fishery reserve is bad, such as observed in East Kalimantan (HARTOTO 1997) and Central Kalimantan (HARTOTO 2000)

Conceptual background on limnology and fish ecology is required in developing manual for site selection and evaluation of inland fishery reserve. Implementation of meta-population principles is considered important in the development of management tools of conservation practice (ANGERMEIER & WINSTON 1997). The concept indicated the existence of *source* and *sink* structure of natural fish population in inland water. Source population is defined as fish population that is characterised by its high reproduction, survival and emigration rates and the sink population is a population that only persists through dispersal contact with nearby source population (Hanski & Gilpin in ANGERMEIR & WINSTON 1997). Inland water that has high conservation value is the area that supports many source fish populations. To guarantee the survival of fish stock (sink population) in adjacent fishing ground, a reserve should have part(s) that capable to facilitate successful reproduction, survival and emigration process of source population.

Since the time unrecorded in history, in area such as West Sumatra (SABAR 1983), East Kalimantan (HARTOTO 1997) and Central Kalimantan (HARTOTO 1998), local people already indifferently applied indigenous wisdom to sustain fish stock. The local wisdom could be described as follows. There should be available an area where its fishes were not allowed to be captured by any methods, by any one at any time in order to sustain fish stock. Consequently, local customary authority in those places introduced the *restricted area for fishing* in inland water adjacent to the fishing ground. The rules are usually enforced by penalty system introduced by the community, where its entire member monitors the violation of rules. This style of activity considered as one example of community based management of natural resources.

Learning from the wisdom and available reports on Indonesian inland water, basic principle of fishery reserve development could be summarised as follows. Any inland fishery reserve should be regarded as operational tool of principle of balance in the science of fish population dynamic. In this context, any activity related to fish stock management should contribute in balancing the sum of Recruitment Rate (R_c) and Growth Rate (G) with the sum of Fishing Mortality Rate (F) and Natural Mortality Rate (M). The balance can be mathematically outlined as $(R_c+G) \approx (M+F)$. In relation to that, an inland fishery reserve should consist of a water body that has part(s) that sustain the source fish population. Adjacent fishing ground that is harvested regularly is expected to sustain the sink fish population or the fishing stock. There should be no hindrance for contact dispersal process between source population in reserve and sink population in adjacent fishing ground. This is to guarantee sufficient amount of recruitment and adequate opportunity for the fish to grow into adult individuals.

The basic principle is implemented by zonation within the reserve (HARTOTO *et al.* 1993). The zonation includes the introduction of **core zone**, which is defined as the area where the fishes were not allowed to be caught at all. The core zone is expected to support source population in order to ensure sufficient supply of brood stock and fingerlings to the sink population in adjacent economic zone. To fulfil this limnological function, the core zone should be consisted of five important habitats that includes the spawning, feeding, rearing, roaming and refuge sites for fishes (HARTOTO *et al.* 1998). **Economic zone** is the water body where the fishes are allowable to be captured by any legal methods at any time. Water body that separate economic zone from core zone refers as the buffer zone.

Buffer zone is defined as the area where the fishes only permitted to be captured at certain times or periods and or with certain fishing gear. This buffer zone also functions as the boundary of the core zone. The local people already practise zonation principles in aquatic resources conservation for many decades in West Sumatra (SABAR 1983). The other conservation principle proposed is that the meta-population concept should be implemented in combination with the approach of community based in management of resources.

In 1993, Fishery Department of Jambi Province started to develop four inland fishery reserves according to above principles. The reserves are the Lubuk Sahap Fishery Reserve (LSFR), Taman Ciri Fishery Reserve (TCFR), Teluk Kayu Putih Fishery Reserve (TKFR) and Danau Mahligai Fishery Reserve (DMFR). The reserves were located in different type of river segment. Three reserves were located in tributary rivers and one reserve in the main river (Table 1).

This study was aimed to evaluate the success of zonation that is applied in combination with the community-based approach in management of reserves. The evaluation was conducted in terms of its potentiality to support fish biodiversity and to increase fish production; its restorative potentials to depleted fish stock, limnological condition and management status. The study was based on primary data collection and review of existing limnological reports on those reserves.

MATERIALS AND METHODS

Fish biodiversity; fish catch and restorative impact

The study was conducted in the period of 1996 to 1999. Some fishes were sampled with locally available fishing gear operated in the economy zone. The samples were preserved in formaldehyde (4 % v/v) for identification in the laboratory. Most of fish sampling were conducted before reserve introduction. Identification of fish samples was done using the keys described by WEBER & BEAUFORT (1916-1952). Reviewed on limnology report of the area were also done to complete the evaluation of ichthyofauna community in the reserve (SJAFEI *et al.* 1995, DINAS PERIKANAN DT I JAMBI, 1995). Interviews to local fishers and Creel Census Survey (HARTOTO *et al.* 1999) were done to collect data on fish catch and restorative impact of reserve introduction. This data includes the occurrence of lateral spawning migration and the sighting of key indicator species. HARTOTO *et al.* (1998) suggested some fish species regarded as indicator of ecological integrity of an aquatic system. The indicator species includes the existence of King Carp or the Semah (*Tor spp*) as the large size omnivore, the Snakeheads (*Channa micropeltes*) or other species as the large piscivore or top carnivores and the "Seluang Group" (*Rasbora spp* and small size *Puntius spp*) as the dominant detrivores.

Limnological condition

Primary data that includes parameters such as pH, Dissolved Oxygen (DO) and Conductivity were measured directly in the field using HORIBA U-10 Checker, before and after reserve introduction. The measurement was conducted at least twelve times randomly in the surface water column of each zone on each reserve, but only the average values were reported. For TKFR and DMFR, the measurements were also conducted in triplicates for surface to the bottom. Composite water samples from the same layers were also taken. Then the water samples were preserved and analyzed for parameters such as Total Nitrogen (T-N), Total Phosphorus (T-P), ammonia and nitrate-nitrogen. All analyses and samples preservation was conducted according to the Standard Methods (EATON *et al* 1995). Some values of water quality parameter were already reported for TCFR (HARTOTO *et al.* 1999) and LSFR (HARTOTO *et al.* 1995). More detailed data on the reserves but will be reported separately.

Management status of fishery reserves

Management status of fishery reserve was evaluated using evaluation criteria developed by HARTOTO *et al.* (1998). The criteria include criterion for legal status, boundaries of reserve, reserve protection and maintenance as well as participation of fisher community in management. Each criterion has some sub-criterion and each sub-criterion was scored into the range of one to five according to observed condition. The mean of scores was calculated for each reserve. Further more, the results were used to classify the reserve into one of the five Classes of Fishery Reserves that ranges from the Juwana Class (Class I) for the worst managed to the Adimina Class (Class V) for the best one.

RESULTS AND DISCUSSION

Table 1 showed that the reserves are located at different habitat types and the naming of them is following local tradition. Local tradition in naming habitat near a water body usually refers to the name of its special character. In accordance to that, the naming of the reserve is following the name of the pool or the *lubuk* of the core zone. All the core zone of the fishery reserve consisted of a lubuk and a riffle. For example, the name of Lubuk Sahap Fishery Reserve refers to the name of the lubuk in the core zone that located in River Batang Merangin. River Batang Merangin is a tributary of Batang Hari River that lies in the upstream part of Batang Hari watershed (700-m asl.). The River Batang Merangin is one of the low order rivers that flow out from Lake Kerinci. LSFR is the representative of fishery reserve located in the tributary river located in the upstream part of the watershed.

The TCFR (300 m asl) is located in River Batang Tabir that also a tributary of River Batang Hari but it connected with the main river in the middle part of the watershed. From hydrological point of view, the TCFR could be considered as reserve that represents the tributary river that drained the middle part of the watershed. The DMFR is located in River Berembang, another tributary of River Batang Hari that flows in the lower part of the watershed (50-m asl.). Different with the other three reserves, the TKFR is located in the segment of River Batang Hari. In Indonesia, this reserve is the only one that located in this habitat type.

Table 1. The data of the four newly introduced fishery reserves in Jambi Province

Regency, District and Position of Reserve	Name of Reserve and Total Surfac Area (ha)	Name of zones	Habitat types and type of riparian habitat	Name of Local Customary Society that managed the reserve	Year of Introduction Source of Information
1	2	3	4	5	6
Kerinci, Pulau Sangkar Village, District Danau Kerinci S: 2° 09' 56.8" E: 101° 35' 11.1"	Lubuk Sahap 3.36 ha	Core: Lubuk Sahap (10 m) Buffer: Lubuk Muan and Lubuk Paku Economic: Lubuk Penidai and Lubuk Batu Banyak	A segment of tributary river (R. Batang Merangin), located in upstream part of Batang Hari watershed Riparian: paddy rice fields	*Ulayat Datuk Rencong Telang*	1994 Hartoto *et al* (1995)
Sarolangun Bangko, Telentam Village District Tabir Ulu S: 1° 55' 12.6" E:101° 56' 15.8"	Taman Ciri 4.01 ha	Core: Lubuk Taman Ciri (7 m) Buffer: Lubuk Pauh Hulu and Lubuk Lanca Bemban Economic: Lubuk Pauh Hilir and Lubuk Lintan	A segment of a tributary river (R. Batang Tabir), located in the middle part of Batang Hari watershed Riparian: paddy rice field and tropical forest	*Ulayat Datuk Rajo Gumoyang*	1995 Hartoto *et al* (1999)
Bungo Tebo, Teluk Kayu Putih Village, District VII Koto S: 1° 10' 42.2" E:101° 59' 44.3"	Teluk Kayu Putih 4.32 ha	Core: Lubuk Teluk Kayu Putih (12 m) Buffer: Lubuk Luncuran Nago and Lubuk Inti Air Economic: Lubuk Batu Belang and Lubuk Pembentungan	A segment of a main stream (R. Batang Hari), Located in the middle part of Batang Hari watershed. Riparian: villages and rice fields. There is a tributary river (R. Batang Jujuhan) near the economy zone	*Ulayat Datuk Intan Penghulu, Datuk Majo Indo, Datuk Elang Berantai, Datuk Perdano and Datuk Bagindo*	1996
Batang Hari, Dano Lamo Village, District Muara Sebo S: 1° 27' 50" E: 103° 38' 35"	Danau Mahligai 4.14 ha	Core: Lubuk Kuburan (5 m) Buffer: Lubuk Terusan and Lubuk Raman Economic: Ruas Simpang Berembang and Lubuk Cempo	A segment of a tributary river (R. Berembang), located in the downstream part of Batang Hari watershed Riparian: a swamp forest	People Representation Body of Danau Lamo Village	1997

Fish species listed in Table 2 can be considered as the species presumably to be found in the core zones of each reserve. The four new fishery reserves in Jambi Province are potential in sustaining 115 species of freshwater fishes. The core zone of each fishery reserve includes at least a pool and a riffle segment of the river. The pools or "lubuk" always containing some water even at longest dry period such was experienced during the phenomenon of El Nino of 1997. The deep-water column in core zone is most likely function as refuge site for adult fishes at dry season. There is usually a mechanism of organic material deposition in the centre of deep pool with swirling water (HARTOTO *et al.* 1998). In relation to that it is reasonably that the deepest part of the core zone also expected to function as feeding ground for fishes. Riparian vegetation nearby, assumed to function as the source of allochthonous food for the fishes. HARTOTO *et al.* (in press) revealed the existence of an ichthyofauna community in a tropical oxbow lake that indicate a detrivores food chain, which depend upon allochthonous detritus of terrestrial origin.

Fish biodiversity sustain by one fishery reserve is different from another. Fishery reserve that is located in higher area of the watershed (i.e. LSFR), support less fish species. Highest number of fish species was found in DMFR, which is a representative of downstream part of River Batang Hari watershed. There are still a relatively intake primary forest and a freshwater swamp that always connected to DMFR during high water time.

Fish species belong to Cyprinidae is predominant in all reserves. The percentage of Cyprinid species number to total fish species sustained by the reserve is 58.3, 50.0, 33.3 and 34.3 percents for LSFR, TCFR, TKFR and DMFR respectively. The dominance of Cyprinid is common in Indonesian inland water, such as found in Central Kalimantan (HARTOTO 2000) and in East Kalimantan (HARTOTO 1997, LUKMAN 1997). Cyprinid fish species represents a wide spectrum of feeding behaviors. The spectrum includes the detrivores such as found in the *Seluang* Group (HARTOTO *et al. 1999*). Seluang is a group of fishes refer to species belong to Rasborinae Sub-family and the small size Puntius (TL <15 cm). There are also plant and plankton feeder such as the large size *Puntius*. The large fishes such as the *Sebarau* (*Hampala macrolepidota* and *Hampala ampalong*) represented the large size predator. The Cyprinid species also can utilize a relatively wide range of spatial habitat resources. They can be found either in the upper and lower segment of the river but probably not in the estuarine system.

There are two rare fish species (*Chaca chaca* and *Balantiocheilus melanopterus*) and more than 40 fish species of high economic values. These fishes are potentially conserved by the four fishery reserves. There is one endangered species, the Bony Tongued Fish (*Scleropages formosus)* that also potentially conserved in TKFR and DMFR.

The r- and K-fish species according to Pianka principles of ecological selection and adaptation (KREBS 1985) defined as below. The r-species is the species which is characterised by the catastrophic and density independent mortality, low survival rate at early life stages, rapid growth, variable population size which is usually under carrying capacity, small body size, early and single reproduction, variable but lax inter and intra specific competition and less than one year life span. On the contrary, the K-species is characterised by directed and density dependent mortality, medium or large survival rate at the early life stage, slower growth, relatively constant population size near the carrying capacity, large body size, delayed and repeated reproduction, keen intra and inter-specific competition and more than one year life span.

Table 2. List of fish species found in the economy zone of each inland fishery reserve in Jambi Province.

No.	Scientific names	Local name	LSFR	TCFR	TKFR	DMFR
1.	*Arius argyropleuron*^{1}	Ariidae		+	+	
2.	*Anabas testudineus*^{1}	Anabantidae	+		+	+
3.	*Betta picta*	Anabantidae	+			+
4.	*Betta splendens*	Anabantidae			+	
5.	*Betta taeniata*	Anabantidae			+	
6.	*Ctenops vittatus*	Anabantidae				+
7.	*Helostoma temminckii*^{1}	Anabantidae			+	+
8.	*Luciocephalus pulcher*	Anabantidae				+
9.	*Osphronemus gouramy*^{1}	Anabantidae		+	+	+
10.	*Polyacanthus hasseltii*	Anabantidae				+
11.	*Trichogaster leeri*	Anabantidae			+	+
12.	*Trichogaster pectoralis*	Anabantidae				+
13.	*Trichogaster trichopterus*	Anabantidae	+		+	+
14.	*Bagrichthys hypseloterus*	Bagridae			+	+
15.	*Bagroides melapterus*	Bagridae				+
16.	*Brachygobius doriae*	Bagridae			+	+
17.	*Leiocassis stenemus*	Bagridae			+	
18.	*Mystus nemurus*^{1}	Bagridae		+	+	+
19.	*Mystus nigriceps*	Bagridae		+	+	+
20.	*Mystus planiceps*	Bagridae	+			+
21.	*Mystus wolfii*	Bagridae			+	+
22.	*Mystus micracanthus*	Bagridae				+
23.	*Sphaerichthyes osphromenoides*	Bagridae				+
24.	*Chaca chaca*^{2}	Chacidae				+
25.	*Channa lucius*^{1}	Channidae		+		+
26.	*Channa micropeltes*^{1}	Channidae	+		+	+
27.	*Channa pleorophtalmus*^{1}	Channidae				+
28.	*Channa striata*^{1}	Channidae	+		+	+
29.	*Channa gachua*	Channidae				+
30.	*Clarias batrachus*^{1}	Clariidae		+	+	+
31.	*Clarias leiacanthus*^{1}	Clariidae		+	+	+
32	*Clarias melanoderma*^{1}	Clariidae				+
33.	*Clarias nieuhoffi*^{1}	Clariidae			+	+
34	*Acanthopsis choirorhynchos*	Cobitidae		+	+	+
35.	*Botia macracantha*^{1}	Cobitidae		+	+	+
36.	*Botia hymenophysa*^{1}	Cobitidae		+	+	+
37.	*Cynoglossus sp*	Cynoglossidae			+	+
38	*Amblyrhynchichthys truncatus*	Cyprinidae		+	+	+
39	*Balantiochelus melanopterus*^{2}	Cyprinidae			+	+
40.	*Barbichthys laevis*	Cyprinidae		+	+	+
41.	*Chela oxygasteroides*	Cyprinidae			+	+
42.	*Crossocheilus gnathopogon*	Cyprinidae			+	
43.	*Cyclocheilichthys enoplos*	Cyprinidae			+	+
44.	*Cyclocheilichthys apogon*	Cyprinidae		+	+	+
45.	*Dangila fasciata*	Cyprinidae	+	+	+	+
46.	*Dangila festiva*	Cyprinidae		+		+
47.	*Dangila ocellata*	Cyprinidae		+	+	+
48.	*Dangila sp*	Cyprinidae	+		+	+
49.	*Epalzeorhynchos kallopterus*	Cyprinidae		+	+	+
50.	*Hampala ampalong*^{1}	Cyprinidae	+	+	+	+
51.	*Hampala macrolepidota*^{1}	Cyprinidae	+	+	+	
52.	*Labeo chrysopekadion*	Cyprinidae		+	+	+
53.	*Labeo sp*	Cyprinidae	+			+

Table 2. (continued)

No.	Scientific names	Family	LSFR	TCFR	TKFR	DMFR
54.	*Leptobarbus hoeveni*[1]	Cyprinidae			+	+
55.	*Luciosoma setigerum*	Cyprinidae		+	+	
56.	*Macrochirichthys macrochirus*	Cyprinidae			+	
57.	*Mystacoleucus padangensis*	Cyprinidae		+		+
58.	*Osteochilus hasselti*[1]	Cyprinidae		+	+	+
59.	*Osteochilus melanopleura*	Cyprinidae				
60.	*Osteochilus vittatus*	Cyprinidae	+	+	+	
61.	*Osteochilus schlegeli*	Cyprinidae				+
62.	*Osteochilus repang*	Cyprinidae				+
63.	*Osteochilus sp*	Cyprinidae				+
64.	*Puntius bulu*	Cyprinidae				+
65.	*Puntius fasciatus*	Cyprinidae				+
66.	*Puntius hexazona*	Cyprinidae				+
67.	*Puntius huguenini*	Cyprinidae	+	+	+	
68.	*Puntius lawak*	Cyprinidae				+
69.	*Puntius schwanefeldi*	Cyprinidae	+	+	+	+
70.	*Puntius tawarensis*	Cyprinidae	+		+	+
71.	*Puntius tetrazona*	Cyprinidae				+
72.	*Puntius waandersi*	Cyprinidae				+
73.	*Rasbora argyrotaenia*	Cyprinidae	+	+	+	+
74.	*Rasbora einthoveni*	Cyprinidae	+			+
75.	*Rasbora trilineata*	Cyprinidae	+			+
76.	*Rasbora sp1*	Cyprinidae	+			+
77.	*Rasbora sp2*	Cyprinidae		+		+
78.	*Schismatorhynchos choirorhynchos*	Cyprinidae		+		
79.	*Thinnichthyes thinnoides*[1]	Cyprinidae		+	+	+
80.	*Thynnichthyes polylepis*	Cyprinidae				+
81.	*Tor douronensis*[1]	Cyprinidae	+	+	+	
82.	*Dasyatis sephen*	Dasyatidae		+	+	+
83.	*Oxyeleotris marmorata*[1]	Eleotridae			+	+
84.	*Fluta alba*	Flutidae	+		+	+
85,	*Glossogobius giuris*	Gobiidae			+	+
86.	*Xenentodon canciloides*	Hemirhampidae			+	+
87.	*Kurtus indicus*	Kurtidae		+		+
88.	*Mastacembelus maculatus*[1]	Mastacembelidae	+	+	+	+
89.	*Mastacembelus erythrotaenia*[1]	Mastacembelidae	+	+	+	+
90.	*Macrognathus aculeatus*[1]	Mastacembelidae	+	+	+	+
91.	*Pristolepis fasciatus*	Nandidae			+	+
92.	*Nandus nebulosus*	Nandidae				+
93.	*Notopterus borneensis*[1]	Notopteridae			+	+
94.	*Notopterus chitala*[1]	Notopteridae			+	+
95.	*Notopterus notopterus*[1]	Notopteridae			+	+
96.	*Scleropagus formosus*[3]	Osteoglossidae			+	+
97.	*Pangasius polyuranodon*[1]	Pangasidae			+	+
98.	*Pangasius pangasius*	Pangasidae			+	+
99.	*Pangasius nieuwenhuisi*[1]	Pangasidae			+	+
100	*Pangasius nasutus*	Pangasidae				+
101	*Polynemus multifiliis*	Polinemidae			+	+
102	*Belodontichthys dinema*[1]	Siluridae			+	+
103	*Cryptopterus limpok*[1]	Siluridae			+	+
104	*Cryptopterus bichiris*[1]	Siluridae			+	+
105	*Cryptopterus cryptopterus*[1]	Siluridae				+

Table 2 (continued)

No.	Scientific names	Family	LSFR	TCFR	TKFR	DMFR
106	*Cryptopterus hexapterus*[1]	Siluridae				+
107	*Cryptopterus schilbeides*	Siluridae			+	
108	*Cryptopterus apogon*	Siluridae				+
109	*Cryptopterus macrocephalus*[1]	Siluridae			+	+
110	*Hemisilurus moolenburghii 1*	Siluridae				+
111	*Silurodes hyphophtalmus*	Siluridae			+	+
112	*Wallago attu*[1]	Siluridae		+	+	+
113	*Wallago miostoma* [1]	Siluridae		+	+	+
114	*Toxotes jaculator*	Toxotidae			+	+
115	*Tetraodon reticulatus*	Tetraodontidae		+	+	+
	Number species		24	40	75	103
	Number of families		6	11	21	20
	Number of economically important fish species		10	13	34	35
	Number of endangered fish species		-	-	1	1
	Number of rare species		-	-	1	2

Note: [1]: species of high economic values, [2]: rare species, [3]: endangered species

ALI and KARTHEGANY (1987) stated that *Rasbora sumatrana, Oxygaster anomalura, Osteochilus hasseltii, Cyclocheilichthys apogon, Mystacoleucus marinates, Puntius schwanefeldi* and *Labiobarbus lineatus* are classified as the fishes that have the r-type competitive ability. Conversely, the *Puntius bulu, Tor tambra, Osteochilus melanopleurus, Thynnichthys thynnoides, Puntius daruphani, Channa micropeltes, Oxyeleotris marmorata, Notopterus chitala* and *Pangasius micronema* are classified as the fish that more adapted to K-type natural selection process. Those r and K type fishes are well represented in the ichthyofauna of the four fishery reserves. Balance proportion of r-and K-type fish species in fish community probably an indicator of community resilience to environmental changes.

Increasing fish catch in adjacent fishing ground was experienced after the introduction of fishery reserve (Table 3). Fish production in the economic zone of DMFR is increasing from 2-3 tons before 1997 to 18 tons in 1999. The fishing time to capture one kilogram of fish in the economy zone of TCFR was decreased significantly. Before reserve introduction, the time to catch one kilogram of fishes is around two hours but it decreased into less than one hour after two years of reserve introduction (HARTOTO *et al.* 1999). These facts indicated that the fishing stock or the sink population in the economy zone, capable to be sustained by the source population in the core zone.

It was deducted that the introduction of TCFR also capable to trigger lateral migration of the "Medik" (*Osteochilus vittatus*) in adjacent segment of River Batang Tabir. This phenomenon exists probably because the core zone is available as refuge, feeding and roaming sites for the adult fishes. Presumably there is a significant size of brood stock grew in the core zone. This potential breeding stock also has larger chance to survive from the danger of being capture by the fishers. If there is no core zone introduced in the reserve area, the sexually matured fish probably will be caught by the fisher before they execute their reproductive cycle. It is suspected that the existing brood stock lived in the core zone was triggered to migrate laterally to nearby canal to spawn when the environmental condition stimulate them. The facts indicate that fishery reserve introduction also can function as a restorative tool for depleted fish stock. HARTOTO *et al.* (1994) and HARTOTO et *al.* (1995) already identified the potential of fishery reserves introduction as a tool to restore fish population.

The alteration of fishing method in LSFR indicated that local people already perceived that fishing in the core zone is prohibited. However, they also knew that there is fish population potential for fishing in Lubuk Sahap and Lubuk Muan. Probably, to adapt to this situation, the fisher invent the "Cemetih" as special fishing tool that can give them a chance to capture the fishes without receiving penalties from local community. Operation of Cemetih was increasing significantly at three years after LSFR introduction. Zonation seemed also already contribute to restoration of depleted fish stock in LSFR case.

In TCFR, the school of the King Carp or Ikan Semah *(Tor douronensis)* can be observed with naked eyes in the core zone. It is observed that the core zone in 1998 supported larger stocks of Ikan Semah. The Semah shares the spatial habitat resources with the "Sebarau" (*Hampala macrolepidota*) and other fishes.

The school of the "Seluang Group" (*Rasbora* spp and small size *Puntius*) is more frequently observed in LSFR, TCFR and TKFR. The existence of Seluang Group in any inland water is an indicator of the existence of ichthyofauna food webs that is detritus dependent. The ichthyofauna community in one of Indonesian oxbow lake in Central Kalimantan was reported based on detrivores food chain (HARTOTO *et al*, in press).

The impact of reserve introduction was less observed in TKFR. This probably because the reserve is located in the large main river segment, so it required more times to show response to reserve introduction. However, the schools of the "Seluang Group" were seen more abundant, soon after introduction of all four reserves. Existence of large population of Seluang Group is potential prey for the fishes at higher trophic level.

The presence of top predator fishes, i.e. the Sebarau and the Snakeheads (*Channa* spp) indicated that there is a healthy ichthyofauna community supported by the reserve. The occurrence of the Monitor Lizard (*Varanus salvatorre*) in TCFR was observed frequently. Since the Monitor Lizard eats fish, this means that the ichthyofauna community can sustain the lizard. The Monitor Lizard as the top predator is expected to function ecologically as natural selection agent in eliminating unhealthy and deformed prey fish individuals. This mechanism is function to guarantee that the existing stock constitutes of genetically superior and healthy individuals.

Evaluation of management status showed that TCFR and DMFR are the reserves that have highest scores (Table 4). The TCFR, DMFR and TKFR classified as Class III (Madya Class) fishery reserve according to HARTOTO *et al. (*1998) classification. Highest scores were achieved by the TCFR and DMFR, which mean that these two reserves are the best managed ones in Jambi Province. This is because the fisher communities in these two reserves were most active in daily management of reserve. The fishers who managed the TCFR and DMFR take turn in guarding the reserve at night. Other member of local customary tradition of the village; including the children, woman and the elder citizen; observe and guarding the core and buffer zone during the day. Activity as reserve ranger at lesser intensity was also observed in the fisher community of TKFR.

Table 3. Changes in ichthyofauna community and fish production in the economic zone of each fishery reserve

No.	Name of fishery reserve	Observable changes in ichthyofauna community, at two years after its introduction (based on interview, Creel Census, literature review and direct observation)	Source
1.	Lubuk Sahap	Some fishers operated a semi automatic pole and line-fishing gear refer as *Cemetih*. They leave this fishing tool in the buffer and core zone unattended. When the fish ate the bait, this "Cemetih" will automatically pull the baited fishes out of water. Before reserve introduction, local fisher rarely used this kind of tool. The local fisher reported that they sometimes observed that the "Semah" (*Tor douronensis*) jumps here and there at the core zone in the afternoon. The "Seluang Group" was also observed many times on its shore, which is not the case before reserve introduction.	HARTOTO *et al*, (1995) and obser-vation
2	Taman Ciri	The fishers spent less time to catch one kilogram of fish. Creel Census indicated that the fishery production was increased from very low to 1998.6 kg/year. In the core zone, the school of large Semah (up to 1 m) and the " Sebarau" were found more abundant than before. At two years after reserve introduction, the *Medik* Fish (*Osteochilus vittatus*) started to show lateral spawning migration in the canals adjacent to buffer and core zones. This phenomenon was reported last to occur about thirty years ago.	HARTOTO *et al*, (1999)
3.	Teluk Kayu Putih	There are no significant changes in fishers catch. In Lubuk Teluk Kayu Putih, local fishers reported that now they observed the signs of the *Belido* (*Notopterus notopterus*) existence more frequently. This probably indicates that the fishes are more abundant in the core zone. They also reported that more fish schools were observed to migrate through River Batang Jujuhan to a freshwater swamp. The Seluang Group was observed more abundant in the littoral habitat of the core and buffer zones.	Observation and interview
4.	Danau Mahligai	Significant changes in fish production were observed at one and half years after reserve introduction and reserve restocking with the Sepat Siam (*Trichogaster pectoralis*). A fish trader reported that in 1999, he bought 18-tons of fish from local fishers that caught natural fish stock in adjacent economy zones. This phenomenon is never been experienced for more than twenty years.	Observation and interview

Table 4. The scores of evaluation of management status of four new fishery reserves in Jambi Province

Management criteria and expected condition	Evaluation score of fishery reserve			
	LSFR	TCFR	TKFR	DMFR
1. The legal status of reserve	2	2	2	2
2. Fishery reserve boundary				
a. The availability of the map of fishery reserve.	3	3	3	3
b. The boundary of the fishery reserve is clearly defined.	3	3	3	3
c. The billboards of fishery reserve exist.	2	4	3	3
d. The zonation is introduced in fishery reserve.	3	3	3	3
1. Protection of fishery reserve				
a. The availability of reserve ranger system	2	5	3	5
b. The availability of ranger post.	2	5	3	3
c. The availability of utility system (boat, flashlight, lantern and others)	1	3	3	3
d. The existence of Government Officer that has duty as a Special Prosecutor for Fishery Act violation.	1	3	1	3
4. Fishery reserve maintenance				
a. Maintenance of riparian vegetation is conducted regularly or still keeps in its almost natural condition.	1	1	2	2
5. Participation of fisher community in the management of fishery reserve				
a. There is positive perception on the importance of fishery reserve as one of fishery management tool.	2	5	5	5
b. The fisher already understood of the existence of direct economic benefit due to the introduction of harvest fishery reserve systems	1	3	2	3
Total Scores	23	40	33	38
Average	1.92	3.33	2.75	3.17
Classification of reserve	Juwana	Madya	Madya	Madya
Time of evaluation	1999	1998	1999	1999

The success of community base management of TCFR, TKFR and DMFR deducted to strongly related to the following two facts. The first fact is that because of a proper extension program to develop community-based management of reserve. The second fact is because of proper zonation within the reserve. Experienced during the study also taught that proper extension program should includes important information about the ecological base of zonation and potential of social benefit and economical profit of reserves introduction for local fisher society. Explanation on why a reserve is necessary for the fisher benefit is one of the most important aspects of the extension program. Reserve zonation should meet the limnological criteria for habitat selection of proposed fishery reserves (HARTOTO *et al.* 1998).

In 1999, the Government of Republic of Indonesia introduced the Act Number 22, on Local Government. One of the spirits of this new Act is to distribute the rights and responsibilities of natural resources management to local government authority. The responsibilities and the rights were distributed from the Central Government, down to the Provincial Government, Regeny Government, and District Government and last but not the least to the village level authority. Implementation of meta-population concept in combination with the approach of community based approach on management of natural resource seemed compatible with the spirit of this Act.

LSFR was the worst managed reserve in Jambi Province. This reserve classified as the "Juwana" Class (Or Class I), which conceived that the reserves was still at its initial state of development. This situation was analyzed due to improper zonation and extension program, no leader with a suitable integrity in the local society, not large enough fishers population in adjacent villages and there are still a lot of poachers in the villages. LSFR is the first new fishery reserves introduced in Jambi Province. Because of insufficient knowledge at the time of its introduction, the buffer zones (Lubuk Muan and Lubuk Pauh) of LSFR do not lies attach to the core zone (Lubuk Sahap). It was separated by a long segment of Batang Merangin River. The extension program that related to LSFR introduction was conducted more or less with the formal and authoritarian approach. It does not contained sufficient technical and social information on the benefit and the profit of fishery reserves.

Education level of village society member of LSFR is relatively high compared to others. There is some member who was graduated from university, but unfortunately the society is without strong local community leadership. There are many member of local customary tradition society refers as Kerapatan *Adat Datuk Rencong Telang* (Table 1) that lives outside the village (in Jakarta or Jambi City). This situation made the agreement to close Lubuk Sahap in reality do not enforced very well by the local society. Unfortunately, technical explanation about fishery reserve was given in one-way ceremonial approach without proper two-way dialogues. No wonders there are still many poachers fishing in LSFR.

Based on empirical experience in introducing new fishery reserves, social engineering principles related to reserve introduction could be described as follows:

- General limnological evaluation on the potential of an inland water proposed to be developed for fishery reserve should be conducted and concluded prior to formal introduction of the idea to local fisher societies.
- Invite selected member of local fisher society who understood the benefit and the profit of reserve to take part in the limnological study. Some time it is more beneficial to invite them to select the suitable area for the core and buffer zones.
- Scientist and fishery department officers should only act as facilitator of scientific, technical and legal information on fishery reserve.
- Local customary tradition society should be encouraged to make their decision about inland water resource in general and about the proposed fishery reserve.
- No legal action related to reserve introduction should be done before the local customary society giving a written and formal statement that they are agree to let a certain inland water habitat to be developed as fishery reserves. Experiences taught that

the time for local community to reach this agreement is varied from several months to several years. A local customary tradition society may need only three months to reach their agreement (such as for DMFR) to close a certain river segment as the core and buffer zones. The other, such as for TKFR, spent nearly two-year to reach similar agreement. The other one, such as for LSFR, actually never comes into solid agreement between them.

The data of limnological condition of the core zone (Table 5) indicated some differences in water quality between the reserves. The LSFR and TCFR, which were tributary rivers at higher elevation of the watershed, showed higher pH and dissolved oxygen level than that of TKFR and DMFR. DMFR showed pH and dissolved oxygen values characteristics of inland water influenced by peat. The range of pH (5.10-5.68) and the dissolved oxygen (2.61-3.38) of DMFR are comparable to the range of river segment in the peat swamp forest in Central Kalimantan (HARTOTO 1999).

Two years after its introduction, no distinct changes in of water quality were observed in all reserves. Probably, in order to show the differences, more detailed limnological study that includes the biological parameters is required. HARTOTO and MULYANA (1997) found that water quality parameters such as the temperature, pH, dissolved oxygen, conductivity, nitrate, ammonia and orthophosphate are significantly correlated with the fish biodiversity and fish biomass in the inland water of Siberut Island.

Table 5. The average values of some water quality parameter of four new fisheries reserve in Jambi Province

Name of fishery reserve	Average values of water quality parameters in the core zone of each fishery reserve															
	pH		Dissolved Oxygen, mg/l		Conductivity uS/cm		N-NH$_3$ mg/L		N-NO$_3$ mg/L		Total N mg/L		Total P mg/L		Year	Reference
	A	B	A	B	A	B	A	B	A	B	A	B	A	B		
Lubuk Sahap	8.10	7.24	7.02	8.80	72	99	0.020	0.004	0.465	0.075	0.565	0.891	0.188	0.049	1999	1
Taman Ciri	7.86	7.41	9.00	8.75	39	42	0.054	0.147	1.961	0.031	6.815	0.341	0.572	0.080	1998	2
Teluk Kayu Putih	7.04	6.87	7.19	6.93	82	92	-	0.022	-	0.342	-	0.809	-	0.105	1999	3
Danau Mahligai	5.68	5.10	2.61	3.38	67	38	0.062	0.026	-	0.315	-	1.053	0.063	0.165	1999	

Note: A: at the time of its introduction; B: at the time of evaluation; 1: Hartoto *et al*. (1995) and direct monitoring: 2. Hartoto *et al*. (1999); 3: Hartoto & Yustiawati (1999), Boyd (1990)

CONCLUSION

There are several conclusions withdrawn from the study. The first conclusion is that the application of meta-population concept in combination with the approach of community based management, proved effective as conservation measure in term of biodiversity sustainability and cost. The meta-population concept proposed to be implemented for fishery reserve development in other provinces in Indonesia. This type of conservation measure is considered more effective and required lower cost in conserving fish biodiversity compared to National Park and other conservation system.

It was also deducted that zonation system also has restorative impacts to the depleted fish population in the core zone. Introduction of fishery reserves system that was developed using zonation system proposed to be used as an alternative technique to restore depleted fish population. The third conclusion is that zonation is capable to sustain and to increase the total catch in adjacent fishing ground.

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